Sudan University of Science & Technology

College of Postgraduate Studies

Accuracy Evaluation of Digital Photogrammetric Projects. Khartoum State, Case Study

تقييم دقة مشروع مساحة تصويرية رقمية دراسة حالة ولاية الخرطوم

A thesis Submitted for the degree of Ph.D in Surveying Engineering

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بسم الله الرحمن الرحيم

وَإِذْ قَالَ رَبُّكَ لِلْمَلَٰٓئِكَةِ إِنِّى جَاعِلٌ فِى ٱلْأَرْضِ خَلِيفَةً
قَالُوٓا۟ أَتَجْعَلُ فِيهَا مَن يُفْسِدُ فِيهَا وَيَسْفِكُ ٱلدِّمَآءَ وَنَحْنُ
نُسَبِّحُ بِحَمْدِكَ وَنُقَدِّسُ لَكَ قَالَ إِنِّىٓ أَعْلَمُ مَا لَا تَعْلَمُونَ
﴿٣٠﴾ وَعَلَّمَ ءَادَمَ ٱلْأَسْمَآءَ كُلَّهَا ثُمَّ عَرَضَهُمْ عَلَى ٱلْمَلَٰٓئِكَةِ
فَقَالَ أَنۢبِـُٔونِى بِأَسْمَآءِ هَٰٓؤُلَآءِ إِن كُنتُمْ صَٰدِقِينَ ﴿٣١﴾ قَالُوا۟
سُبْحَٰنَكَ لَا عِلْمَ لَنَآ إِلَّا مَا عَلَّمْتَنَآ إِنَّكَ أَنتَ ٱلْعَلِيمُ ٱلْحَكِيمُ
﴿٣٢﴾

البقرة

Abstract

In spite of the development and digital replacement of the conventional techniques, there is a need for evaluating and assessing photogrammetric mapping projects, to see if they conform to specifications.

In order to develop infrastructure and improve services and utilities, Khartoum State (Sudan) signed a contract in (2010) to cover the state by large scale topographic maps. Digital photogrammetric methods and techniques were planned to be used in this project.

The planned project was divided into two parts; the first part covers the centre of the state by 1:5000 photographic coverage to produce maps at scale 1:1000, while the second part, cover the rural areas of the state by 1:20000 photographic scale coverage to produce maps at scale 1:10000.

Technical specifications and criteria of this photogrammetric project were suggested by a high technical committee.

The output of this project, including photographic coverage and the maps, were not subject to evaluation and assessment because of the absence of supervision.

This research work is oriented to make some sort of technical evaluation and assessment of this project. Camera specifications, flying height, scale of the photography, accuracy of vector mapsproduced and other points were taken into account.

Two sets of measurements and tests were carried out, for each part of the project. The laid specifications for the project and samples of the executed project were the refrain data.

A number of ground points were observed by Differential Global Positioning System (DGPS),with their coordinates based on Universal Transverse Mercator (UTM) projection, at zone 36 north and the World Geodetic System 1984 (WGS84) datum. The Leica Photogrammetric Set (LPS), included in Erdas Imagine package, was used.

The results obtained showed that, the used camera, photographic coverage in centre of the state project, and the produced line maps are all in disagreement with the specifications, but it is satisfied with the specifications of the rural area of the state.

المستخلص

علىالرغممنالتطورالذىحدثوالاحلالالرقميالذىتمللتقنياتالتقليدية ،
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بغرضتطويرالبنيةالتحتيةوتحسينالخدمات ، قامتولايةالخرطومفى ٢٠١٠
بتوقيععقدلتغطيةالولايةبخرائططبوغرافيةذاتمقاييسرسمكبيرة .
وتماختيارالمساحةالتصويريةالرقميةعلىانتكونهىالتقنيةالمستخدمةفىإعدادهذهالخرائط. ينقسمالمشروعالمقترحالىقسمين ،
الأوليغطىوسطالولايةبصوررقميةبمقياسرسم ١:٥٠٠٠ بغرضانتاجخرائططبوغرافيةبمقياسرسم ١:١٠٠٠
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وقدقامتلجنةمتخصصةفىوضعالمواصفاتالمطلوبةلتنفيذالمشروع ، غيرانمخرجاتهذاالمشروعسواء
كانتالصورالجويةأوالخرائطالمنتجةلمتخضعللتقييمنسبةلغياب الإشراف على المشروع.
تمتوجيههذهالدراسةلعملنوعمنالتقييملهذاالمشروعآخذينفىالاعتبارمواصفاتالكاميراوإرتفاعالطيرانومقياسرسمالتصويروالخرائطا
لمنتجةوعدداًمنالنقاطالاخرىالتىوضعتفىالإعتبار .
تمعملقياساتلكلجزء منأجزاء المشروعوتمالإعتمادعلىالتقييمعلىالمواصفاتالموضوعةلتنفيذالمشروعبالإضافةالىعيناتمنمخرجات
المشروع.
تمإنشاء نقاطضبطأرضيةعنطريقنظامالموقعالعالميالتفاضلي ، وبنيت إحداثياتها على مسقط ماركيتر المستعرض العالمى فى
النطاق ٣٦ شمال ، وعلى سطح الاسناد الجيوديسي العالمي للعام ١٩٨٤كماتماستخدامحزمةبرامج لايكا
التصويريةالمضمنةفىبرنامج ايرداس .
أوضحتالنتائجالتىتمالحصولعليهاانالكاميراتالمستخدمةفىعمليةالتصويروالصورالمنتجةبالإضافةالىالخرائطالمنتجة,جميعهالاتطابق
المواصفات الموضوعة لوسط الولاية ولكنها تطابق الموصفات الموضوعة لمشروع أطراف الولاية .

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Dedication

I dedicate this work to:

My parents

Who were the causes in my presence in this life…

My brothers & sisters

On whom I relied in my life…

My small family

Asma, Lamiss, and Yassein who are my safe refuge…

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CHAPTER ONE

INTRODUCTION

1.1 Overview

The development of nations is determined with its own infrastructure. Many countries of the world followed innovations in science and technology and created for themselves landslides in the fields of industries, and other activities making life easy for economic and social development guided by well planned strategies. The face of any country is reflected by its architectural appearance based on scientific plans showing the state of the art in horizontal and vertical setups. The other side of the coin in such plans refers to the drainage system related to sewage, storm water and irrigation canal. Furthermore, they also show transportation systems in land, sea, and air, together with some others show the electric networks and more other vided services.

The development, reaches its climax in presence of up-to date topographic maps and plans showing all human activities in their exact / correct location and in various mapping scales.
Definition of a topographic map is that it is a basic type of maps upon which, strategic vision of infrastructure projects and future developments can be planned. Therefore, all developed countries are completely covered with this type of maps. A topographic map is a representation of natural and man-made features, of part - or the entire surface of the earth at an appropriate scale. Map production is not a simple matter, but it includes different difficult and complicated stages, starting from data collection to the stages of the plotting and distribution.

Conventional land surveying techniques of map production, are very expensive, and time consuming, especially when covering large areas. So, photogrammetric methods of map production are practical alternative methods of land surveying. Here, measurements are taken indirectly from photograph rather than the field i.e. transforming the direct measurements from the nature, to indirect measurements from the photograph.
In fact photogrammetry is not one of the late sciences, but it is the most developed of in terms of instrumentation, equipments, tools, or computer programs on the other hand in terms of technologies applications and various technologies implemented in execution and high performance (Kilford.W.K,(1998).The history of the air surveys date back to the fifteenth

century, when the world witnessed the emergence of photography and perspective geometry technology. In real practice there are many institutions and organizations specialized in the field of photogrammetry attempted to define this science their own way, but most comprehensive, mostly used, is that of the American Society of Photogrammetry and Remote Sensing as 'the art, science, and technology of obtaining reliable information about the physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena'(Johnston,2007). According to type of data extraction, photogrammetry can be divided into two distinct areas:

- Metric photogrammetry; consists of making precise measurements from photographs and other information sources to determine in general, the relative locations of points. This enables finding distances, angles, volumes, elevations, size and shape of the objects, the most common application of metric photogrammetry is the preparation of planimetric and topographic maps from photographs.
- Interpretative photogrammetry; deals principally in recognizing and identifying objects and judging their significance through careful and systematic analysis. It includes branches of photographic interpretation and remote sensing.

Photographic interpretation involves the study of photographic images, while remote sensing which is a newer branch of interpretative photogrammetry, includes not only the analysis of photography but also the use of gathered data from a wide variety of sensing instruments, including multispectral cameras, infrared sensors, thermal scanners, and side looking airborne radar. Remote sensing instruments which are often carried in vehicles, as remote as orbiting satellites, are capable of providing quantitative as well as qualitative information about objects.

The science of photogrammetry goes hand in hand with the tremendous development that occurred in scientific knowledge and the introduction of digital technologies in most scientific fields. This innovation were automatically reflected in the diversity of traditional analogue techniques to modern ones. This in fact can be seen in the new ways of data collection, taking photography and the related processes of manipulating the digital image to make it workable to all users. The old optical cameras are replaced by digital ones giving a high performance of image quality, accuracy, durability, and permanence. The ease and cost of obtaining high resolution imagery can be easily extremely sustained. To some extent, image reproduction processes are highly established. Analytical photogrammetric plotting and Digital photogrammetric softcopy are now in use and under continuous research for better results. That led to ease and speed data collection and data processing which is reflected in time, effort and cost reduction.

Importance of Khartoum state makes it keen on the introduction of modern technologies in the field of data collection. The development which attended the state in the past two decades, roads, bridges, banks, planning extension and residential services generally need a master plan outlining the shape and future of the state. To be modern, accurate maps, help distribute those services and utilities.

Since the maps production from the corresponding remote sensing imageries of Khartoum state, does not satisfy the accuracy requirements as well as the lack of topographic data of the state.The state government tried to produce up to date topographic maps of the sates in two scales utilizing modern digital photogrammetric techniques. Accordingly, the state was covered by two types of photographs: 1:5,000 photography for the center of the state to produce topographic maps at scale 1:1,000 and the other is 1:20,000 photography for the rural areas to produce topographic maps at 1:10,000 scale.

1.2 Problem of the Research

In recent years, Khartoum state received many migrations from rural areas and some large cities looking for wider jop opportunities or better health and education services. As a result of this irregular migrations,an increase in population and residential rates were appeared. This affected, negatively, the level of services in the state. Khartoum State Government created extensions to the four parts of state.This led to an increase in state area. For these resons,in addition to the new manifestations of structures , such as, bridges, roadsand buildingsall of which require updated topographic maps of the state. Initially, the state produced topographic maps at various scales from satellite images and other tools. Some problems faced this project, such as horizontal and vertical displacements of features from their correct locations. Therefore project was mended to use digital photogrammetric techinques to produce a new two types of topographic maps for the central and rural parts of the state.

Unfortunately the final outputs of the project is not checked to match the agreed specificationsas.

This research aims at making some sort of accuracy evaluation of the project and study the factors that affect, positively or negatively, such projects.

1.3 Research Objectives

This research aims to study and investigate some methods and techniques by which one can justify the accuracy of topographic maps produced using a digital photogrammetric project and consequently sets out standards for the evaluationof the various degrees of accuracies attainable. The guide to the factors influencing such results, of which the following points can be quoted:

- evaluate the horizontal accuracy of 1: 1,000 maps produced for central area of Khartoum state,
- evaluate the horizontal accuracy of 1:10,000 maps produced for rural areas of Khartoum state,
- determine the effect of camera pixel resolution of the final product,
- examine the impact of the scale of photography on the map accuracy,
- study the different parameters affecting the geometrical accuracy in the digital photogrammetric project, and
- make some sort of reliability assessment for the national companies working in the field of mapping services.

1.4 Research Methodology

Evaluation of a digital photogrammetric projects of Khartoum state for the purpose of production of topographic maps with two different scales (1: 1,000 for the central area of state and the other at scale is 1: 10,000 for the rural areas) planned to pass through the following steps:

i. Get and study the specifications of the aerial photogrammetric project,
ii. Study the flight plan of the project,
iii. Get a number of overlapping stereo-pairs of photographs which represent samples for each scale.
iv. Study the data associated with the orientation parameters of each photograph such as exposure station.
v. Provide a number of ground control points to assist in model orientation and adjustment.
vi. Use a digital photogrammetric work station to develop three dimensional models of the area under consideration.

vii. Utilize a commercial digital photogrammetric package such as Erdas Imagine, to process available data in personal computer.
viii. Produce digital maps from the developed models and evaluate the accuracy.
ix. Compare the results obtained with those of the project.
x. Assess the accuracy of the results obtained from available commercial softwares and the possibility of producing maps for large projects.

1.5 Thesis Layout

This research is, arranged in nine chapters and five appendices. Chapter one contains general definition of topographic mapping, and some of the problems facing the data collection processes, to produce these types of mapswith a solution to address the alternative methods used for land surveying. In addition to the definition of conventional and digital photogrammetry and discusses the case study.

Chapter two discusses the main and auxiliary equipments that are used in photogrammetric survey projectsincluding conventional film, digital image,types of cameras, and their specifications and taking into account their effects on ensuring the success or failure of survey projects.

Definition of topographic maps is discussed in Chapter three. Some details of the maps projections in addition to the world geodetic system 1984 (WGS84) as a global datum, were also discussed. Besides that, the various types of ground control points for aerial surveying work were illustrated.

Chapter four contains the techniques of aerial triangulation in addition to illustrating the concept of analytical machines. Also it includes some important specifications for aerial triangulation.

In Chapter five, the use of Global Positioning System (GPS) in photogrammetry is discussed. Types of position, observation methods and determination of camera position and attitude at the time of exposure were also discussed.

Chapter six contains the definition of digital photogrammetric work stations, their components and internal and external orientations. It also includes its software and hardware components. Furthermore it also discuss how to improve and enhance digital images and, management of digital data and advanced photogrammetric functionality.

Chapter seven discuss, in some detail, the measurementsthat are carried out and important results obtained.
Chapter eight discuss the standard accuracy evaluation of the photogrammetric projects
Finally, conclusions obtained and suggested recommendations for the future are arranged in Chapter nine.

The research also contains five Appendices. Appendix (A) illustrates the specifications of the aerial survey project of Khartoum state. Appendix (B) includes the analytical triangulation report fromthe LPS system for the centre of Khartoum state project, while Appendix (C) contains the analytical triangulation report from the LPS system for the rural areas of Khartoum state project, Appendices (D) and (E) respectively show the created aerial triangulation blocks for the centre and rural areas of Khartoum state projects.

CHAPTER TWO

PHOTOGRAMMETRIC CONCEPTS

2-1 Introduction

In imaging operations in general, and in particular aerial photography, a camera cannot be alone getting a static image for objects that can be used in photogrammetric projects. There are a number of tools and equipments working beside a camera to assist in the success of any aerial survey process.

Anyway, these elements cannot be less important than the camera. In conventional photogrammetry, in the absence of the film and the sensitive material, for pictures printing there wouldn't be any possibility for obtaining any static image.Also if there is no analogue or analytical photogrammetric plotting machines, there wouldn't be any possibility for obtaining a stereo-model that simulates a real world of the project area at the moment of exposure; so also in the digital photogrammetry environment. If there is no enough memory it is impossible to store the raw digital image, and if there is no good computer specifications, there wouldn't be any processing or measuring from the digital image.

So, it could be said that a photograph is the result of integrating the previous elements with each other. All these elements are called the assistance imaging process techniques, which can be explained as follows.

2.2 Conventional Photogrammetric Techniques

Before computer science and software widespreaded in uses of photogrammetry, all the processes of photogrammetry were based on the use of analogue frame cameras for image acquisition, which lead to obtain analogue images from films.The images are then processed by analogue or analytical photogrammetric instruments to obtain photogrammetric models. These classical processes are called the conventional photogrammetry techniques(Zheng.Y.J,(1995)) .

2.2.1Cameras

There are so many important instruments in photogrammetry that would be difficult tospecify the most significant. Surely the camera is one of the most important since it is used to obtain the photographs upon which much photogrammetry depends. (Wolf,(1983)).

There are, now, two different types of cameras provided into the photogrammetric instruments, market. These are used in two different types of photogrammetric techniques for map production. Thefirst type is the frame cameras, which are used in conventional photogrammetry. The second type is the digital cameras, which are used in digital photogrammetry.Anyone of them has different components but both types are used for the purpose of image acquisition processes.

2.2.1.1 Frame Cameras

In conventional or classical photogrammetry as the photogrametrists say,there are many types of frame cameras used to produce photographs for topographic mapping or other types of maps. The selected camera depends mainly on the purpose of the exposed images. Anyhow there are four main types of frame cameras used in photogrammetry. These are:-

1- Single-lens frame cameras,
2- Multi-lens frame cameras,
3- Strip cameras, and
4- Panoramic cameras.

2.2.1.1.1 Single-lens Frame Cameras

Single-lens frame cameras are use to obtain photographs for mapping purpose. This type of cameras providethe highest quality geometric picture compared to the other three types, because they are characterized by the use of a single lens.

2.2.1.1.2 Multilens Frame Cameras

Multilens frame cameras have the basic characteristics of single-lens frame cameras, except that they have two or more lenses and expose two or more pictures simultaneously.

2.2.1.1.3 Strip Cameras

Strip cameras expose a continuous photograph of strip of terrain beneath the path of the aircraft.

2.2.1.1.4 Panoramic Cameras

A panoramic camera photographs a strip of terrain from horizon to horizon, the strip being transverse to the direction of the flight.

2.2.1.2 Conventional Photogrammetric Camera Components

An imaging camera is considered as the backbone which is based upon the general concept of photogrammetry. There are many aerial photograph camerasin commercial markets. However, they vary in their shapes and specifications refered to their different manufacturers. Nevertheless, they all agree in three main components as illustrated in Figure (2.1) below.

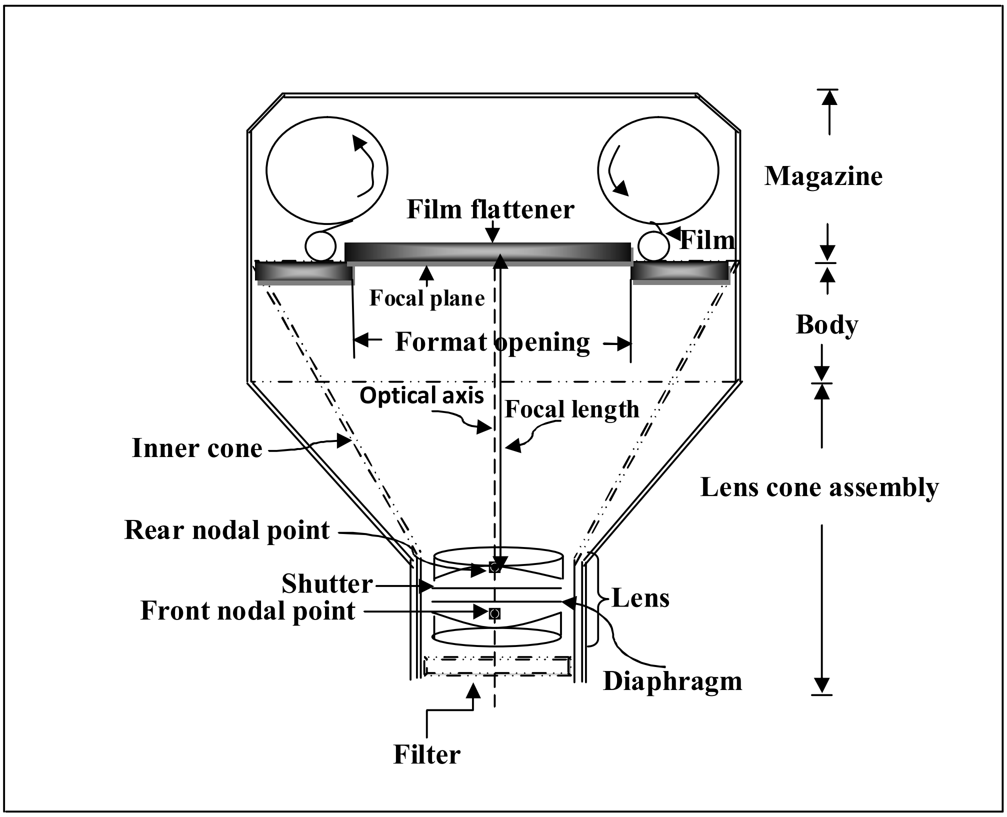


Figure (2.1) Generalized cross section of a frame aerial camera.

1- Camera magazine

The camera magazine houses the reels which hold exposed and unexposed film.It also contains the film advancing and flattening mechanism.

2- Camera body

The camera body is a one piece casting which usually houses the drive mechanism.

3- Lens cone assembly

The lens cone assembly contains a number of parts and serves several functions. Figure (2-1) above defines each part in the assemblyarranged as:-

a- Lens: it is the most important part of a camera. It gathers light rays from the object space and brings them to focus in the focal plane behind the lens.

b- Filter : It serves three purposes:

  i- Reduces the effect of atmospheric haze.

  ii- Helpsin providing uniform light distribution over the entire camera.

  iii- Protects the lens from damage and dust.

c- Shutter and diaphragm: They, together, regulate the length of time a given amount of light is allowed to pass through the lens to make the exposure. Shutter controls the length of time that light is permitted to pass through the lens.

2.2.1.3 Characteristics of Aerial Frame Cameras

There are many geometrical properties whereby aerial frame cameras can be distinguished. These characteristics help in the extraction of information and the definition of the image coordinates system. The most important of these elements are the focal plane of an aerial camera.This is the plane in which all incident light rays are brought to focus. Therefore, aerial frame cameras have their focus fixed for infinite object distances (Kilford.W.K, (1989)). Camera fiducial marks are one of the important features of the frame camera. These are usually four or eight marks in number, situated in the middle sides of the focal plane opening or in its corners or in both locations. Fiducial marks can be utilized in a variety of tasks such as, to define the location of the principal point by the intersection of the lines joining opposite marks.This point of intersection is an exceedingly important reference in photogrammetric work. In addition to that the fiducial marks also provide a rectangular coordinate axis system for measuring image positions on a photograph, which is the major unit of data in photogrammetry.It is of vital importance that the camera selected for a particular project is capable of exposing an image of sufficient quality for the required task. The collinearityequations refer to plate and camera coordinate systems and, in the majority ofcases in photogrammetry, it is necessary for the camera employed to define these coordinate systems on the photograph (Atkinson, K.B, 1997). This relationship between plate and camera coordinate systems is illustrated in Figure (2.2) below.

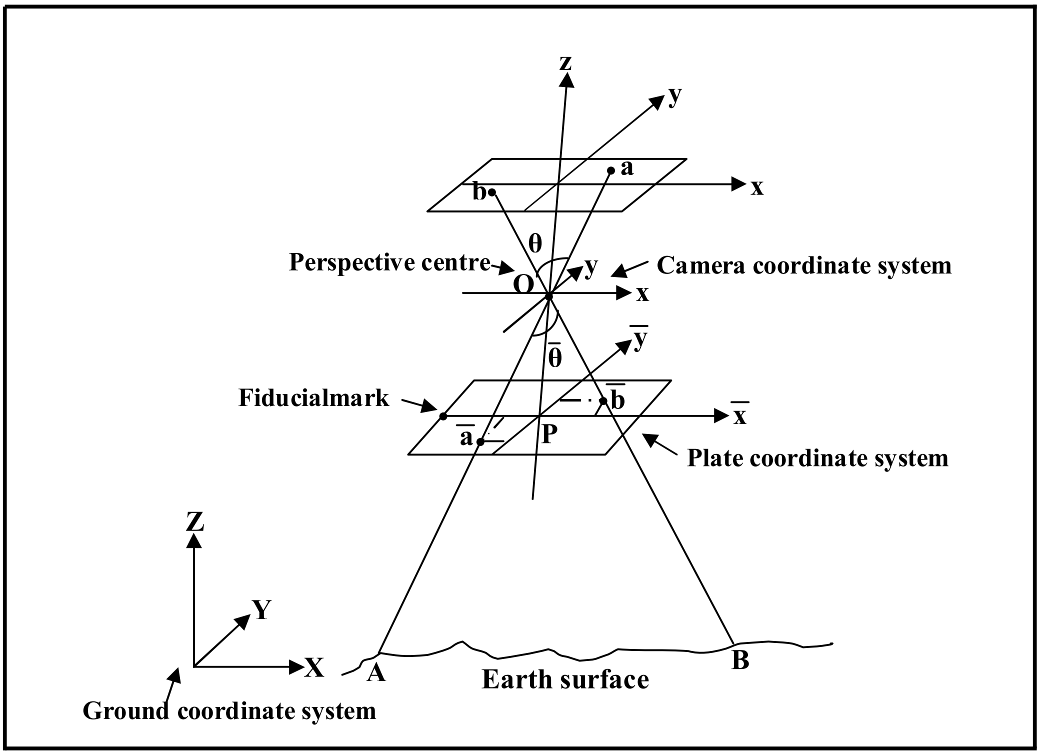


Figure (2.2) Photographic coordinates systems

Referring to Figure (2.2), it can be seen that it contains many of the terms and geometric properties of the image based on the camera which is used, these properties can be obtained by analyzing the Figure as the following:

A, B: are the object pointsrespectively imaged at a and b on the negative plane.

$\bar{a}$, $\bar{b}$: is the imaged points of A and B respectively on the positive plane.

Θ: is the angle subtended at O by A and B; it is recreated inside the camera by the angle Θ subtended at $\bar{O}$ by a and $\bar{b}$.

P: is the principal point. It can be defined as the intersection point of the ray which passes through the perspective center ,O, and intersects the film plane normal to it. This point represents the origin of the plate coordinates.

OP: is the principal distance, defined as the distance between the perspective centers and the principal point, or more commonly the focal length fand this is the *z* coordinate of the camera coordinates system.

Refering to the plate and camera coordinates system, and in the majority of cases in photogrammetry, it is necessary that the camera be able to define these coordinate systems on the photograph. Cameras which are capable of supplying this information are called metric cameras while those which cannot define these coordinate systems are known as non-metric cameras.

2.2.2 Conventional films

In traditional photogrammetry there are two types of films used to produce negatives and fixed dimension photographs.These are explained in the coming paragraphs.

2.2.2.1 Black and white films

These are the basic type of photogrammetric films which are used to produce topographic maps from aerial photographs. Black and white films are branched into three categories :

i- Orthochromatic films which are sensitive to the blue and green range, which have the optical radiation wavelength ranging between 0.3μm - 0.6 μm.

ii- Panchromatic films which are sensitive to the blue, green, and red colours of the visible spectrum, ranging between 0.4μm - 0.7 μm in wavelength.That is the actually same range, which the human eye is sensitive for the wavelength.

iii-InfraRed(IR) films which are sensitive to the optical radiation wavelengths ranging between 0.7μm - 1.2μm.This type is nowadays widely used for a variety of applications such as detection of crop stress, tree species mapping…etc.

In traditional photogrammetry, silver halide photographic emulsion are used as the sensitive material on the film.

The emulsion has to be supported by a base material which is either a flexible plastic film or a plane glass plate.

Dimensional stability of the base material is of prime importance. If the camera is fitted with a reseau plate and an analytical solution is to be employed, then significant film distortion can be allowed for by transforming the measured images of the reseau marks back to their calibrated values.

The unflatness of the base material is very important and is much harder to model. To keep unflatness to a minimum the camera should have some form of film-flattening device.This can be in the form of either a vacuum back with pump to hold the film flat or a pressure plate system which presses the film forward on to plane glass plate mounted in the focal plane of the camera.

2.2.2.1.1 Black and White film Components

A black and white film consists of two basic layers.The first layer is the emulation which contains sensitive crystals of silver halide, and is too sensitive to the light, which works to disintegrate a chemical compound. Accordingly, invisible images are received on the sensitive layer are called latent images. Black and white films are exposed to many chemical processes; completely separate from each other, that areas follows:-

- Developing: in this first step the exposed emulation is placed in a chemical solution called the developer.
- Stop Bath: used to stop the developing action after the proper darkness and contrast of the image has been attained from the developing process.
- Fixing: necessary to remove the undeveloped silver halide grains from the film.
- Washing: it is necessary to remove any remain chemicals.
- Drying: this is the final step, and it is necessary to remove the water from the emulation and backing martial.

. The final outcome is a positive visible image.

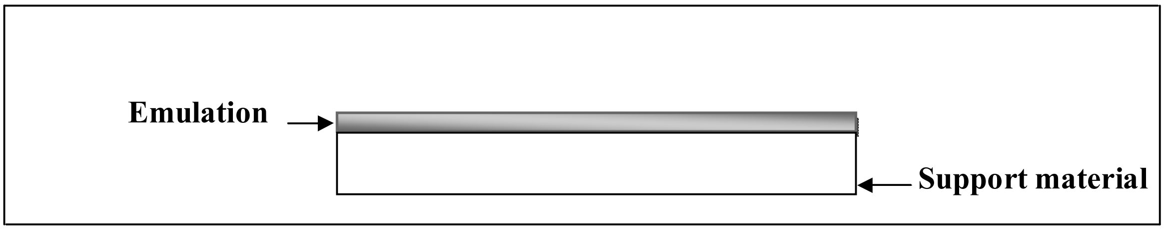


Figure (2.3) Cross section of a black and white film.

The second layer is known as the film base which acts as a support for the emulation layer. It may be made from paper, glass, or plastic material. Today, most films used for photogrammetric applications (called aerial films), have a polyester base that provides stability over the entire frame of a few microns.

2.2.2.2 Colored films

There are two types of colored films used in photogrammetric process. Normal colored films, thatcontain three thin layers of gelatin in which sensitive silver halide crystalsare suspended. The top layer is sensitive to red light only, the second layer is sensitive to the green light, and the lower third layer is sensitive to the blue light of spectrum. Figure (2.4) depicts a cross-section of a coloured film layers.

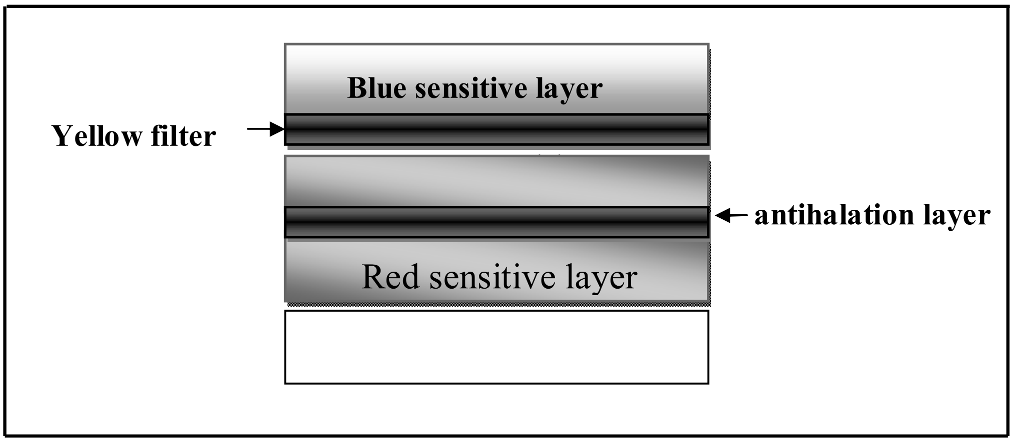


Figure (2.4) Cross section of a coloured film.

The second type of colored films is the infrared colored films, or the falsecolored films.Sometimes, in military uses, are called a camouflage detection film. The IR colored films, also, contain three layers, each sensitive layer has a spectrum photogravure different from the second layer. The top layer is sensitive to the ultraviolet, blue, and green. The middle layer has a sensitivity peak in the red portion of the spectrum, but it is very sensitive to ultraviolet light.Thelast layer, is sensitive to both ultraviolet rays and infrared.

Usually, in both colored films a yellow filter which blocks wavelengths shorter than 0.5µmis used.

2.2.2.2.1 Processing Colored Film

During the development process of natural colored and false colored films the situation is reversed; a red layer becomes transparent for red light. Wherever, green was incident the red layer becomes magenta (white minus green).Likewise, blue changes to yellow. If this developed film is viewed under a white light, the original colors are perceived. (T. Schenk, 2005) Figures,(2.5) and (2.6) illustrate the concept of natural colored and false colored film material, respectively.

The final outcome of integration of the colored IR film and a yellow filter any object that reflects infrared energy will appear red on the final processed image as appeared in Figure (2.6).

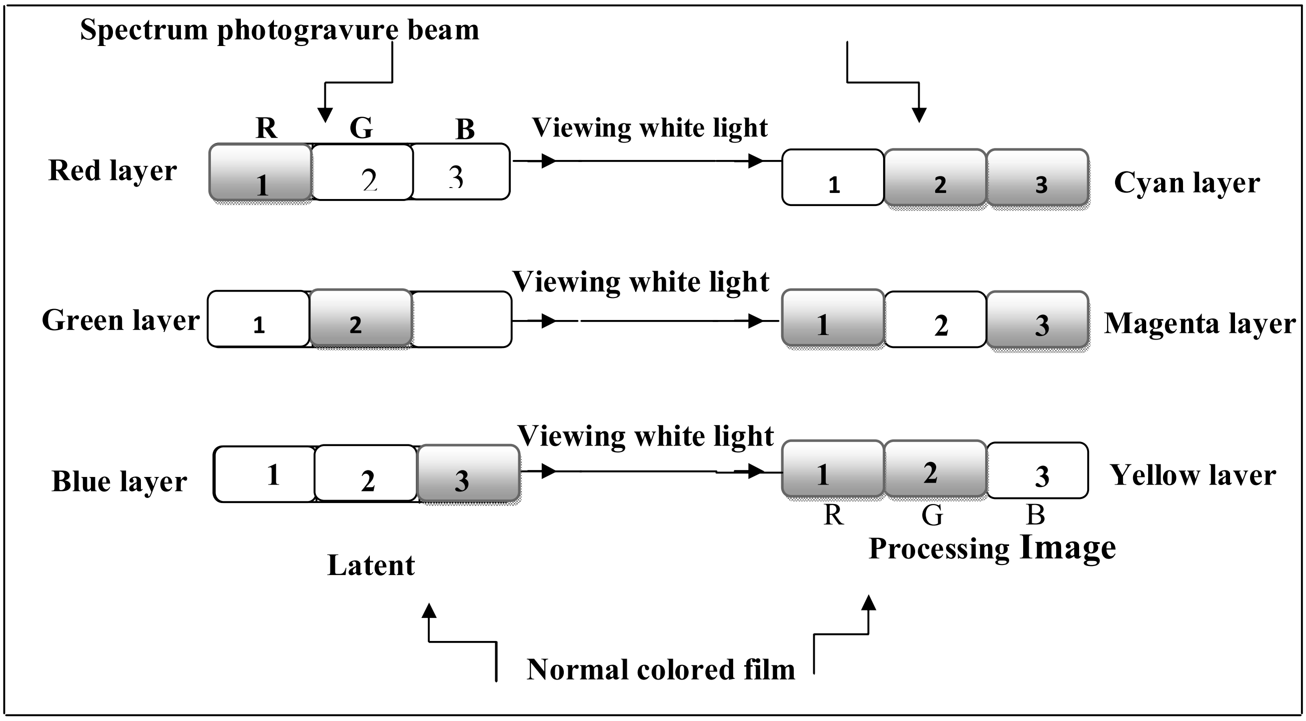
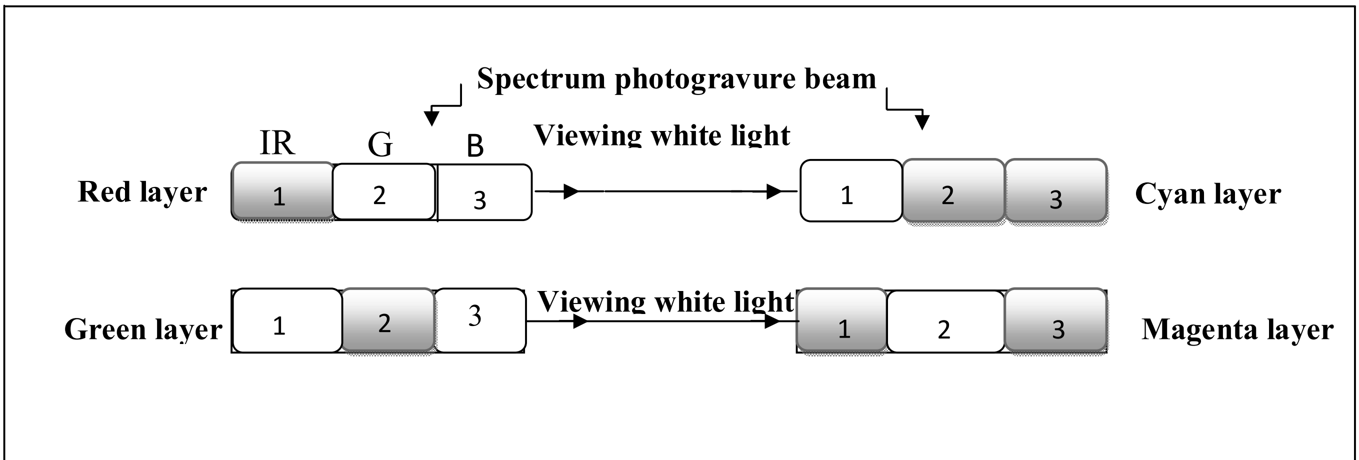


Figure (2.5) Concept of a normal colored film material.



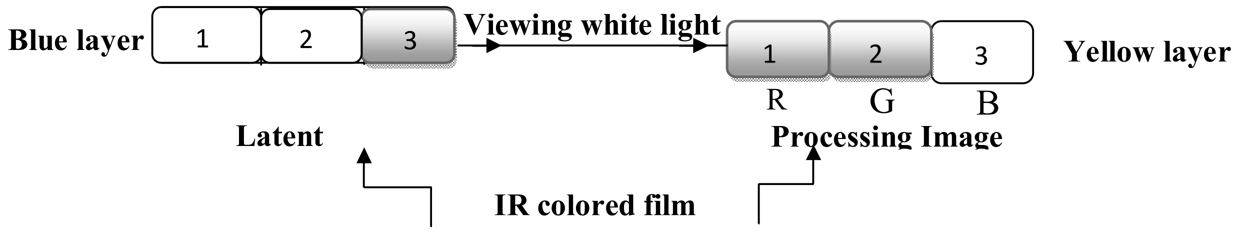


Figure (2.6) Concept of IR colored film materials.

2.2.3 Mathematical models used in conventional photogrammetry

The conventional mathematical models concern with all geometric computations which are carried out to produce topographic maps. In a conventional photography, there are two types of photographs obtained.

2.2.3.1 Vertical photographs

In vertical aerial photographs the optical axis of the camera is vertical, or nearly vertical as possible, at the moment of image acquisition. The situation is as shown in Figure (2.7) below.

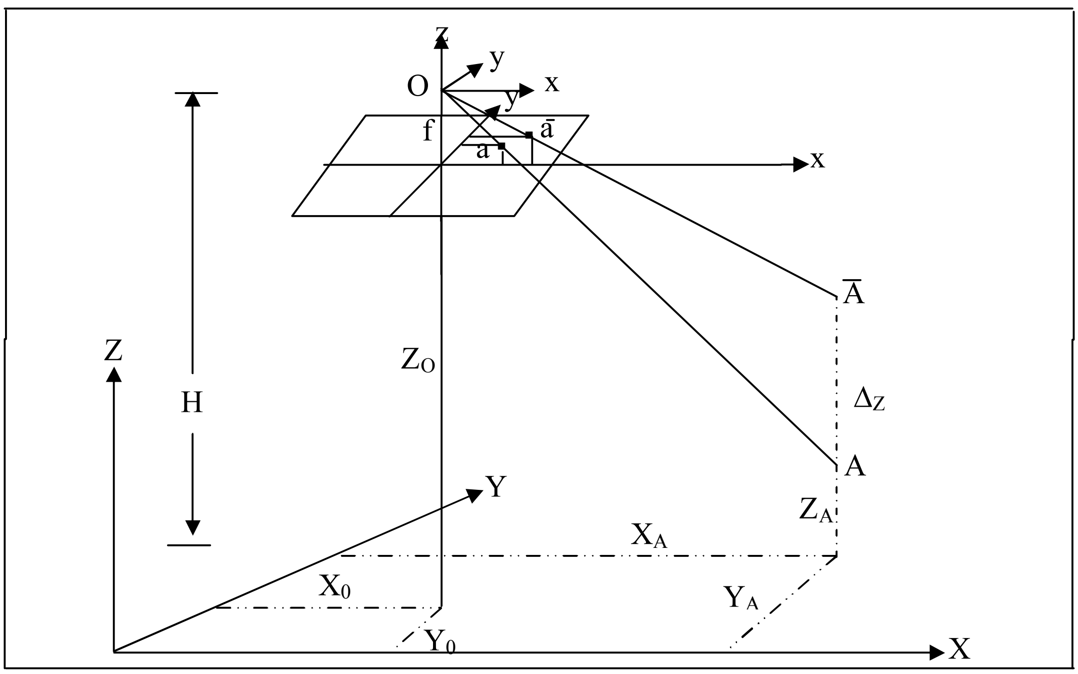


Figure (2.7) Vertical photograph with camera and object coordinates system.

Where,

f: the camera focal length.

H: the flight height above datum.

O: the origin point of the camera coordinate system.

x, y, z : the camera coordinates system.

X, Y, Z: the ground coordinates system.

X_0, Y_0, Z_0: the ground coordinates of the perspective center.

X_A, Y_A, Z_A: the ground coordinates of point A, imaged of at point *a* on photograph.

x_a, y_a: the image coordinates of point a.

Δz: the height of point $\bar{A}$ (imaged on photograph at point $\bar{a}$) above the point A.

x_a, y_a, z_a: the camera coordinates of point a

In a completely vertical aerial image, or the ortho-image (rectified image), thecoordinate system is parallel with the ground coordinates system.Therefore, it is very easy to calculate the geometric relationships between the two systems given an image scale factor. From Figure (2.7) we can derive the ground coordinates from image coordinates using the following equations:

$$S = \frac{f}{H} \quad \text{[scale of vertical image]} \quad (2.1)$$

$$\left.\begin{aligned} X_A &= S_a.x_a + X_0 \\ Y_A &= S_a.y_a + Y_0 \\ Z_A &= S_a.z_a + Z_0 \end{aligned}\right] \quad (2.2)$$

Where z_a is the focal length of the camera when we use the negative image or the focal length with a sign changed to negative when we use the positive image. In the same way the coordinates of any point laid above the surface datum, also can be computed from the same above equations; but we must keep in mind the effects of the relief displacement in our calculations as follows.

$$\left.\begin{aligned} X_A - X_O &= S_a.x_a \\ Y_A - Y_O &= S_a.\, y_a \\ Z_A - Z_O &= S_a.\, z_a \end{aligned}\right] \quad (2.3)$$

where

(2.4)

$$S_a = \frac{Z_A - Z_0}{z_a}$$

2.2.3.2 Tilted photographs

As a result of many factors, such as natural factors or others,it is very difficult to get a completely vertical image.Therefore, the optical axis of the camera makes a small angle with its vertical axis at the moment of photography.This results in atilted image as shown in Figure (2.8).

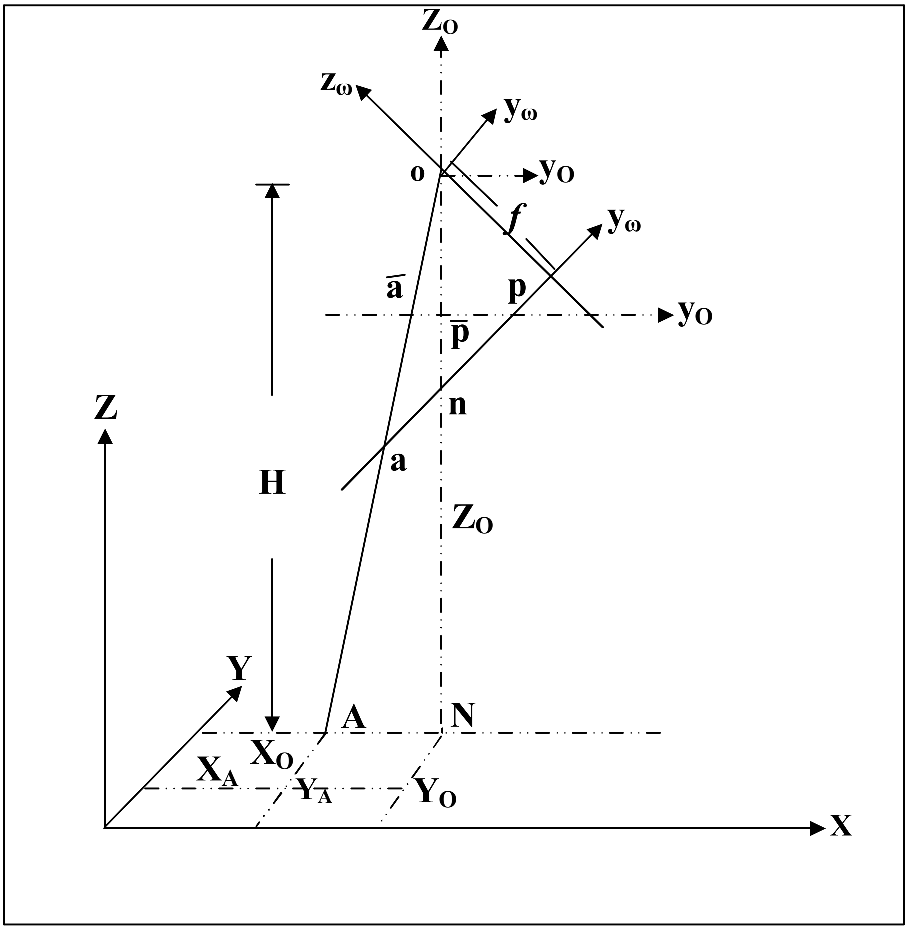


Figure (2.8) Tilted photograph with camera and object coordinates system

For this reason, the mathematical calculations of such images are fundamentally different from those of the vertical image. The Figureshows a tilted image, taken from altitude *H*as flying height above the datum surface, by a camera whose focal length equals *f*.

Usually, in such images, thecoordinates system is non-parallel to the object ground coordinates system.To resolve this issue we need to rotate the image coordinates system around the required axes.In addition to this, the scale factor between the two systemsbesides knowledge of the displacements along the *x*, *y*, and *z* axis are to be considered. This is known as projective transformation. If the photograph is rotated about *x* axis through a small angle ω, these will result in a tilted camera coordinate system x_ω, y_ω, z_ω and therefore it is necessary to transform tilted camera coordinate system to vertical camera coordinate system. The projective transformation equations can be derived as follows:
To be able to use the projective transformation equations in (2.2) it is necessary to transform the tilted camera coordinates to their corresponding untitled coordinates.
Consider the fist rotation ω around the tilted x axis:

$$\left.\begin{aligned} x_o &= x_\omega \\ y_o &= y_\omega \cos\omega - z_\omega \sin\omega \\ z_o &= z_\omega \sin\omega + z_\omega \cos\omega \end{aligned}\right] \quad \text{———————} \quad (2.5)$$

In matrix form equations (2.5) can be written as follows:

$$\begin{bmatrix} x_o \\ y_o \\ z_o \end{bmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{pmatrix} . \begin{bmatrix} x_\omega \\ y_\omega \\ z_\omega \end{bmatrix} \quad \text{———————} \quad (2.6)$$

Now consider the secondary rotation Φ around the tilted y axis:

$$\begin{bmatrix} x_\omega \\ y_\omega \\ z_\omega \end{bmatrix} = \begin{pmatrix} \cos\Phi & 0 & \sin\Phi \\ 0 & 1 & 0 \\ -\sin\Phi & 0 & \cos\Phi \end{pmatrix} . \begin{bmatrix} x_{\omega\Phi} \\ y_{\omega\Phi} \\ z_{\omega\Phi} \end{bmatrix} \quad \text{———————} \quad (2.7)$$

Finally, consider the tertiary rotation κ around the tilted y axis:

$$\begin{bmatrix} x_{\omega\Phi} \\ \\ \end{bmatrix} \begin{pmatrix} \cos\kappa & -\sin\kappa & 0 \\ & & \\ \end{pmatrix} \begin{bmatrix} x_{\omega\Phi\kappa} \\ \\ \end{bmatrix}$$

$$\begin{matrix} y_{\omega\Phi} \\ z_{\omega\Phi} \end{matrix} = \begin{matrix} \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{matrix} \cdot \begin{matrix} y_{\omega\Phi\kappa} \\ z_{\omega\Phi\kappa} \end{matrix} \qquad (2.8)$$

Normally the camera is tilted around all axes so the transformation from the tilted to the corresponding vertical plate coordinates involves a rotation matrix resulting from the sequential rotation of ω, Φ, and κ. This is usually written as:

$$\begin{bmatrix} x_o \\ y_o \\ z_o \end{bmatrix} = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \cdot \begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} \qquad (2.9)$$

Where x_a, y_a, z_a are the tilted plate coordinates; x_o, y_o, $z_o$are thecorresponding vertical plate coordinates; and r_{11} to r_{33} are the nine elements of the three-dimensional orthogonal rotation matrix resulting from combining equations (2.2) with equations (2.9) which gives:

$$\begin{aligned} X_A - X_O &= S_a\,[r_{11}x_a + r_{12}y_a - r_{13}z_a] \\ Y_A - Y_O &= S_a\,[r_{21}x_a + r_{22}y_a - r_{23}z_a] \\ Z_A - Z_O &= S_a\,[r_{31}x_a + r_{32}y_a - r_{33}z_a] \end{aligned} \qquad 2.10$$

Equation (2.10) can be written in matrix form as:

$$\begin{pmatrix} X_A - X_O \\ Y_A - Y_O \\ Z_A - Z_O \end{pmatrix} = S_a \cdot \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \cdot \begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} \qquad (2.11)$$

Rearrangingt gives:

$$\begin{bmatrix} x_a \\ y_a \\ z_a \end{bmatrix} = S^{-1} \cdot \begin{pmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{pmatrix} \cdot \begin{pmatrix} X_A - X_O \\ Y_A - Y_O \\ Z_A - Z_O \end{pmatrix} \qquad (2.12)$$

Dividing the first two lines by the third line and substituting, $-f$, for, z_a gives us the most important equations (2.13) and (2.14)' called the collinearity equations' which are used to resolve the most problems in photogrammetry, (Stirling. (2001).

$$x_a = -f \frac{[r_{11}(X_A - X_0) + r_{21}(Y_A - Y_0) + r_{31}(Z_A - Z_0)]}{[r_{13}(X_A - X_0) + r_{23}(Y_A - Y_0) + r_{33}(Z_A - Z_0)]} \qquad (2.13)$$

$$y_a = -f \frac{[r_{12}(X_A - X_0) + r_{22}(Y_A - Y_0) + r_{32}(Z_A - Z_0)]}{[r_{13}(X_A - X_0) + r_{23}(Y_A - Y_0) + r_{33}(Z_A - Z_0)]} \qquad (2.14)$$

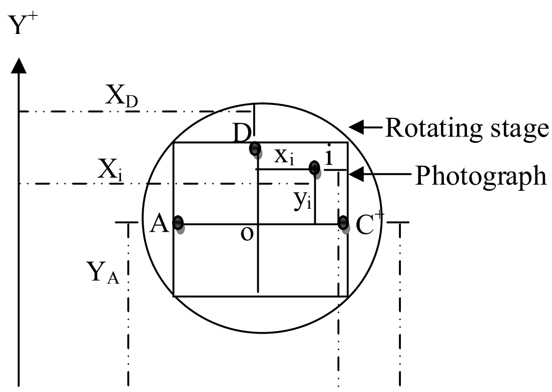
These equations are based on a theoretical hypothetical condition that does not exist in practice. It is the condition which says that the object point A, the perspective centre$O$, and the image point a in a photograph, all lie on one straight line.

2.2.4 Coordinates' measuring instruments in conventional photogrammetry

Usually the analogue image coordinates measurementsare done using an acceptable coordinates system; the origin of which is the intersection point resulting from the intersection of the lines joining opposite fiducial marks. This point is often called the centre of collimation.For a precise mapping camera it is very near to the principal point. There are many techniques which are used in photogrammetry to measure the coordinates.Each technique depends on the tool or instrument used. One of these methods is based on a mechanical technique such as comparators, and others such as those used in analytical plotters.

2.2.4.1Comparators

The idea of measuring the coordinates using a comparator is based on a rectangular coordinates system. There are two types of comparators one of which is the mono-comparator that uses a single photograph placed on a stage plate. The second type is the stereo-comparator that uses a pair of stereo-photographs.It is consists of the following components (fig (2.9)).



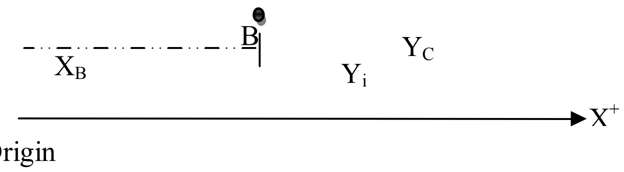


Figure (2.9) Relationship between the comparator and image coordinates

i- Image stabilization board. ii- Binoculars. iii- Lighting system.

iv- Screw to move the table in both axial perpendicular directions *x* and *y*.

v- Rulers to read distances in both *x* and *y*directions.

There are two methods used to measure photographic coordinates with this instrument. The first method is done by making the photographic x axis parallel to the *X* axis of the comparator. This is a trial and error procedure, using the y- rotary slow motion screw to make the y coordinates of both fiducial marks A and C, in Figure (2.9), equal. If the X and Y readings are taken on the four fiducial marks then the photographic coordinates x_i and y_i of point *i,* are reduced from the comparator readings to the photographic coordinates as follows:

$$x_i = X_i - \frac{X_B + X_D}{2} \qquad (2.23)$$

$$Y_i = Y_i - \frac{Y_A + Y_C}{2} \qquad (2.24)$$

The second method used to measure image coordinates by a comparator, is done with the help of a computer. In this method the Y coordinates of fiducial points A and C are made equal without the need to orient the plate. The measurements are then taken to all fiducial points and all image point whose coordinates are desired. The photographic coordinates are reduced numerically from comparator coordinates X,Y system to the photograph x, y coordinates system.

2.2.4.2 Analytical plotters

Obtaining precise and continuous measurements requiresan improvement of the traditional methods used, while saving the fundamentals of the devices used. Although comparators are considered as high degree precision devices for linear measurements up to 0.1 of a millimeter, all types of these instruments are considered as point measurement devices. For this resonanalytical plotters have been wide spreaded in the past years.Nowadays, analytical plotters have been replaced by Digital Photogrammetric Workstation devices in the processes of topographic maps' production.

In general analytical plotters are similarto stereo comparators and consistof a stereo binocular viewing system, two stage plates and a controlling computer. The main difference between the two types of instruments is the way in which the photographs are moved in the machine.

In a comparator there is a direct mechanical connection between the operator input (via handweels). In analytical plotters this mechanical connection has been removed and replaced by an electronic connection. The operators' inputs are sensed, either by rotary encoders attached to handweels or a digitizing table below a sensitised mouse.
Analytical plotters can be operated in either a comparator mode or a plotter mode. The comparator mode is used for the initial measurement of fiducial marks to solve for the inner orientation .
Once the camera parameters have been computed the method of operation changes to plotter mode i.e. looking through the binocular viewing system to see a three-dimensional stereoscopic image of the object photographed (Stirling(2001)).

The analytical plotter also features a closed-loop system in which the computer provides a real-time solution of the analytical photogrammetric equations.Therefore, the provision of the software required to implement the analytical plotter concept is essential. This includes:- (Zomrawi (2005)).

a. **Orientation and rectification programs:** For purposes of image rectification, and automatic processes related to model formations and orientation.
b. **Real time program:** Carries out the necessary corrections for the measured coordinates and computes the image or object coordinates from the measured input data.
c. **Application programs:** These programs have the ability to carry out all photogrammetric techniques analytically; such as formation of 3-D scaled model for the purpose of production of topographic maps, linking more than one model for the purpose of densification of air control points, providing numerical data in the form of three-dimensional coordinates of random points, formation of estimated models in an estimated space (i.e. independent models).Finally and the most important aim is the ability to analyze the observations and provide statistical reports such as the Root Mean Square Error(RMSE).

2.2.4.2.1 Functionality of an analytical plotter

In conventional stereo-plotters the *x, y, z* coordinates of points aredetermined by the plotter user at the scale of the stereo model depending on the observed x , y coordinates of points found in the overlapping area.

In an analytical plotter the (x,y) coordinates of points are determined by moving the floating mark around on the model surface .i.e. the operator inputs are interpreted as movements along the x, y, and z coordinates axes.For the solution of the interior orientation parameters, the computer calculates the object coordinates. The analytical plotter functioning is shown in Figure (2.10) below.

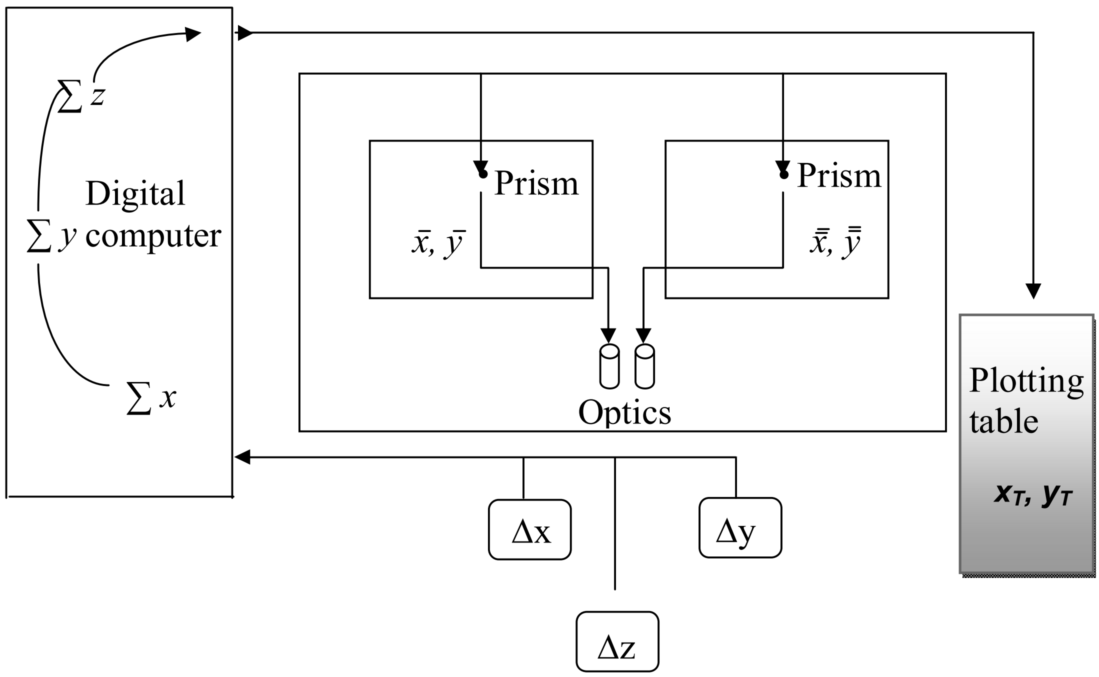


Figure (2.10) Functionality of an analytical plotter.

2.3 Digital photogrammetric Techniques

The term Digital photogrammetry is used to describe the softcopy photogrammetrywhich converts the conventional photogrammetry equipments; such as analogue cameras into digital cameras, analogue images into digital ones, and analytical plotters to digital plotters. The most important sources of information in digital photogrammetric techniques are the camerasto be used and methods required for digital image measurements and processing.

2.3.1Digital cameras

Digital imaging camerasare identical to conventional imaging cameras, in terms of the goal of their use, but they are quite different in terms of shape, performance, and nature of the configuration. In conventional imaging cameras mentioned in the beginning of this Chapter, the recepted images are printed on films specifically designed for this purpose. However, in digital cameras the recepted images are configurated by sensitive sensors known as photo-detectors.These sensors normally take the form of an arrangement of a Charged Coupled Device (CCD) or other sensor types, such as Charge Injection Devices (CID), Closed Circuit Television (CCTV), and Metal Oxide Semiconductors (MOS).(Li,(1999))

2.3.1.1Fundamentals of Solid State Sensing

There are many different concepts for solid state sensing fundamentals, all of them agree that image detector elements are the main component. The first generation of image detector elements CCD was initially developed as a memory device consisting of 8 elements built on existing fabrication linesof metal oxide semiconductors.(Tompsett et al, 1970). Their main advantages are that they are small in size, low power consumption, low cost, and low noise. Due to these characteristics many commercial companies raced to produce these types of CCD detector, with some improvements such as increasing thenumber of image detector elements.

2.3.1.2Sensor basics

An often used analogy for a solid state sensor is that of a bucketing anarray which catches the light photons. Each bucket in the array corresponds to a discrete photo sensitive detector known as sensor element. The amount of light falling on each element is read out by extending the analogy to mounting the lines of buckets on conveyors. The last conveyor line in array is shift register which takes each line of buckets off to serially measure. By maintaining a line count and timing the buckets as they are shifted along the final conveyor, the location of any bucket in the original array can be determined (Shortis& Beyer, (1995)).

2.3.1.3Charge Coupled Device camera systems design

Digital cameras have ahigh potential and a huge storage capacity, in a smaller zone, compared with the length and width of the films which are used in conventional aerial cameras causing them to be lighter in weight and ease of camera movement. All different types of digital cameras are consist of the main parts shown in the following. Figure (2.11).

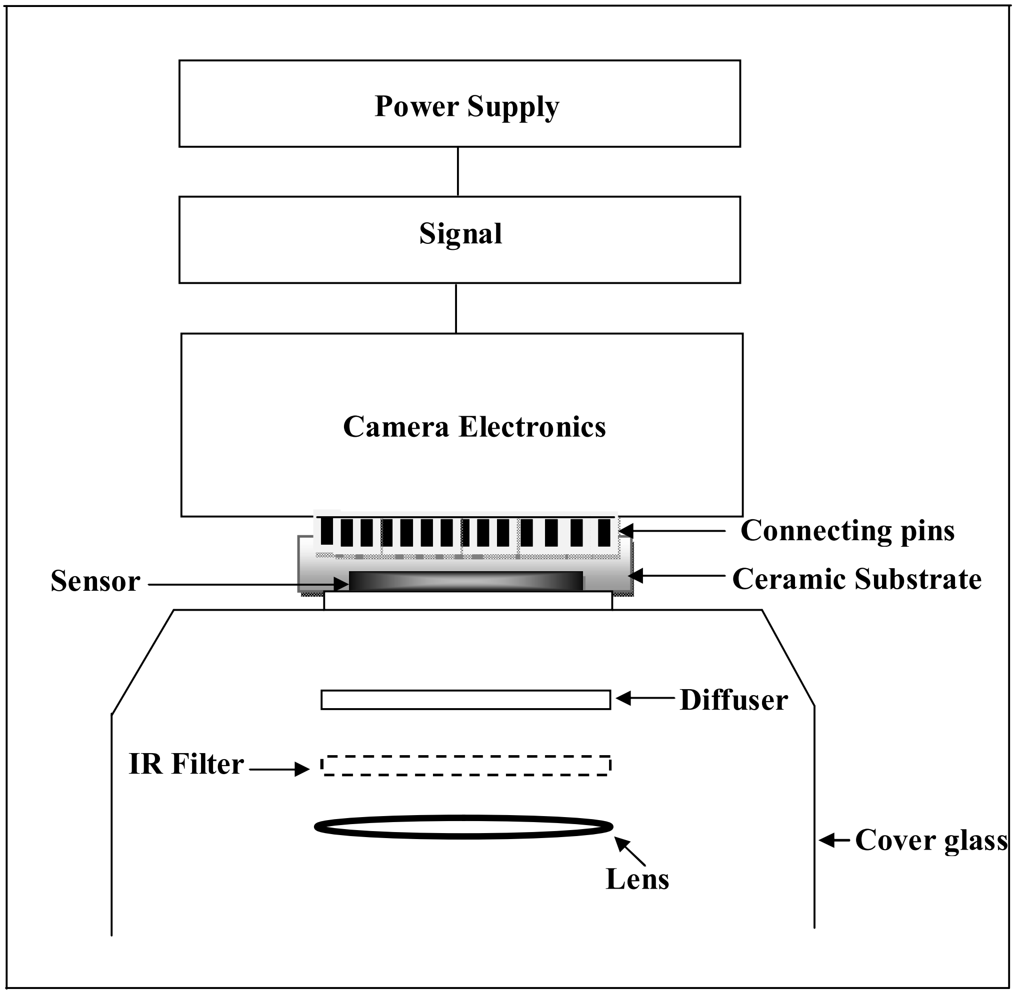


Figure (2.11) Main parts of a digital camera.

The solid CCD digital camera components can be defined as below:

- **Lens:** itis installed in the front part of the camera, and it is of a Closed Circuit Television (CCTV) type, chosen for its, low cost, and high reliability.
- **Infrared filter:** installed between the lens and the CCD sensor.There is more than one function forthe use of an IR filter, but the most important function is similar to that used in conventional aerial cameras. Itis used in orderto absorb ultraviolet radiation and not allow it to enter the CCD sensor. On the other hand, it allows the visible spectrum radiations or the X-ray radiationin the same way as with conventional aerial films.
- **Diffuser:** it is made from a bilateral refractive quartz plate is found in most cameras using interline transfer sensors as it serves as an optical low-pass filter to suppress aliasing.
- **Cover glass:** safeguards the lens from outside impurities, such as dust mites.
- **Ceramic substrate:** consists of small pockets and is used to connect the sensor to the pins.
- **Sensor:** used for picking up the light photonscoming from ground objects.
- **DIP (Dual Inline Pins):**used for electrical connection.
- **Power supply:** used tosupply the system with the operational energy.
- **Camera electronics:**contains the precise electronic units used for processing operations.

To date,there isa very huge number of digital camerasmanufactured by different worldwide companies in the global markets.However, there are apparent differences in the precision, digital image resolution, the number of pixels or lines per mm in a camera lens for each type of cameras, the dimensions of the pixel and the area of the earth surface covered by an image. Table (2.1) illustrates the major types of digital cameras use in digital photogrammetry, showing their most important features, as an example, and not as a limitation.

Table (2.1) Major types of digital cameras.(Shortis et al, (1995))

Array camera	Pixels	Pixels size	Mean focal length
VexelUltrCam$_D$	7500 X 11500	9µm	100.0mm
VexelUltrCam$_X$	3140 X 4810	21µm	100.5mm
Z/IDMC	8000 X 14000	12µm	120.0mm

DIAMC	4080 X 5440	9µm	60.0mm – 150.0mm
Applanix DSS	4092 X 4077	9µm	55.0mm or 35.0mm

The obvious advantages of digital cameras are the better image quality, shorter turn around, and at least the same accuracy leadto a clear trend in replacing the analogue cameras by digital ones . The small format cameras DSS and DIMAC do have their special field of application. The combination of up to 4 original cameras in the DIMAC cannot be compared with the DMC or the UltrCam$_D$ because there is no fixed relation between the cameras and they have to be handled like independent cameras. The quite higher number of images required to for cover the same ground area is leading to economic limitations for the classic bundle orientation. This is compensated by the direct sensor orientation, but still quite more lines are required. Table (2.2) illustrates the major types and specifications of digital CCD- line cameras that are used in digital photogrammetry, in corridor mapping of traverses and roads as an example.

Table (2.2) Major types of digital CCD- line cameras

Line camera	**Pixels**	**Pixels size**	**View direction in flight direction**	**Field of view across**
HRSC	5272	7µm	±18.9° , ±12.8°	11.8°
Lieca ADS40	2 X 12000	6.5µm	-16° , nader,26°	64°
StarlaboStarImage	14400	5µm	-23° , nader,17°	62°
Wehrli 3DAS-1	8032	9µm	-16° , nader,26°	42°

The CCD-line cameras cannot be compared directly with the digital array cameras. Achievable object point accuracy is dominated by the required direct sensor orientation, in addition to the combination of Global Positioning System (GPS) and an Inertial Measurement Unit (IMU).Also, accuracy can be improved by a bundle orientation without which the y-parallaxes can exceed the tolerance levels (Shortis& Beyer, (1995)).

2.3.2 Digital images

The term digital image means a softcopy image that can be stored in a computer CentralProcessing Unit (CPU) or displayed on a computer monitor.

Mathematically, the photograph can be described by a continuous function F(x, y), called an image. When the function becomes discrete,then the result is a digital image. Consequently digital images are considred as a non-continuous function in the variables *x*, *y*. There are special variables (Δx ,Δy) known as sampling; the discrete Δx and Δy is the pixel and the Δg is the gray level. By these elements a digital image can be represented by f (Δx. i, Δy. j) where i = 0, …n-1; j = 0,…m-1, i and j are the pixel addresses (n is the number of rows and m is the number of columns).This image function f(x,y) can be illustrated clearly in Figure(2.12) below(Schenk(1998)

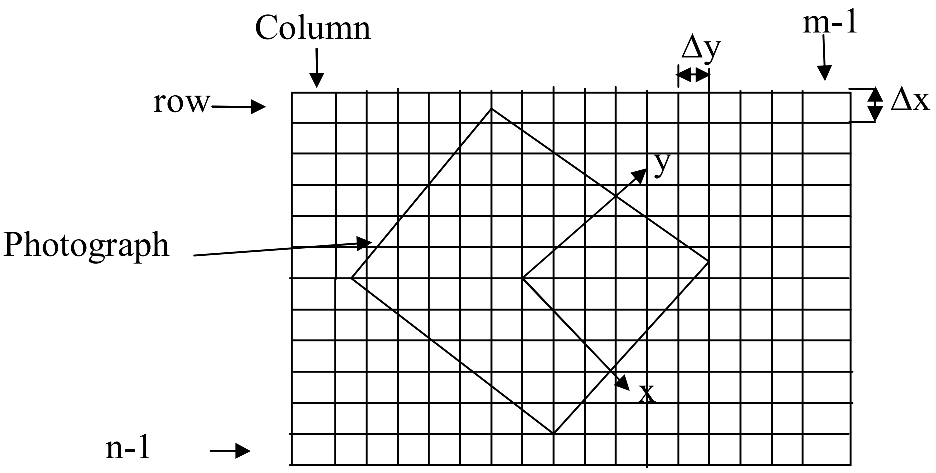


Figure (2.12) Coordinates system of a digital image.

A digital image can be recognized in a computer by a file containing a group of digits, confined between the two numbers, 0 and 255for a black and white image digital number 0 means complete blackness and 255 means total brightness.The rest of digital numbers confined between these two numbers represent the gradient of the gray. The final complete image is made up of a two- dimensional array.

On the other hand, the colored image file contains three sets of intensity values for each pixelwhichis an integrated colors of red, green, and blue bands dueto their ability to form the image.

2.3.2.1 Configuration of the Digital Image

Digital photogrammetric systems use the digitized aerial photographs or digital images as the primary source of point definition. Digital imagery can be obtained either indirectly or directly. (LPS Users Guide, 2008):

The indirect method consists of digitizing existing analogue photographs, while the indirect method consists of using digital cameras to record imagery or using sensors onboard satellites such as Landsat, SPOT, and IRS to record imagery.

2.3.2.2 Digital image Processing

Digital image processing contains several components.These are as follows:-

2.3.2.2.1Digital image acquisition

This is the first stage in getting a digital image by any means ormethod available .

2.3.2.2.2 Storage and Compression

Storing a digital image requires a large memory especially in conducting a photogrammetric project having a huge number of images.In such cases, there must be a mechanism to compress these images without any data influence, and then having another mechanism for retrieving the compressed images again. For example digital image with 16k X 16k resolution (pixel size approx. $13\mu m$) required that a storage capacity of 256MB per uncompressed black and white. Consider a compression rate of three we arrive at the typical number of 80 MB per image (Kasser andEgels(2002)).

2.3.2.2.3 Digital image enhancement.

By the term digital image enhancementismeant finding all techniques which are used to improvethe appearance of the digital image. It cancan be divided into the following:

- **Image smoothing.**

  Means intending to remove distortions such as distortions resulting from the noise, as an example.

- **Sharpening the image.**

  A process to clarify the objects and letters in the digital image.

- **Correcting defects**

They are either geometric defects or errors which are resulting from the digitizer.

- **Segmentation.**

Is means the process of dividing the digital image into segments (smaller parts).

- **Visualization**

It includes all the techniques which are used to view digital images in different media, such as the screen , magnetic tape, printer, and other output tools.

2.3.3Digital methods of image measurement

Digital methods are used to describe instruments or processes which use digital images as opposed to conventional film images. The photogrammetric computations are generally the same as those used in analytical instruments. In digital methods all required is a computer display screen and some methods of extracting image coordinates off the screen (such as a mouse) is used to move the cursor across the image. Many commercial image processing packages have a facility for displaying the pixel coordinates of cursor position.

Digital photogrammetric systems were based on Unix workstations. However these have generally been superseded with systems based on high performance PC_S. The major market for these systems is aerial mapping. In order to meet this requirement they include stereo-viewing systems utilizing either polarising or liquid crystal viewing spectacles.

This stereo viewing system is used in plotter mode. In initial operation, as with analytical plotters, the instrument operates in comparator mode where photographs are measured individually to recover the inner orientation and camera parameters.(Zheng, (1995),)

2.3.3.1Advantages of Digital Method of Image Measurement

There are a number of advantages of digital method of image measurement over analytical ones. These may include:

- More than one person can view the images at the same time,
- scan conventional photogrammetric images,
- use a disk or a flash to store required images,
- an image can be compressed ,
- high precision result can be obtained.

2.4Automation of Photogrammetric Processes

Automation of photogrammetric processes means to benefit from the advantages of all automatic digital technologies in all stages of photogrammetric operations.This automation may lead to time saving, reduced costs and human efforts, when compared with traditional techniques.One of the most important automation processes is the digital image correlation.

2.4.1 Digital image correlation

Digital image correlation is a technique of matching the overlapping area in the images stereo pairs automatically by a computer by comparing thepattern and the number of pixels in the selected area on the first image with the corresponding second image. Therefore, the digital image correlation involves a process of area based matching in which a computer attempts to find the same pattern pixel intensities on the second photograph as the one in a small image areain the first phonograph. Referring to Figure (2.13),a small area of 3 X 3pixels is selected on an image. A larger area of 5 X 5 pixels is searched to find a similar pattern.

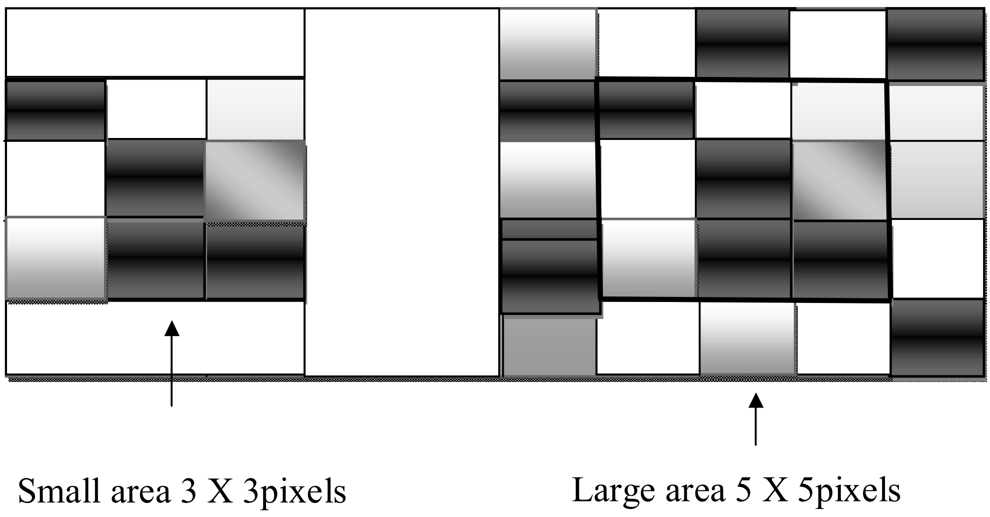


Figure (2.13) Digital image correlation

2.5 Control Points for photography

The quantity and quality of the required control points depend on the dimensions and target area of the desired project,besides the covered area in one image and its corresponding area on the ground surface. Theoretically the least number of required control points to link the image area with the same ground area is two full plus one vertical control points. Based on that, the required numbers of unknown parameters to establish the relationship between the image areas with the same ground area becomes seven, outlined as follows:

- A scale factor *S* (one parameter) that relates the dimensions on the image with the same dimensions on the ground.
- Rotation angles omega ω, phi Φ, and kappa κ (three parameters) they define the attitude of the camera at the moment of image capture.
- Three translationsΔX, ΔY, and ΔZ (three parameters), they define the position of the image relative to the ground object space.

Therefore,to obtain a unique solution for the previous seven unknowns, we need at least seven equations. To increase the level of accuracy the least number of control points can be increased and in that case the method of least squares should be used to obtain the most probable values for the unknowns.For more illustration, we can give the following:

- **Processing One Image**

Processing a single-image is generally carried out in order to rectify the tilted image. The smallest number of control points, which can be used is three full control points, well distributed to ensure that the camera or sensor is accurately modeled.

- **Processing a Strip of Images**

The smallest number of control points, which can be used to process adjacent images in one strip is two full control pointsfor each set of three consecutive images.To improve the level of rectification, three ground control points, well distributed, at the corner edges of a strip, as shown in Figure (2.6).(Leica february2008)can be used.

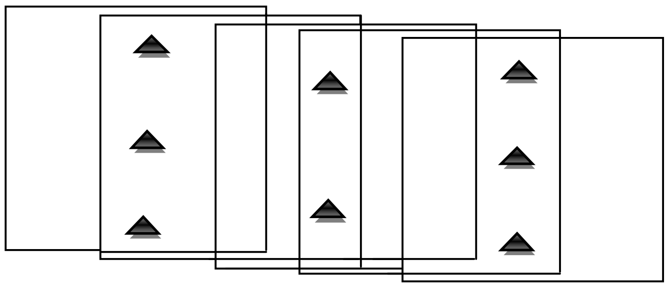


Figure (2.6) A ground control points configuration for a strip

- **Processing Multiple Strips of Images**

Processing multiple strips of images technique depends on the combination of the method used for Processing one image, and a strip of images as in Figure (2.7),showing a block comprising four strips of eight image each.

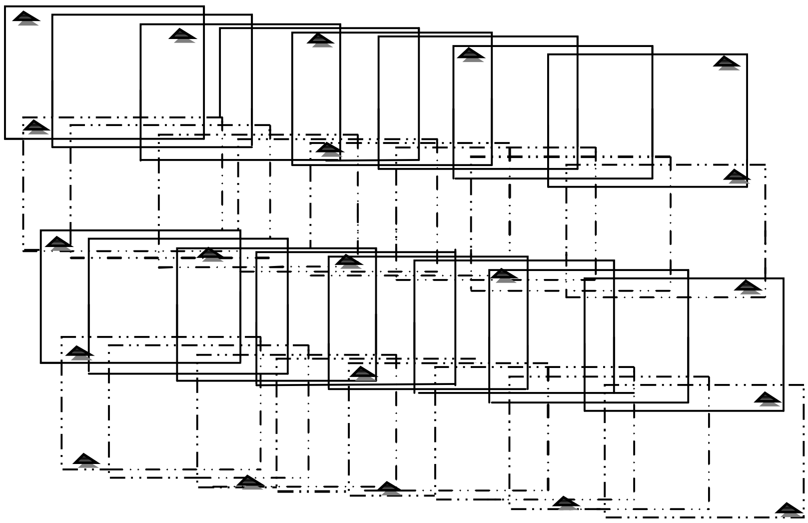


Figure (2.7) Ground control points in a block of images

Referring to Figure (2.7),generally there is specific strategies that can be followed to locate the positions of the ground control points.The strategy is that:-

- There should be at least, one ground control point to tie each three consecutive imagesof a strip (i.e in the area of triple overlapping).
- The first and last stripsshould have only one GCP on a single image at the beginning and end of each strip.
- The numbers of GCPs lying at the edges of block boundaries should be the same.

2.5.1 Selection of Ground Control Points (GCP) for Aerial Surveying

Generally the main purpose of any photogrammetric output is to createa 3-D model representing the actual real world at the moment of imaging. Therefore ground control points are needed to adjust the created 3-Dmodel.

Aerial surveying ground control points can be defined as points having known horizontal and,or vertical coordinates and can be defined clearly in both image and model.

Selection of the ground control points for aerial surveying depends on the flight mapping. There is more than one method used to obtain ground control points such as:

- The Global Positioning System (GPS).
- Old maps containing the project areatargeted.

To mention the least but not all.

2.5.2 Types of Aerial Surveying Control Points

Based on the known horizontal and vertical coordinates of the points the aerial surveying ground control points can be divided into three sections as follows:-

2.5.2.1Full Control Points

These are points having known horizontal and vertical coordinates.Sometimes they are called completed control points.

2.5.2.2Horizontal Control Points

These are points having known horizontal coordinates (X, Y or E, N or Φ, λ) relative to the origin.

2.5.2.3Vertical Control Points

These are points withZcoordinates only i.e. levels (height) above a specified datum.

CHAPTER THREE

TOPOGRAPHIC MAPS

3.1 Introduction

A map is a representation of all, or a portion, of the earth's surface, with specified scale, to locate the positions of points thereby helping to transition ease, keeping the ownership records, which help intaking proper decisions. The first map was created in the Babylonian era, in the year 2300 BC.The maps are empossed on stones and wood slabs and are used for tax collection purposes and levies from the parish.(Microsoft, 2003)

Maps have passed through many advancing stages, coupled with the developments in the various fields of science in general, and geographical science, in particular.They are printed on papers and plastics slabs till they reached to the stage of softcopies conservedand stored in computers with the help ofmany specialized and multipurpose programs.

Now, there are many types of maps in commercial markets produced by many scientific institutions that differ in their contents and their components, such as:

a) Thematic Maps

Thematic maps are designed to illustrate the farmland boundaries and residential areas by measuring lengths, heights, and areas.These help to establish a record to look after the rights of the state and of individuals, and save the ownerships. The final layout of thematic maps contain and communicate a concept or an idea.Moreover the maps are often meant to support textual information (United Nations, 2000)

b) Engineering Maps

Engineering maps are designed using a largedrawing scale to depictclearerly and more comprehensively the elevations, profiles, crossections, and any other informations which help in the implementation of engineering projectsin the most efficient ways.

c) Hydrographic Maps

These maps are mainly designed to represent the water bodies with their different types ranging from oceans and seas to riversand lakes. They can also show shallow and deep waters.In addition, these maps describe the positions of protruding rocks, millat marine drilling, coral reefs, and other relics or constructions found near the coasts.

d) Mining Maps

These maps specialize in determining the positions of all acts of mining such as coal extraction, gas oil boreholes…etc. they also show marine, ground and underground surface topographies.

Despite all these vast amounts of maps topographic maps remain the most common and widely used mapslocally and globally.

3.2Topographic Maps

The term “topographic” in Latin language consists of two-pronged:Topo which means placeand Graphic which means drawing i.e. it means drawing a place. Based on this any topographic mapshows the positions of natural and artificial features appearing on the ground.It also shows heightsof points from a given datum or surfaces such as hydrographic surfaces. The heights are represented by using, for example, contour lines method which distinguishes topographic maps from other maps. Contour linesare imaginary lines connecting points of equal heights associated with and referred to a specified and agreed surface (datum).Usually topographic maps are drawn with scales rangingbetween 1: 5000 to 1: 250000(Petrie. (1997).

3.2.1 Components of Topographic Maps

In addition to contour lines, topographic maps contains a set of symbols and signs that describe the natural features such as; rivers, trees, mountains, or the man-made features such as ; railway lines, roads,…etc. These symbols can be divided into three types as follows:

- Point symbols which are used to represent the raster features such as the ground control points, mines, wells…etc.
- Line symbols which are used to represent the longitudinal features such as; roads, railways, waterways …etc.
- Area symbols which are used to represent closed (regular or irregular) features such as; buildings, ponds...etc.

These symbols are formed with globally agreed colors, resulting in a global use of topographic maps. These most internationally used coloursare (Lonergan, (1999)) :

- Green:usually used to represent the green features relevant to plants and weeds.
- Red:often used to represent residential areas, industrial areas, and limited services buildings.
- Brown:always used to draw contour lines (i.e. used to represent surfaces and heights).
- Blue: usually used to represent the different types of water bodies.
- Black: ordinarily used to represent the general longitudinal features.

Finally topographic maps contain a key which is one of the important characteristics of these maps.They act as a solution for the map talismans and define the meanings of the symbols used.

3.2.2 Topographic Map Scale

Scale is the relative relationship linking the dimensions of features on the map with their corresponding real dimension on the earth's surface.

3.2.2.1Types of Topographic MapScales

There are more than one type of scale which are used in the design topographic maps.Each type is characterized by its purpose of use. These types are illustrated below:

3.2.2.1.1 The longitudinal graphical scale: it is a small ruler painted on the bottom of the map. If the map is exposed to any process of contraction, expansion or dilation, the scale is automatically exposed to the same process.

3.2.2.1.2 The numerical scale: mathematically can be in a regular fracture form or a proportion form.

3.2.2.1.3 The reticulate graphical scale: this type of scale is used when the desired accuracy is difficult to be clarified in the longitudinal graphical scale.

3.2.3 Topographic MapsDatums

In any topographic map it is possible to identify the locations of points and describe places with a high accuracy level.This requires anappropriate reading of horizontal and vertical coordinates from the map.Ttherefore we must have a good knowledge of the reference surfaces, adopted for the purposeof measuring ground coordinates. Reference surfaces vary according to the different locations of countries on the globe.As a result, each country uses the reference surface which commensurates with the shape and topography of that country.

There aretwo main elements that distinguish thedeterminationof one referencesurface fromthe other. These are the semi-major axis,a, and the flattening, f,of the surface as shown in Figure (3.1).

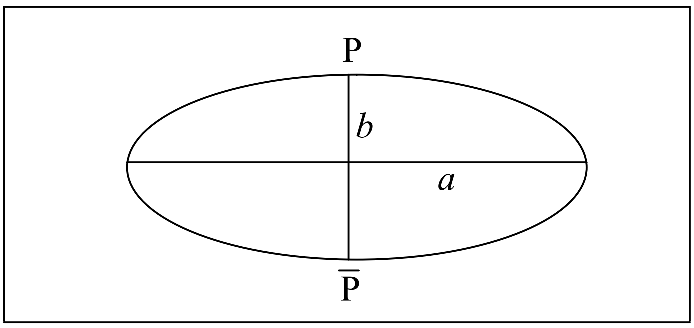


Figure (3.1) Elements of a reference surface

In this Figure:-

$b$is the semi-minor axis

$a$is the semi-major axis

The geometric elements of a reference surface can be calculated as follows:

1- The flattening ,*f*, of the surface

$$f = \frac{a-b}{a} \quad (3.1)$$

2-First eccentricity *e*

$$e^2 = \frac{a^2-b^2}{a^2} = 1 - \frac{b^2}{a^2} \quad (3.2)$$

3- Linear eccentricity *E*

$$E^2 = a^2 - b^2 \quad (3.3)$$

The main reference surface used worldwide are shown in Table(3.1) below.

Table (3.1) number of certified reference surfaces. (WGS84 Implementation Manual, (1998))

Reference surface Datum	Semi-major axis(m)	Flattening f^{-1}
Airy 1830	6377593.396	299.3249646
Australian National	6378160	298.25
Bessel 1841	6377397.155	299.1528128

Table (3.1) continued

Clarke 1866	6378206.4	294.9786982
Clarke 1880	6378249.145	293.465
Everest	6377298.556	300.8017
India1830	6377276.345	300.8017
India1956	6377301.243	300.8017
W. Malaysia and Singapore 1948	6377304.063	300.8017
W. Malaysia 1960	6377295.664	300.8017

Geodetic Reference System1980	6378137	298.257222101
Helmert 1906	6378200	298.3
Hough 1960	6378270	297
International 1924 (Hayford)	6378388	297
Krassovsky 1940	6378245	298.3
Modified Fischer 1960	6378155	298.3
South American 1969	6378160	298.25
WGS 1972	6378135	298.26
WGS 1984	6378137	298.257223563

Since the advent of the Global Positioning System (GPS), which relies on satellites to determine location, World Geodetic System of 1984 (WGS84)was chosen as a global reference surface to can be used in all countries of the worldto find the coordinates.

3.2.3.1 Definition of the World Geodetic System 1984

WGS84 was established by the American Ministry of Defense (Pentagon) to work as an integrated system with the global positioning system. The WGS84 was used as the reference frame to broadcast orbits on 23 January 1987(Rabbany, 2002). In this system:

- The earth represents the origin of the system.
- The *Z* axis is the direction of the conventional terrestrial pole for polar motion.
- The *X* axis is the line joining the intersection of the zero meridian and the equator and the origin.
- The *Y* axis completes a right-handed, earth centered, earth fixed orthogonal coordinates system.

3.2.4 Topographic Maps Projections

The aim of using projections in cartography,in general, andfor topographic maps' production, in particular, is to convert the curved surface of the earth to a paper plane surface.

3.2.4.1 Types of Topographic Maps Projections

There are several foundations criteria used to classify the projections in cartography based on the mathematical relationships as analog projections, equivalent projections, and equal distances projections. Techniques used for of packaging the globe are divided into three types as follows:

3.2.4.1.1 Cylindrical Projections:in these projection the earth is enveloped by a cylinder and the latitudes and longitudes are projected into this cylinder. The cylinder is then an warped to become a flat surface as shown in Figure (3.2) below.

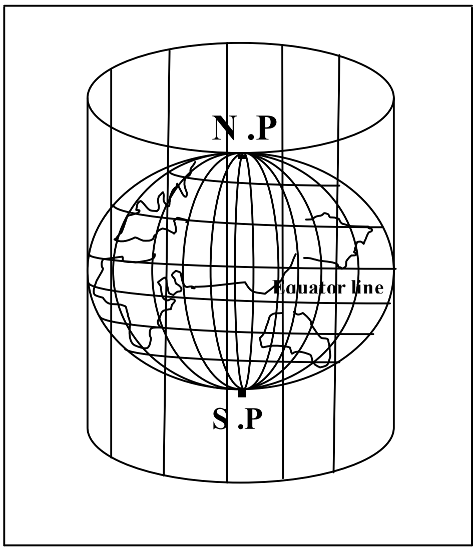


Figure (3.2) Process of the envelop earth by a cylinder

3.2.4.1.2 Conical Projections: these projections, are obtained when half of the earth is enveloped by a conical section and the projection is done in the conic, After that, the conical surface is then unwrapped to become flat as shown in figure (3.3)

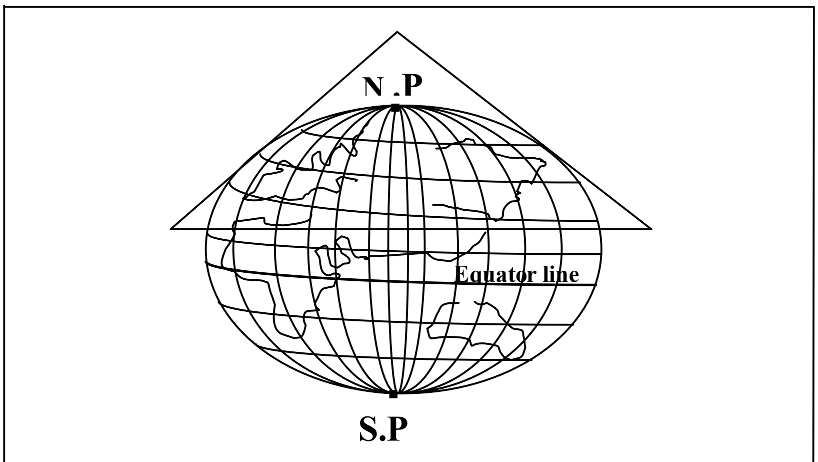


Figure (3.3) Process of the enveloped earth by a conic

3.2.4.1.3 Azimuth Projections: Also known as plane projections and obtained when the projection surface touches the surface of the ball (sphere) in a point or cut it off in a small circle as shown in Figure (3.4)

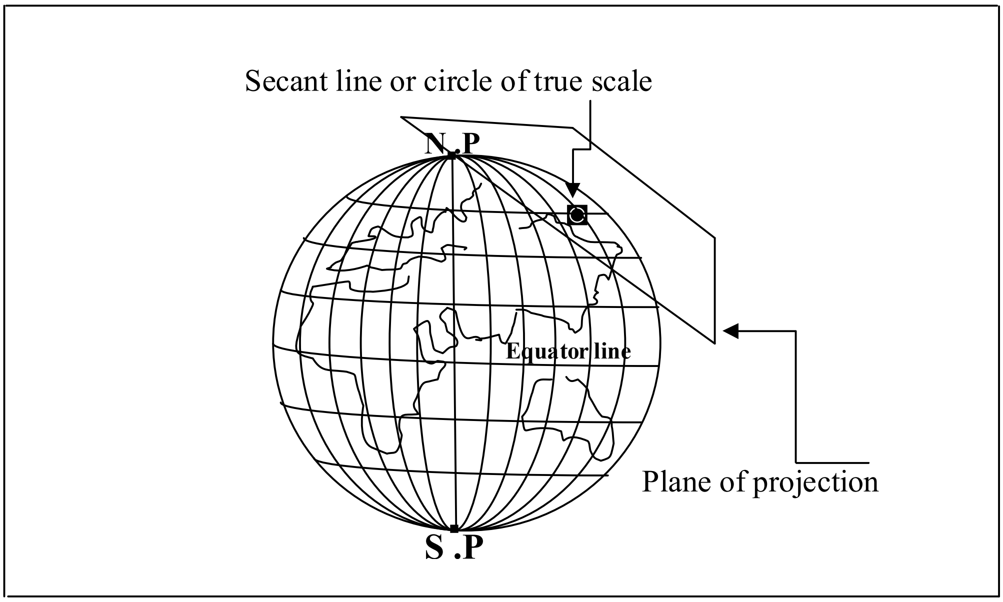


Figure (3.4) Plane projection surface tangent to surface of the ball

Projections can also be classified on the basis of the tilts of projections surfaces, into three types: normal projections, oblique projections, and transversal projections(Lonergan,.,1999).

3.2.4.1.4 Normal Projections: In these projection, the surface is made perpendicular to the direction of the earth's axis of rotation and tangent to the earth along the equator.This is when the projection isa cylindrical Projection. If the projection isa conical one, the projection surface is perpendicular to the direction of the earth's axis and tangent to one of the Latitude circuits.When the projection surface is perpendicular to the direction of the earth axis and touches the earth's surface at one of the earth poles then the projection surface is a plane projection.

3.2.4.1.5 Oblique Projections: In oblique projections the projection surface is tangent to the earth's surface in major circles, except the equator and meridians. This happens only if the projection is a cylindrical Projection. In a conical projection, the oblique surface touches the earth's surface in a small circle other than a latitude.If the projection surface is a plane then the oblique projection surface is tangent to the earth's surface at any point other than points on the equator or the earth poles.

3.2.4.1.6 Transverse Projections: In transverse projections, the projection surface is tangent to the meridians if it is a cylindrical Projection, but if the Projection is conical, then the tangent small circle which is parallel to the rotation axis of the earth whereas if the projection surface is tangent to the equator if it is a plane projection.

The most important type of transverse projections is the Universal Transverse Mercator Projection (UTM)(Lonergan, 1999). .

The cartographer Gerrards Mercator (1594-1512) who established this projection is considered as one of the most famous cartographers in the sixteenth century. His works' till now, occupies a large space in modern cartography (Lonergan,.,1999). The main characteristics of a UTM projection can be illustrated as follows:

- Considered as one of the similarity projections which mean that the projection preserves angles which result in correct directions.
- Covers most of the earth's surface area (between Latitudes 80º *N* and 80º *S*)
- Usually used in the production ofnavigational maps.
- The meridians appear perpendicular to latitudes as shows in Figure (3.5) below.
- Distances between meridians appear equal, which is opposite to their appearance on the earth's surface.
- One of its advantages is that there is no distortions in the equator.

Considered to be unsuitable to use in polar regions because distortions increase with distances from the equator. This is considered as one of the disadvantages of this projection.

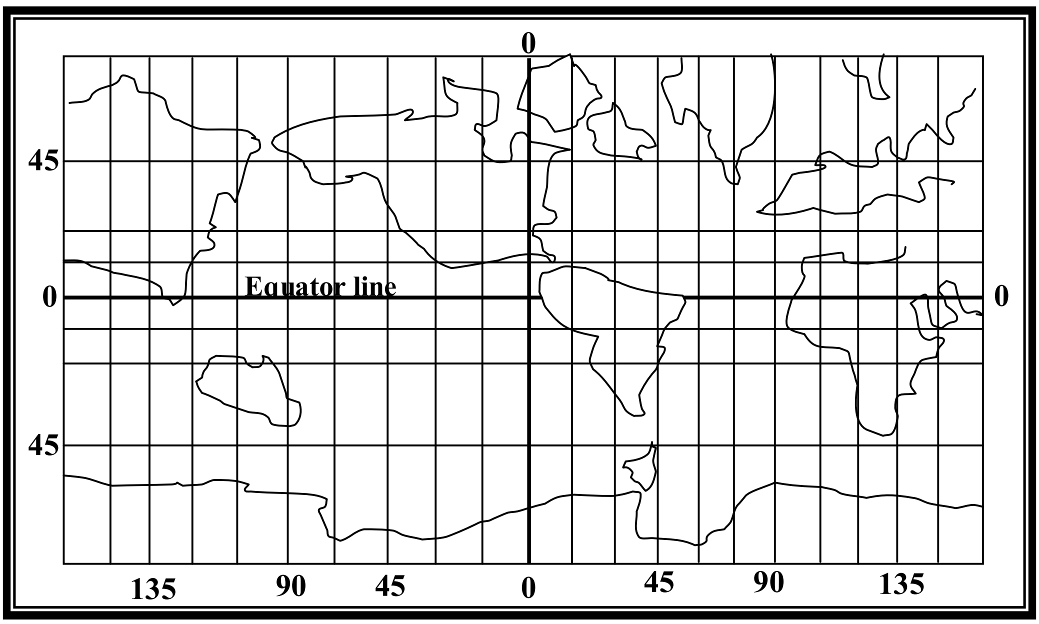


Figure (3.5) Map of the world on the UTM projection

3.2.4.2 Uses of Topographic Maps

There are more than one use of the topographic maps in civilian fields such as:

- Knowledge of the sources of the national resources and wealth.
- Assist in the planning of civil constructions in general.
- Provide good grounds for appropriate places for energy generation.
- Various military uses; such as determining the locations of the campsites, identifying the stores and training areas.
- Help to implement large engineering projects such as dams, roads and others.
- Use in agricultural projects such as the establishment of farms, monuments and forest protection.

CHAPTER FOUR

AERIAL TRAINGULATION

4.1 Introduction

Aerial Triangulation is one of the key steps which is used for the implementation of photogrammetric projects, it is the process of determining X, Y and Z coordinates of points in the target project area from photographs.

There are many applications of aerial triangulation. One of the principal applications is densifying ground control points through strips or blocks of photographs for use in subsequent photogrammetric operations. Besides this purpose aerial triangulation has other benefits such as:-

i. Having an economic advantage over field surveying.
ii. Most of the work is done under laboratory conditions.
iii. Access to much of the property within a project area is not required.
iv. Minimized field surveying in the difficult areas.

4.2 Aerial Triangulation Methods.

Aerial triangulation techniques are classified into four broad categories these are:

i. Analogue aerial triangulation
ii. Semi analytical aerial triangulation
iii. Analytical aerial triangulation
iv. Digital aerial triangulation

4.2.1 Analogue Aerial Triangulation

This method involves manual relative and absolute orientation of model using stereoscopic plotting instruments followed by measurement of model coordinates. Aerial triangulation by using this technique also called a stereo-triangulation.

4.2.1.1 Analogue Aerial Triangulation Instruments

This method of photogrammetric aerial triangulation utilizes a multi-projector stereo-plotter. In extending control by this method, adjacent stereo-models of a strip are successively oriented to each other to form a continuous "strip model." Coordinates of all pass points and control points are read from the strip model and then all points are transformed to limited amount of field surveyed ground control to arrive at their final coordinates.

The first stage in aerial triangulation with a multi-projector instrument is the preparation of a long manuscript map which will accommodate the strip model. Horizontal and vertical ground control points are plotted thereon. The manuscript is placed in the plotting table, and assuming enough control exists in the first model, it is complete by oriented.

Disadvantages of the multi-projector technique is that a continuous strip aerial triangulation requires a rather large instrument equipped with many projectors. Therefore, the manufacturers solved this problem by producing a universal instrument that possess bas-in and base-out capabilities. The same procedure of continuous strip can be accomplished here with a stereoplotter having only two projectors.

Types of control points, used in aerial triangulation are divided into three types.

i- **Ground control points:** The coordinates of the points are determined using one of the land surveying methods or from the global positioning system.

ii-**Pass points:** It is a set of points with unknown coordinates that appear in the margins of the overlapping areas.They work as links between adjacent photographs(images) in each flight strip.

iv- **Tie points:**These points are similar to the pass points. Their only difference is that they are chosen to link each two adjacent flight strips. Sometimes image positions of tie points may appear on overlapping areas of multiple photographs. Required, when choosing these points, to be distributed over the area of the block; typically, nine tie points in each image are adequate for block triangulation (Leica, 2008) Figures (4.1) and (4.2) respectively depict the placement of tie points in a single image and in multiple images lying in between two adjacent strips

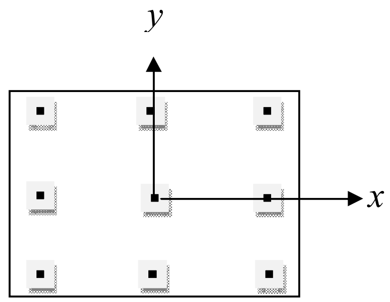


Figure (4.1) Tie points distribution for triangulation in a single image

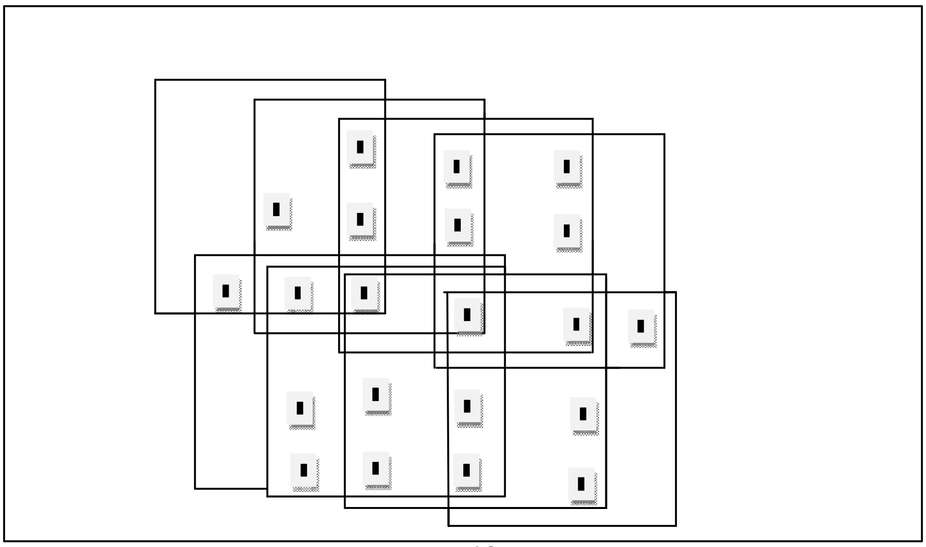


Figure (4.2) Tie points distribution for triangulation in a block of images

4.2.2Semi Analytical Aerial Triangulation

Semi analytical aerial triangulation often referred to as independent model aerial triangulation. The method involves manual relative orientation of stereo models within a stereo plotter, followed by measurement of model coordinates. Since the absolute orientation is done numerically therefore this method is *called semi analytical*. The most significant advantage of the method over analogue aerial triangulation is that:

- Any two-projector stereo-plotter can be used, provided that it is equipped with a coordinatograph for reading model coordinates.
- Absolute orientation is performed analytically and is therefore unnecessary in the plotter; thus time is saved, and least squares can be used in numerical strip formation which increases precision.

In semi analytical aerial triangulation, each stereo-pair of a strip is relatively oriented in the plotter, the coordinate system of each model being independent from the others. Figure (4.3) and Figure (4.4) illustrate the first three relatively oriented stereo-models and show plan views of their respective independent coordinates system.

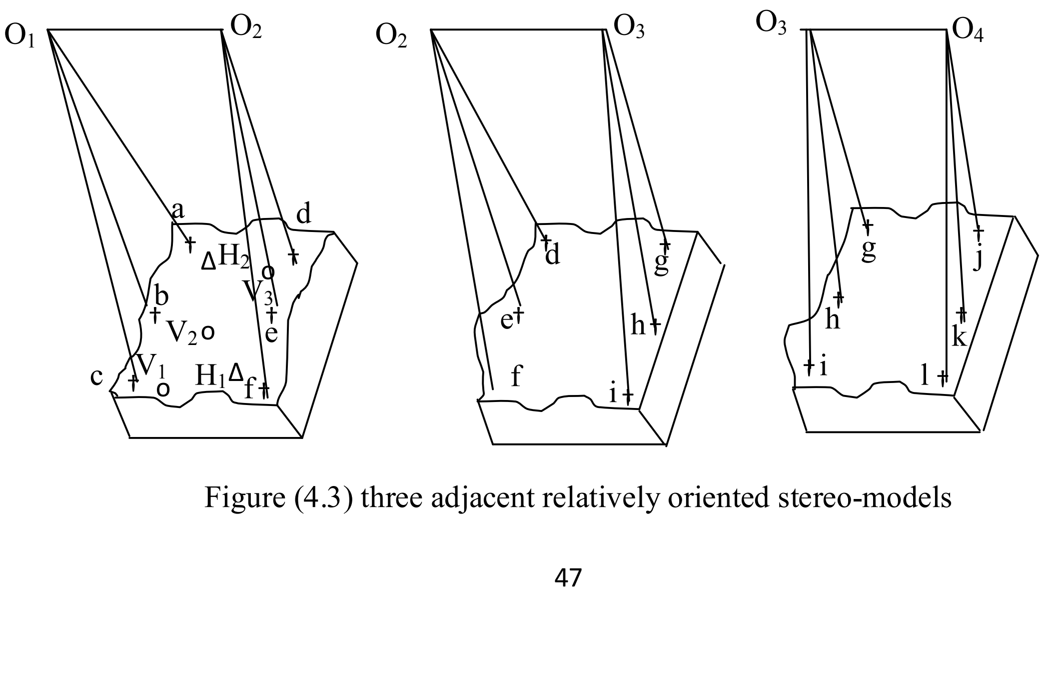


Figure (4.3) three adjacent relatively oriented stereo-models

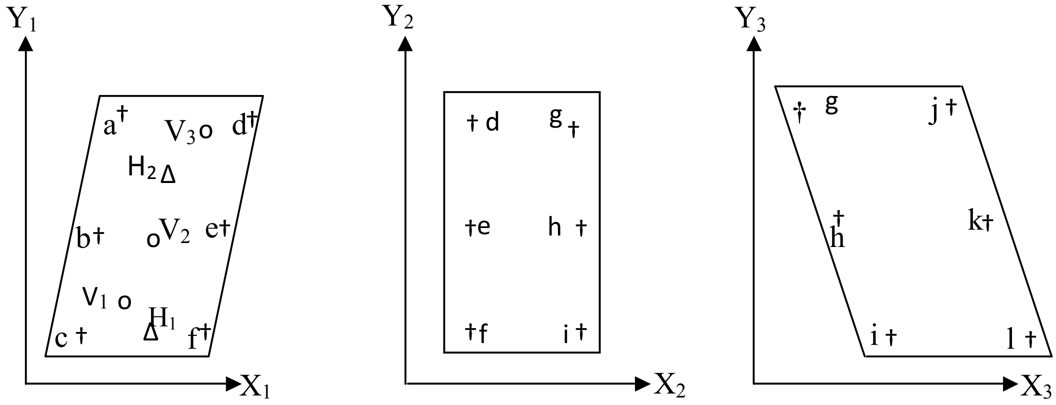


Figure (4.4) Individual arbitrary coordinates system

By applying successive coordinate transformations, a continuous strip of stereo-models may be formed, as illustrated in Figure (4.5) below

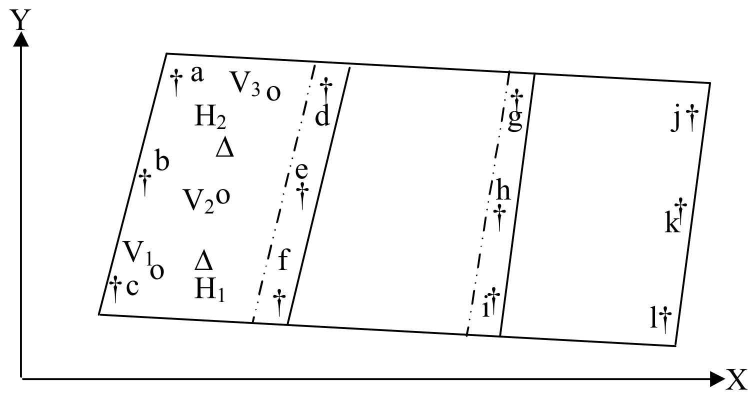


Figure (4.5) A continuous strip of stereo-models

4.2.3Analytical Aerial Triangulation

The most elementary approach to analytical aerial triangulation consist of the same basic steps as those of analogue methods and include:

1. Relative orientation of each stereo-model,
2. Connection of adjacent models to from a continuous strip,
3. Adjustment of the strip to field surveyed ground control.

The difference only of analytical techniques from those of analogue ones is that the basic input consists of precisely measured photo-coordinates of control and tie points. Relative orientation is performed analytically based upon the measured coordinates and known camera constant.

Analytical aerial triangulation tends to be more accurate than analogue and semi analytical, largely because analytic techniques can more effectively eliminate systematic errors such as film shrinkage, atmospheric refraction distortions, camera lens distortions, and other systematic effects.

4.2.3.1Advantages of Analytical Aerial Triangulation

The most significant advantage of the method over analogue and semi analytical aerial triangulation is that:

1. Higher accuracies are possible with specialized procedures.
2. Freedom from the mechanical or optical limitations imposed by stereo-plotters.
3. Photography of any focal length, tilt, and flying height can be handled with the same efficiency.

The disadvantage of analytical aerial triangulation method is that:

1. Computations are somewhat complicated and difficult to comprehend.
2. Necessitates a computer with a relatively large storage capacity.

4.2.3.2Basic Concept of Analytical Plotter

The aerial triangulation system consists of two independent parts, one is the measuring system and the other is the bundle adjustment system which share a common data base (Helsinki University of technology, 1984). The following figure (4.4) illustrates the aerial triangulation system implemented in analytical stereo plotter.

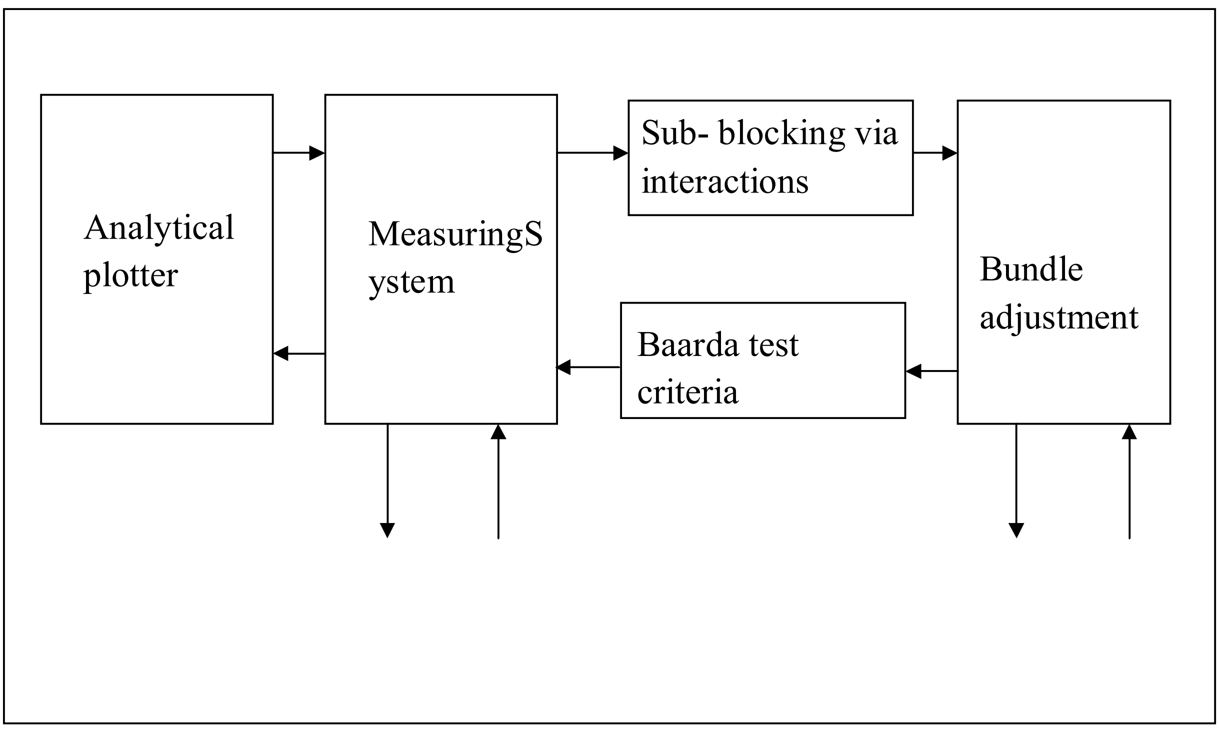


Figure (4.6) Basic concept of an analytical stereo plotter.

The connection between the two independent parts directly happens directly with the help of two small routines, or indirectly through the data base set. This called the communication media.

The block adjustment is performed by choosing the block data immediately in a form of sub-blocking. After the block adjustments are completed,an adjustment report is received automatically and contains weight coefficients of the residuals.Through the analysis of these residual errorsone can know what are the measurements which are accurately made and the measurements that need to be measured again.

The data base combinationunit depends on the following items:

1. Number of points that are required to be adjusted.
2. Number of images in the project.
3. Number of strips in the project.
4. Number of created blocks in the whole project.
5. Specifications of the used camera.
6. The model set up.
7. Points to be intersected after the final bundle block adjustment.
8. Number of the point groups having the same measuring and adjustment parameters such as pointing precession, accuracy of geodetic coordinates, numbering scheme etc.

To make the bundle block adjustment more efficient all observations must be stored on a point records form.

The most important measurement specifications are taken strip by strip in any form of order, having in mind the performance of successive inner orientations and the measurements on the models; Therefore there are several strategies after each pointing,these are follows:

a. Check on differences for points already measured.

b. Updating of parameters of relative orientation (first model in the strip) or triplet formation (other models).
c. Updating of parameters of similarity transformation between model and object, if object coordinates of the observed point is known (control point, tie point from the previous strip or model etc.)
d. Updating of the total data base. Therefore no measurements are lost whatever happens during the measurement process for example a power cut, if the disk is not scratched.

The process of the detection of gross errors is related automatically with the completion of the model measurement process, i.e. all residual values of the gross errors for model formation and also similarity transformation between the model and the object are computed. Moreover the small gross errors in the object coordinates are detected by using a polynomial adjustment with gross error detection process. If some errors are found, all necessary remeasurements and detecting are made (Helsinki University of technology, 1984).

4.2.3Digital photogrammetric Methods.

Now, with the presence of digital technologies it became possible to carry out aerial triangulation with smooth and fast processes, by using a range of special programs, and use of regimesdigital photogrammetric workstations device. Therefore the aerial triangulation begins with the preparing and annotating photographs and, automatically, a suitable number of well distributed points is carefully selected.After this stage is completed, the pass points and tie points must be transferred to all photographs. The quality of the point transfer affect significantly the success of the aerial triangulation project.

4.2.3.1. Advantages of Digital photogrammetric Methods.

Advantages of the use of automatic aerial triangulation is the possibility to simultaneously determine conjugate points by using the procedure called multiple image matching. Increasing the number of points from the typical 9 point pattern per image to, 50 or even 100 points considerably increases the reliability and the accuracy.Besides that, the automatic aerial triangulation represents an economic system, thus preserving the effort and time together.

4.3 Aerial Triangulation Applications

As a resultant of the aerial triangulation benefits as mentioned above, it is now useful in a variety of applications that include: (to mention the least and not all)

1. Property surveying to locate section corners and property corners or locate evidence that will assist in finding these corners.
2. Develop Digital Terrain Model (DTM) in topographic mapping.

3. Determine ground coordinates of points at various time intervals to monitor movements of dams and retaining walls.
4. Measure ground subsidence due to mining activity or water pumping.
5. Densification of geodetic control networks and precise determination of the relative positions of large machine parts during fabrication.

4.3 Specifications for aerial triangulation

Before embarking on the implementation of the photogrammetric project, there must be presence of specific specifications, depending upon the work to be done, to ensure access to the required precision. Therefore, there are more specifications can be put as a quid or track to access the aerial triangulation stage. These specifications are divided into five integrated branches, as shown in the chart below:

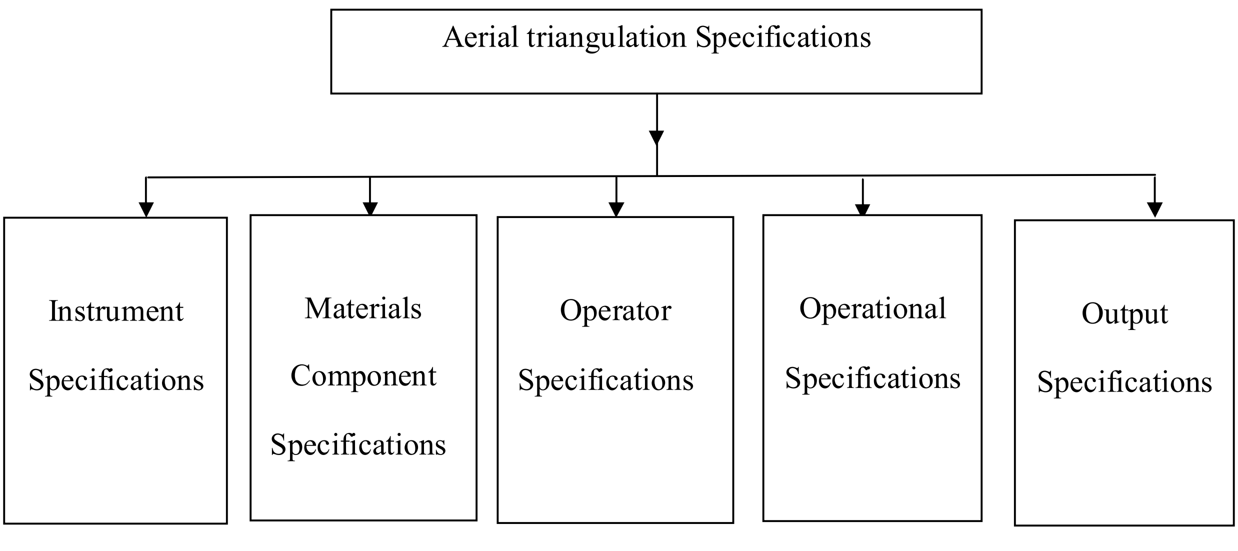


Figure (4.7) guide specifications for aerial triangulation

4.3.1 Instrument Specifications

Instrument specifications include the general and private specificationsfor devices and utilities needed to complete the process of aerial triangulation. They could be clarified as below:

4.3.1.1 Point Marking Device

These devicesare used for the purpose of numbering points by giving numbers and special signs (cross mark)engraved in the emulsion with a maximum diameter of sixty (60) micrometres to distinguish each point from the other. This is done either manuallyas in traditional photogrammetry or automatically as in analytical or digital photogrammetry.

4.3.1.2 Measuring Device

These devices are used to measureimage coordinatesof control points and coordinates of the marks points.Therefore, we must bear in mind the relationship between the reference mark size and the size of the mark whose coordinates are required to be measured.

4.3.1.3 Distortion Correction Devices

When lens, earth curvature, and atmospheric refraction distortions are computed analytically,the corrections are done automatically with the measuring device.Therefore,there is no need to use the distortion correction device. (Ministry of Sustainable Resource Management, 1998).

4.3.2 Material Components' Specifications

This section concerns with the conventional photogrammetry materials, because the materials which are used to print the negative or positive imageisaffected by temperature and humidity.These maylead to a contraction or expansion of these materials as time elapses. This in turn, may cause geometrical effects in the film.To overcome this problem it is preferable to use a material with a very low coefficient of expansion, such as polyester having a sustainable thickness of about 0.17 micrometers.

4.3.3 Operator Specifications

This term is intended to mean the human cadre's specifications who are responsible for the implementation of the photogrammetric project.They, must be selected from a high qualified staff responsible for the photographic process. The second thing to consider is the lab operators responsible for image processing must be chosen from a highly efficient staff. Finally, the aerial triangulation staff responsible for marking, numbering, measuring, and determining the ground; tie , and pass points, must consist of highly skilled, well trained staff, in these fields.

4.3.4 Operational Specifications

These are the specifications intended to carry out the photogrammetric processes dealing with the conversion of geographical features, which can be distinguished on the image and transform them to the required data.

4.3.5 Output Specifications

These are the aerial triangulation products' specifications and quality examination levels which should be specified to be sure that the aerial triangulation process has been designed according to these specifications.The errors are then corrected afterwards using the mathematical review media. One of the most important output specifications is the final complete report that includes the Root Mean Square Errors (RMSE) at image scale.These errors are specified in such a way that they should not exceed the following (at image scale).

i. Tie and pass points: 15 μm in all three coordinates.
ii. Ground control points: 30 μm in all three coordinates.
iii. Lake points: 20 μ in Z coordinates.

No residual error in (microns) at image scale shall exceed the following (at image scale)

(BMGS, 1998)).

i. Tie and pass points: 50 μm in all three coordinates..
ii. Ground control points: 60 μm in all three coordinates.
iii. Lake points: 50 μ in Z coordinates.

iv. Block ties: 70 μm in all three coordinates.

CHAPTER FIVE

GLOBAL POSITIONING SYSTEM IN PHOTOGRAMMETRY

5.1 Introduction

The Global Positioning System (GPS) has been established, in the mid-seventies of the last century by the American Ministry of Defense (Pentagon) such as the development of the TRANSIT system.

The basic purposes for the establishment of the system, are purely defensive and security. The system is divided into three sections as follows:

5.1.1 Administrative Unit

The administrative unit contains five monitoring stations,one of which is used a master control station. These observation stations have been distributed around the globe over the equator. (Rabbany, 2002).

These stations sent informations relating with the satellites orbit such as, satellite clock's to determinate position of a satellite, they also send Kepler factors to determine the shape and orbit size. One of the main functions of this unit isto protectthe system from outside invasion.

5.1.2 Satellites Unit

The second section is the satellites unit, generally known as the space segment. it is related with the set of satellites whichconsists of 24 active satellites distributed in 6 sectors along the equator, with a distance of 60^{o} from each other, as shown in figure(5-1) below.

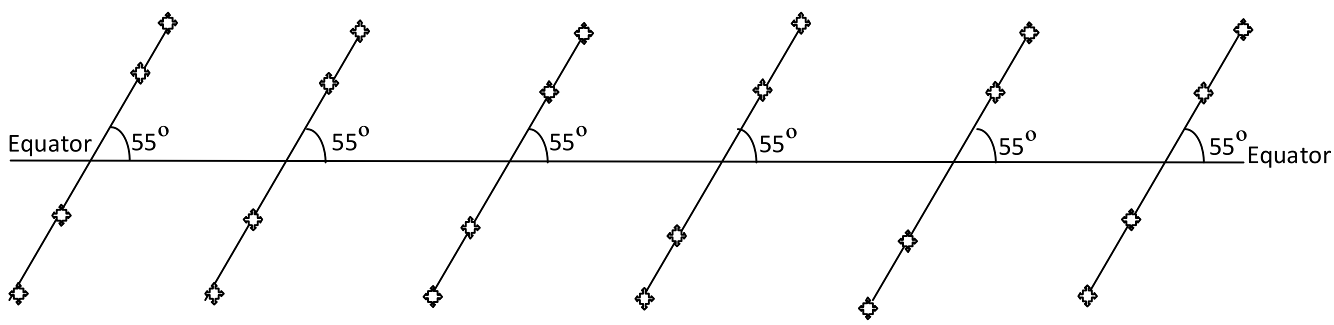


Figure (5-1) distribution of satellites along thequator.

Each satellite completes a session in 12 hours sidereal time. Active satellites operate 24 hours a day to cover the earth's surface, without being influenced by any ritual factor, such as rain, wind, temperature, and humidity. The adverage distance between satellites' orbits and the

earth's surface is about 20,000 km. To determinate a position, it requires at least four active satellites, not necessarily in one orbit, as shown in figure (5-2) below,(Rabbany. (2002).

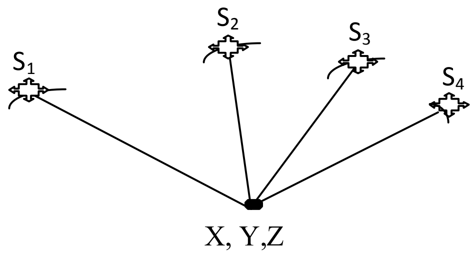


Figure (5-2) Position determinationusing GPS.

5.1.2.1 Frequency and Signals

The satellite sends the message into two different waves, which are known as, Long Band$_1$ (L_1), and Long Band$_2$(L_2). These bands can be obtained as below:

$$\left.\begin{aligned} L_1 &= F_0 \times 154\ \text{MHZ} = 10.23\ X\ 154 = 1575.42\text{MHz} \\ L_2 &= F_0 \times 120\ \text{MHZ} = 10.23\ X\ 120 = 1227.6\ MHz \end{aligned}\right| \text{——— } (5\text{– }1)$$

The waves carrier band $L_1$and L2carry two types of information, one is the L_1 carrier (1575.42 MHz) , and a precise code known as P-Code, with 19mm wavelength,and another carrier frequency signal known as Course Acquisition Code (C/A-Code).In addition to these, there found a navigational message of 50MHz, which exists only inL_1 carrier frequency.This what differentiates L_1 from L_2.Note that L_2 does not have a C/A-Code and its wavelength is 244mm.Figure (5.3) illustrates the modulate carrier code signal pulse.

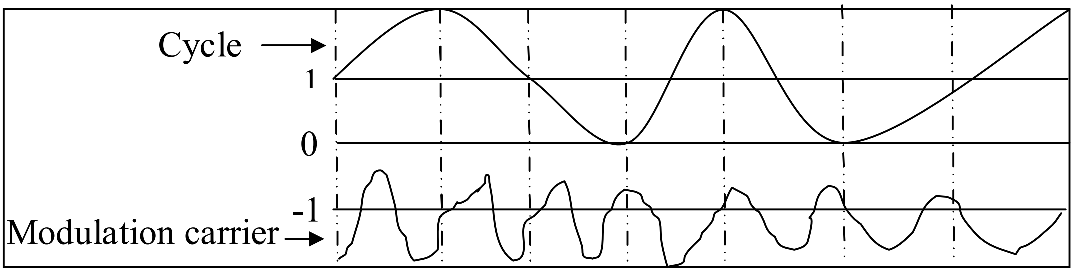


Figure (5-3) modulated carrier code.

Signals are usually found in the random or pseudo form known as Pseudo RandomNoise (PRN), which is used to distinguish between satellites. To interpret a PRN,you need to use special devices (receivers).

There are two types of GPS observationsthat can be used.The first type is the pseudo-range that measures the time of propagation of the pseudo-random modulation of the signal. The second type is the measure of phase, performed on wave carriers on an identical but stable signal generated by the receptor and locked on the satellite signal.

5.1.3 Users Unit

This section is divided into two parts. The first one is a secured partcalled Precise Positioning Service (PPS) which can only be used by the American Ministry of Defense.Itgenerally contains some variables that affect the satellite clock thereby giving false positions. This is what is known as the Selective Availability (S/A).

The second part is the one used by civilians and is known as Standard Positioning Service (SPS).

There are two types of receivers thatcan be used regardless of whether PPS or SPS is used. These are:-

a. Single frequency receivers.
b. Double frequency receivers.

The receiversmainly consistof the following system and device:-

1- Antenna.
2- Control device.
3- Reception and processing device.
4- Storage device.
5- Power supplyunit.

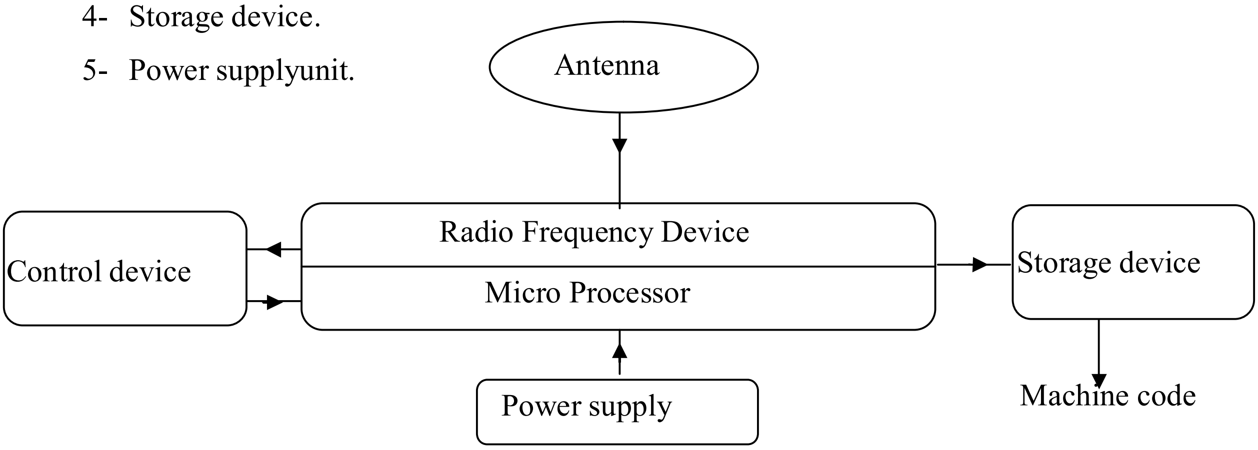


Figure (5-4) Components of GPS receivers.

After the signal enters the antenna, it is transformed into a machine code consisting of two numbers 0, or 1.These are then translated using a system known as Receiver Independent Exchange Format (RINEX).

5.2 Global Positioning Systemand Photogrammetry

Global Positioning System (GPS) can be used in conventional photogrammetry, or digital photogrammetry, in two different ways:

1. The establishment of ground control points in the photogrammetric project target area as explainedin Chapter three.
2. Use to supplement ground control needed for photogrammetric applications or for aircraft navigator during photography.

5.2.1 Use of GPS in Photographic Aircraft

In aerial images acquisition, the Global Positioning System is used inthree various ways:

i. Used to control the navigation of the survey flight,(pin pointing).
ii. Determination of the trajectory of the photographic aircraft.More precisely, thedetermination of the position of the camera lens at thetime of the image acquisition.
iii. Determination of the attitude of the photographic aircraft.

5.2.1.1 The Use of Navigation Global Positioning System for Survey Flights

The Global, Positioning System in photogrammetric observations is used to find an informationabout the centre of the camera at the moment ofphotographsexposure. These informations are require to:

1- Find the actual position of the perspective centre point.This can be obtained by locating the camera at a moment of acquisition of the photograph.
2- Good follow-up along the axis of aviation, and then make sure the theoretical values for the amount of end overlap on one strip and side overlap on adjacent strips are appropriately

5.2.1.1.1 Set GPS Navigation Observation Methods

To complete any observation process, there are specific techniques used to obtain the required information.There are two two types of positioning exist, the; absolute positioning and the relativepositioning. The precision of the positioning varies according to the type of observations, from a positioning accurate at the level of a fewmeters to a relative precision of the order of 2 mm ± 6^{-10} D to 10^{-8} D using the measure of phase; (Michel Kasser, et al, 2002).

Generally precision depends on the purpose of the photogrammetric survey project and on the observation methods. Accuracy of GPS navigation observation can be improved by using a computational method known as differential corrections. Its corrective values can be obtained whenever necessary by any of the following ways:

1. Use the network stations which broadcast these corrections at different frequencies.
2. Linking GPS receptors signal with ground observation stations which have known coordinates where the corrections are calculated and the values of these corrections are they sent.
3. Correctionvalues can be obtained directly from the special service stations corrections. This method is one of the most commonly used methods in photogrammetric observations for its ability of monitoring atmospheric conditions.

5.2.2 Locating the Camera Position

Global Positioning System in an airplane provides high precision camera positions at the time of exposure that are used in aerial triangulation. There are some known problems and errors which have to be solved when using kinematic GPS positioning of a camera in an airplane.

The GPS receiver records ephemeris data emitted by satellites to determine the position of the receiver. However, the position of the camera is required. The GPS antenna offset, or eccentricity vector, has to be measured while the airplane is on the ground. GPS phase measurements have the problem that the initial number of integer cycles, which compose the range to the satellite, is unknown. Known as initial phase ambiguity.This number can be determined by making stationary recordings before take-off and determining the baseline from the stationary receiver on a reference point to the airplane receiver.GPS signaldisruption, called loss of lock, spoils the ambiguity solution. Loss of lock may occur when the airplane wings interrupt signals over many seconds, (Bethel et al, 1996).

There are mathematical relationships between the reference ground control points, GPS antenna, and the signal devices receptors on the GPS plate.This mathematical relationship is known as Trajectography, shown in Figure (5-5).

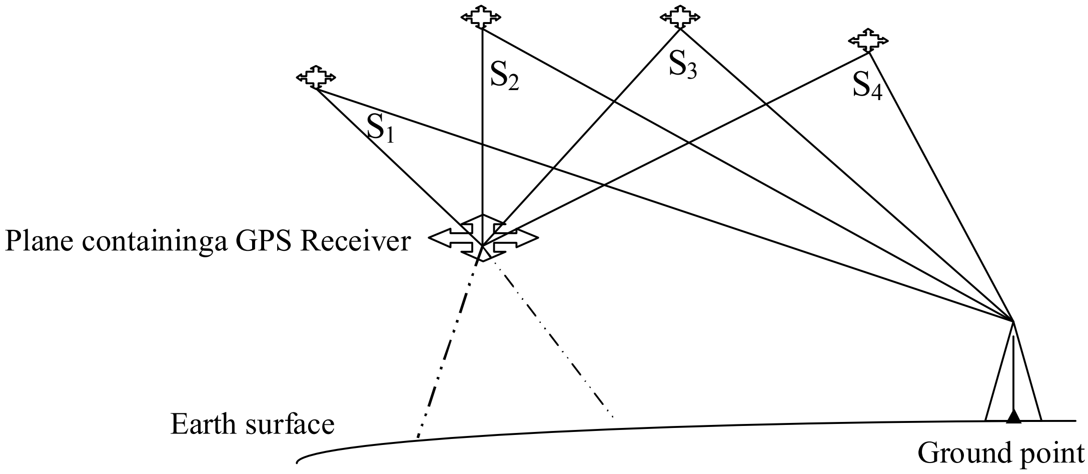


Figure (5.5) Use of GPS in the photography process.

It is known thatthe amount of signal noise coming from the phase measurement, is slightly different compared to the signal noise coming from the pseudo-rang measurements.Therefore, precision of the pseudo-rang can be improved by reducing the noise, using smoothing methods (Michel Kasser, et al, 2002).

The ambiguity resolution when using the differential method, depends on two factors;the first one is the number of receptors and the fixed reference which are used.The second is the distance between these receptors.Whenever the distance between the receptors is short (range between 10-30km), leads to a good connection between satellites and receptors, without any problem in ambiguity resolution. If one of the receptors is a mobile receptor, this may lead to an interruption of the signal (cycle slip).Therefore, the GPS devices equipped with an initialization system to resume the communication with the satellite automatically by using the On The Fly' (OTF) ambiguity resolution can be used to resolve ambiguity.

5.2.3 Measurement of Airplane Attitude

Determiniation of the air plane attitudeisalways obtained by measuring the time of arrival of a signal wave using a number of antennas. There are many types of antenna that can be used with the GPS devices. The best is the antenna that provides angular precision, by measuring the rotational motions, and thereby finding the values of angles of rotation omega (ω), phi (Φ), and kappa (κ). Linking the file of acquisition of images with the camera center coordinates(X_0, Y_0, Z_0), measured by GPS system, is known as Inertial Measurement Unit (IMU) file.

5.2.4 Use of GPS in Aerial triangulation

To make sure of photogrammetric projects accuracy and compliance with the real world results are linked with reality at the moment of photographs acquisition. In photogrammetry, generally, Ground Control Points (GCPs) are considered as liaison that relate the real world with the photographs. Therefore, we need a number of GCPs that depends on the stereo-model. For example, to adjustment of stereo-model requires two horizontal control points and three vertical points. It is obtained either by using field surveying or areal triangulation techniques.

In conventional photogrammetry, aero-triangulation obtained by analytical photogrammetric methods. In digital photogrammetry new control points are obtained automatically, without need to complex and monotonous calculations using only the tie points, between the adjacent images in overlapping areas.

There are many softwaresused for digital photogrammetry.When using digital methods, the number of points required can be reduced to less than what can be obtained, with the required precision to implement the project. For example some softwares only need to adjust one ground control point to use into five or six couples to horizontal positioning, and one vertical ground control point to use into one couple to determinate the vertical height. The process of reducing the number of control points which are used with increasing number of couples is accommodated depends on two factors.

a) The purpose of the photogrammetric survey project, and engineering techniques which are used to ensure the required accuracy.
b) Proportion of the end overlap, and side overlap between the images.

The average proportion of end overlap could be up to 65%, while the average proportion of side lap in some cases up to 35%. Increase of the side overlaps percentage, directly leads to the increase of the number of used images.Therefore, every point is found in three adjacent strips, but at the end it doesn’t permit an appreciable decrease in the number of control points below half of values needed for normal aero-triangulation. On the other hand that lead to a much better reliability and precision is improved as well (Thierry et al, 2002).

5.2.5 Complementary Observations for A photogrammetric Project

Besides the GPSsystem observations, there are some necessary measurements which are extremely helpful to the success of any photogrammetric project. These measurements can be divided into two types the first one is the measurements during the process of aviation and the second is the measurements during the process of images acquisition

5.2.5.1Measurements during the Process of Aviation

The measurements during the process of aviation can be used in both, conventional photogrammetry and in digital photogrammetry. The most important of these measurements at all is the height of the airoplanee above the datum surface, which can be obtained in the traditional photogrammetry in the past by barometric observations. In recent years the flight height is determined using GPS ,on board in the aircraft. There are some photogrammetric problems which can be solved by using the vertical measured distance from an aircraft to the ground surface,such as image scale. The scale of image is the ratio of a distance on the image to that distance on the ground. An aerial image is a perspective projection and, as will be demonstrated herein, its scale varies with the variations in terrain elevations. At first the scale of a vertical analogue image can be computed from the equationsbelow.

$S = \frac{f}{H'}$ can be used in flat terrains.

$S = \frac{f}{H'-h_i}$ can be used in variable terrain heights. (5.1)

Where: S is the image scale,

f is the camera focal length,

H' is the flying height above datum, and

Hi is the elevation of point (i) above datum.

Secondly, the scale of a digital image may be expressed in terms of Ground Resolution Distance (GRD), and the pixel size of lenses measured by micron (μm) or (line/mm) using the following equation:

$$S = Pixel\,Size/GRD \qquad (5.2)$$

5.2.5.2Measurements during The Process Of Images Acquisition

The second type of the complementary measurements are taken at the same time of photographic exposures,todeterminate respectively the (X_0, Y_0, Z_0) and (ω, Φ, κ),position using GPS and rotation elements of camera lens using an Inertial Navigation System (INS).

The orientation of the camera, based on theuse of accelerometers whose values are integrated twice to get the displacements,and on gyrometers or gyroscopes to measure the variations ofattitude, they have by their very nature a random drift more or less proportionalto the square of the time.

The GPS measurements come from receiving signals from satellites to GPS antenna. Therefore, accuracy depends on the size and shape of the antenna.The accuracy of measuring the vertical distance of each antenna should be less than 1cm.This implies as antennas on wings, the nose and the vertical stabilizer of plane cannot be distantby more than 10meters; a precision of measure that is hardly better than some millimeters, (Kasser and Egels ,(2002).

5.2.5.3 Determination of the Location by GPS Systems.

The required precision to locate the camera position at the time of image exposure depends on the geometric elements which are extracted from the image integration with complementary measurements, such as image scale, flying height above the surface datum, and pixel size of the lens.

Design speed of the aerial photography plane, may be entered as one of the factors that also affectsthe precision of the determination of the location of the camera. Overall, a precision can range between 5 cm and 30 cm when the plane's speed is between 100 and 200 m/s .A differential GPS system is used to find in a continuous positioning basis during the movement of the aircraft, every fraction of a second, using the Kinematic differential methods (DGPS).This is based on the measure of phase of at least four satellites. The principal consist in solving the ambiguities by an initialization, then to observe the points a few seconds while preserving the signal on satellites during the flight process, therefore the same integer ambiguities.(Kasser and Egels. 2002).

5.2.5.4The Relationship between GPS antenna and Camera Lens

There is a strong relationship between the GPS antenna and the optical center of the camera lens, to get a good synchronization between them for the moment between image capture and recording the coordinates which are obtained by the aircraft GPS system. Mathematically these relegations can belinked by the following equation:(Thierry et al. 2002)

$$C_0 = A_n + V + R \, . \, E \qquad (5.8)$$

Where: C_0 is the optical center of the camera lens.

A_n is the position of the GPS antenna.

V is the residual systematize of the measures.

R is the rotation matrix of the camera.

E is the link vector ranging from the GPS antenna to the optical center of camera in the aircraft reference system.

CHAPTER SIX

DIGITAL PHOTOGRAMMETRY WORKSTATION

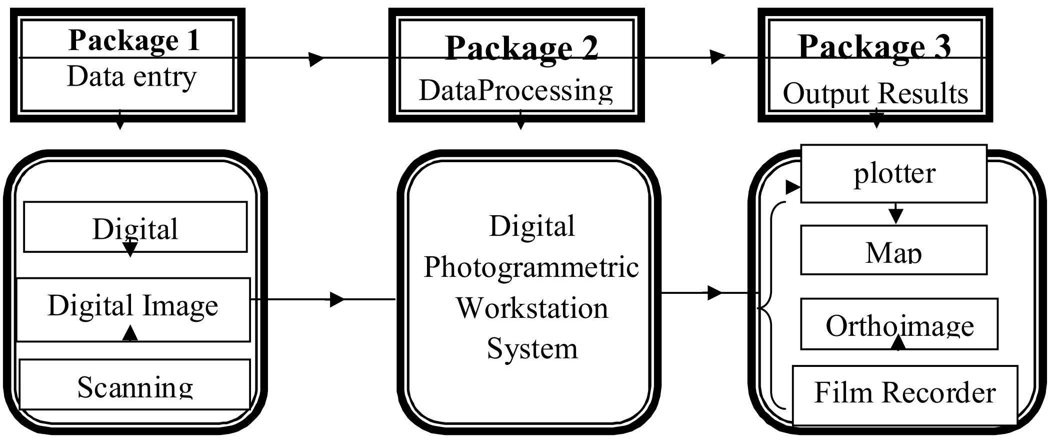
6.1 Introduction

As a result of the developmentsthat occurred in the photogrammetry, due to the prosperity progress and which happened in the computer science fields, led directly to a radical change to the photogrammetric labor market.

Currently, it became possible to deal with several kinds of images, regardless of the source that was used to acquire the images.By that wemean satellite images, analogue aerial images, or digital images specifically and to deal with the unique ability of processing maps generally.To do so, necessary amendments to the existing analytical plotters using high performance computer hardwares, which operate in an integrated environment with specialized software have been made. Accordingly, the specialized companies in the field of photogrammetry competed to produce what is known as Digital Photogrammetric Workstations (DPW_S), also called softcopy workstations. These workstations adopted, in their approach and behavior, the basics and concepts of the Analytical Plotters with the addition of some improvements,(T. Schenk,2005).

6.2 Ergonomics of Digital Photogrammetric Workstations

The concept of the Digital Photogrammetric Workstation generallyincludes the relationship between thescience photogrammetry of and Softcopy Workstation technologies because they work in one environment system, beginningfrom data entry, through data processing and ending with the output results. The packages used in all processes can be divided into three main packages, as shown in Figure (6.1) below.



▼ ►

Figure (6.1) Digital Photogrammetric Workstation and Photogrammetry equipment

- **Package 1:**only contains digital images of the target project area, obtained directly using electronic cameras or aerial photographs digitizedusing a scanner.
- **Package 2:** representsthe backbone of the system. It contains the digital Photogrammetric Workstationused for the purpose of processing digital images, the three -dimensional measurements procedure, and the three- dimensional viewing system.
- **Package 3:** contains the required devices and equipmentswhich help in getting the final produvts of the photogrammetric project such as, film recorder to produce hardcopies in a raster format (orthoimage) and a plotter to provide hardcopy production in a vector format.

6.3General Photogrammetric Algorithms

To implementation the photogrammetric project it was not necessary to reinvent photogrammetry to make it digital. Analytical photogrammetric equations such as the collinearity or coplanarity equations are reaching to the same output results.

There is more than one system are 'multi-sensor', that is to say that they can be use not only process aerial images, but there are many types of geometry image are similarity to the processed aerial image characteristics for example the images from scanning sensors or from radar. Mathematical models are required to setting up the scanned photographic or the photographs from radar system of sure are different from the traditional photographic perspective, possibly parameter able by the operator.

Whatever their origin, once images are set up or georeferenced, the function ‘terrain image‘ allows one to transmit, in real time, the displacement of the terrain introduced with the mouse or the cranks.(Kasser and Egels, 2002).

However, for economic reasons,gain time, and Saving money and effort, the analogue or analytical photogrammetry is converted to digital photogrammeytry. In order to beintegratedin one system, this requires thatmany assisting functions,such as image processing function and shape recognition, be used.

6.4 Digital Photogrammetric Workstation Component

To date there are apparent differences between Digital Photogrammetric Workstation devices in global markets.This is, because there is more than onecompany, widespread around the world produces such devices. It may, therefore, be noted that there are a differences in prices, depending on the quality of the product. All of these devices must be available with the following basic parts; a graphic workstation with enhanced image processing, memory and display capabilities including in must but not at all cases, a facility for stereoscopic viewing (Walker, 1996). These units are perfectly separated from each other,but they work in an integrated form to build the system configuration body. This can be illustrated in Figure (6.2) follows (Miller, (1993)).

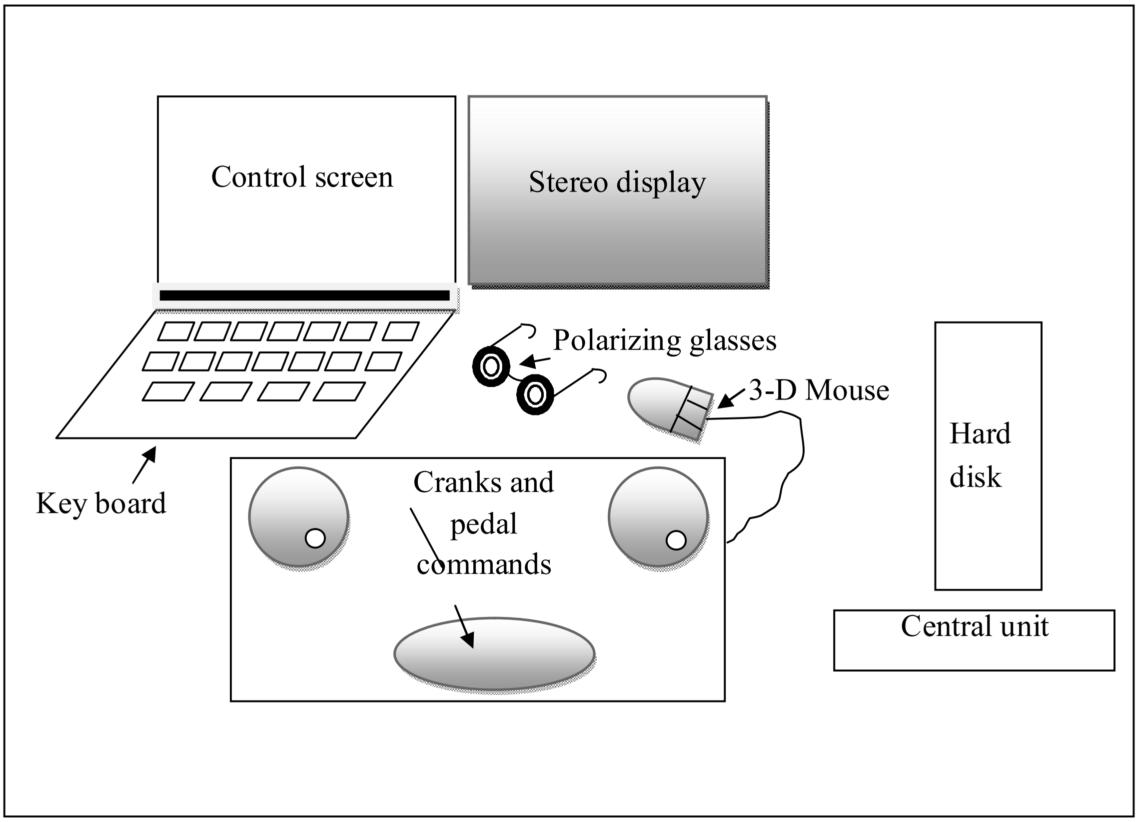


Figure (6.2) Digital Photogrammetric Workstation system

1. Central Processing Unit (CPU)

This unit contains a robust processor and a huge memory acting as storage system, in order to accommodate the huge number of images which are used to cover the project area. In addition, this unit is the one responsible for data and image processing, which is then stored and retrieved and displayed when we needed.Based on these it is possible to differentiated between these three previously mentioned tasks as follows:

1. **Operating System**

For real time processing, the suitable operating system functionality should be of 32 bits. To improve the operations the system uses allot of menus similar to these found in an analytical plotter which allows for communications between the user and the system. These are displayed on the screen of the terminal. In addition a strategy for giving advice to the user is always heavily incorporated.

One special feature of the operating system is the point groupingcapablity, mentioned in Chapter four.

1- **Capacity Memory**

The inventory of a large number of required images processed and the extraction of information, the system must havea sufficient memory. Overall, an ideal memory required to be provided in Software Workstations must be greater than 64 MB of RAM in capacity (T. Schenk,2005).

2. **Storage Systems**

The number of images required to cover a given photogrammetric project depends on the dimensions of the target area of the project generally, railges this from a few hundred images in medium-sized projects to thousands of images in large-sized projects. This leads to overstrain and may fill the existing storage system.As result, an image compression system should be used to reduce the space required to store the images. For example we require 256MB to store one black and white image with 16K X 16K resolution (pixel size approximately 13 μm).When a compression rate of up to three is used the same previous image is stored in only 80 MB. Consequently, the space required to store an image is greatly reducedwithout any effect on the geometry of the image.i.e a compression rate of times reduces the required memory space with a factor 3.2.

Now there are many electronic media which are used to save files and images which mayvaryin terms of capacityandqualitysuch as the following ways.

i. **Hard Disks:**The two types (external and internal hard disks) are characterized by a high storage capacity and fast performance.They are used in applications of roaming and displaying the images related to the project.

ii. **Optical Disks:** These may be weak in terms of performance speed, and lack of storage possibilities compared with the first two types. Its advantages are their low cost and availablity for use by everyone, such as CD-ROM, CD-R (writable), and flashes.

iii. **Magnetic Tapes:** These options of the existing storage systems are similar to a large extent, to the optical disksin terms of speed and performance functionality.For these reasons, they were used in the past as backup devices. However, they recently became a much used in online applications.

3- Graphic System

This system is able to bring the data and work to view or change the images displayed on the screenat full pelt.

4- Viewing System

One of the most important characteristics of the Digital Photogrammetric Workstation system is the possibility of seeing a 3-D model, by more than one person at the same time by using the stereoscopic viewing unit attached to the system. To achieve a three-dimensional viewing stereoscopic composition condition, the system must be able to provide a mechanism to see the left and right conjugate images in isolation from each other.There are more than one technique that can be used to achieve this condition, such as spatial , spectral or temporal illustrated below,(T. Schenk,2005).

i. **Spatialtechniques:** These are done by using a pair of computer screens to display the left and right conjugate images the first screen has a horizontal polarization infront of it, and the second one has a vertical polarization infront of it.There is, also, a reflecting mirror between the two screens. To achieve a stereoscopic viewing, the operator must weara special glasses containing horizontal and vertical polarizing filters.

ii. **Spectraltechniques:** These techniques are sometimes called anaglyphic system which relies on the use of the three main colors; green, blue, and red for their ability to produce a 3-D model. The observer uses a pair of filters in his eyes to enable him to distinguish the right image from the left one.

iii. **Temporal techniques:**These arethe most knownforphotogrammetristsby the name of stereo-image alternator system. This type of viewing depends on using spectacles equipped with alternating shouters synchronized with the alternating images on the screen. The alternative display of the two images is achieved through a device using liquid crystals letting the image passes towards the eye to which it is destined, (Miller, (1993)).

Generally in the professional systems, only this last solution is used for their better ergonomics. The quality of the stereoscopic visualization depends on the type of the screen frequency, because there are two alternative frequency discerned by the operator. To achieve the stereoscopic viewing, there are two solutions:The first one consists of liquid crystals placed directly before the operators eyeand synchronized by a wire or by infrared link.This is a better solution from the economicalview because it is a low-cost solution.The second one is that e liquid crystals are placed directly on the screen.The user uses a couple of passive polarized glasses. This helps the operator to look at the stereoscopic screen and the command screen simultaneously.This is a comfortable solution but it is more expensive when compared with the fist solution.

To distinguish between the viewing systems,refer to the following table , (Schenk, 1998).

Table (6.1) Distinction between separate images viewing systems

Separation	**Implementation**
Spatial	2 Monitors+ Stereoscope
	1Monitor + Stereoscope(split screen)
	2 Monitors+ Polarization
Spectral	Anaglyphic
	Polarization
Temporal	Alternate display of left and right image Synchronized by polarization

2. Measuring System

In conventional or digital photogrammetry and although the viewing system and the measuring system, each has its specific concept and functionality, the measuring system depends on the viewing system components,

In a Digital Photogrammetric Workstation, 3-D cursors that are created by using a pattern of pixels, such as cross or circle, are used for the measurement of ground control points, check points, and tie points on one or more overlapping images. The 3-D cursors can be divided into three categories:

- Point measurement views.
- Point measurement cell arrays.
- Point measurement tools.

The point measurement tool allows for the display, on the screen, of the two conjugate of two images contained within a block. Each image has associated with it an overview, main view and detail view. In most of the digital photogrammetric software, the 3-D cursor located is linked with the overview and main view. This makes it easy to use propertyzoom in and out of the image area and roam around the image to identify the image positions of ground control points, check points, and tie points.(Zomrawi, (2005)).

There are several purposes for the use 3D cursors including:

- Collecting and entering ground control point and check point coordinates.
- Measuring the image positions of ground control point, check point, and tie points.
- Defining the statistical quality ofof the ground control point.
- Launching processes associated with automatic tie point collection and aerial triangulation. (Leica, 2008)).

6.4.4.1 Quality Controlof Measurements

One of the most important characteristics of ,a measuring system is that it enables the control of observations quality to be carried out as early as possible. Moreover, the system direct the operator to improve the geometric quality of the work, as in the general specifications for the implementation of the project.Quality of the model is checked by computing the reliability based on Baard's theory. The gross errors are always detected by computing the standard errors of the residuals and by using the ț- test.(CASPARARY , 1987).

6.5 Basic System Functionality

The basic system functionality is a group of functions working in a circuit integrated system this is one of the aspects to improve the operation of the Digital Photogrammetric Workstation system.Figure (6.3) below illustratesthis system circuit.

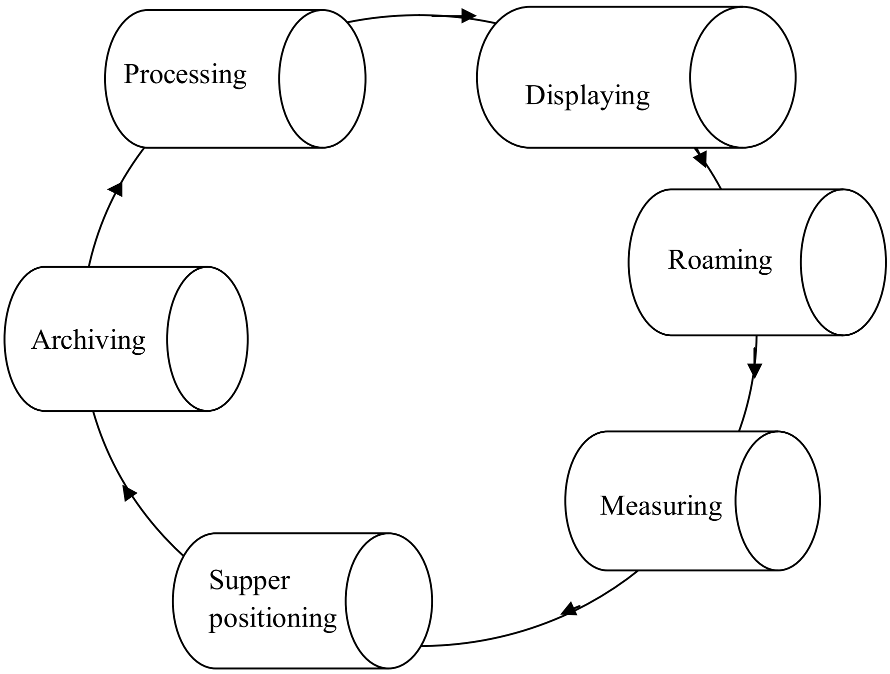


Figure (6.3) Circuit integrated functions of the system

1. Archiving

This function processes a stored compressed digital image or decompresses a stored image.

2. Processing

This function is able to do the process of adjustment of the contrast' or the brightness of positive or negative inversions. Based on the color table of images, it works in real time and don't require the creation of new images. On the other hand, this function has the ability to applyconvolution filters, contours improvement, and smoothing. Also this function plays a great role in the processes of enhancement and image resampling.

The process of image resampling depends on the visualization of the stereoscopic model whose conjugatepoints are acquired by different angles because the two images which contain these points have different scales and orientation.This is a very tedious operation for operators. Performance of usual image matching techniques are degraded, also, by this type of images. Figures (6.4) and (6.5) ,respectively, illustrate the process of visualization and how to do the resampling process for these images by Epipolar resampling method.

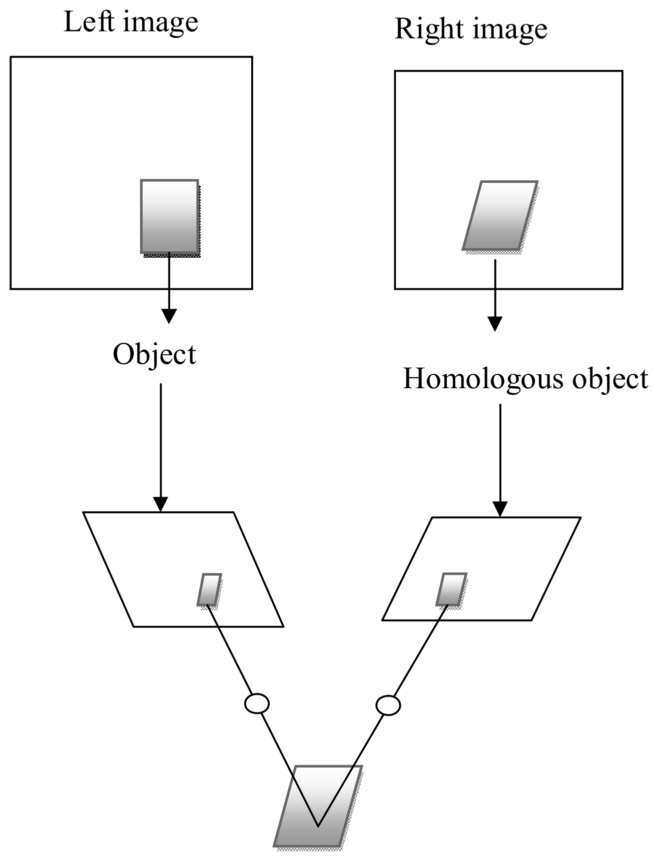


Figure (6.4) visualization of stereoscopic model

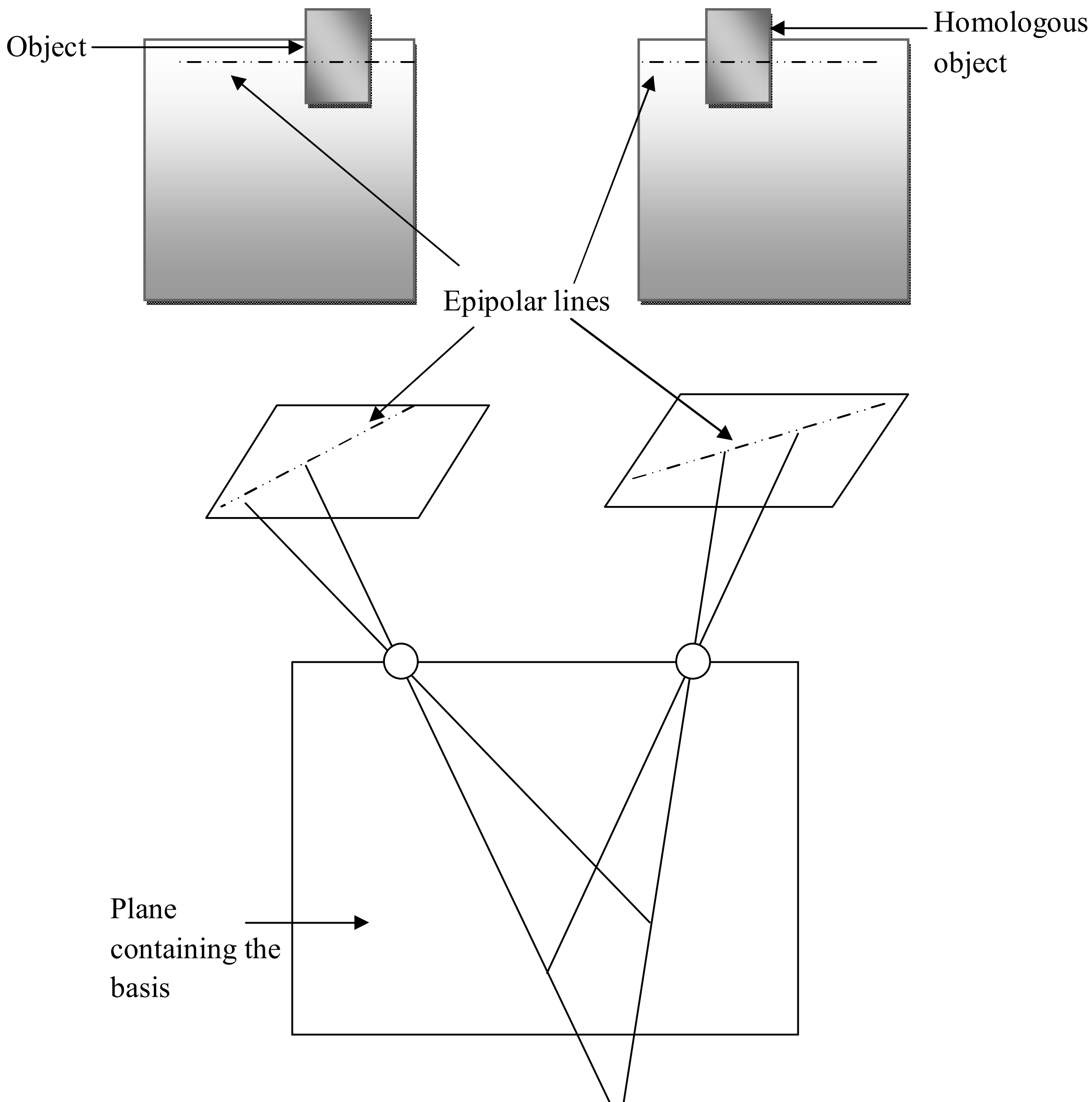

Object
Homologous object
Epipolar lines
Plane containing the basis

Figure (6.5) Epipolar resampling

In Epipolar resampling appreciably that the optical axes of images had been made parallel and perpendicular to the basis. After completing this stage, the two points of the left image will have their counterparts in one line of the right image, and the transverse parallax is constant. The lines of intersection of the planes containing the basis and the two image planes are called *Epipolar lines*.(kasser and Egels,(2002)).

6.5.2.1Advantages and Disadvantages of Epipolar Resampling

Generally in photogrammmetry there are many techniques that use to resample the status of the images in order to configure the models which represent the real world in the target project area, at the moment of images' acquisition. The Epipolar resampling method is considered as one of the most used techniques, because it has many advantages.These are:-

- It has only one couplewhich makes cutting of images possible and very easy.It also deals only with the overlapping parts which the model.
- Provides the user with very little effort, which add to the comfort of the user.
- Accelerates the work of images correlation.
- Can be used for the extraction of Digital Terrain Model (DTM).

3. Displaying

This function enables the operator to display the image or a 3-D model on the system screen.When the size of the image required to be displayed is larger than the display screen,it isnecessary to have a mechanism that works to displace the screen display in order to become suitable to accommodate the entire image. The last operation can be carried out by using one of these two ways:(Schenk, 1998).

1. Image stabilization and moving the cursor to carried out the measurement.
2. Cursor stabilization and moving the image.

a- Image Stabilization Method.

The success of this method depends on the geometry of the image resampling process.This is because if images are not reprocessed geometrically, leads to the appearance of some parallax when the cursor of the measurement is moved and the parallax is eliminated only from the centre point of the image. This makes the pointing impreciseif not impossible.

b- Cursor StabilizationMethod.

This method requires the calculation of the mobile image and the central cursor configuration which recalls the analytical devices. On the other hand, this method is preferable to dedicate the maximum surface of the stereo screen to display the two images. In additionthis method is suitable for to displaying every point in all images when carrying out aerial triangulation.

4. Roaming

The main purpose of this function is to carry out the processes of zoom in and zoom out for all or part of the images or a 3-D model. One of the virtues of this function is usually to allow to point with a better precision than the real pixel of an image.However, this may be lead to a decrease in the resolution of an image. Besides that, ablurred image can be obtained at a magnification processwhich is considered as one of the defects of roaming. Unfortunately, the solution of this problem is not available in standard graphic libraries.

In the case where the image is fixed, it is enough to resample the cursor so that it appears positioned between two pixels, which require that it is even-formed of several pixels. If the image is mobile, then it is the totalityof the displayed image that it is necessary to recomputed.

Concerning the rear zooms, they are immediately calculated or generated in advance under the shape of a pyramid of physical images of decreasing resolution as shows inFigure (6.6) below. In the case of image pyramids, one won't be able to zoom back at any scale.,(kasser and Egels,(2002)).

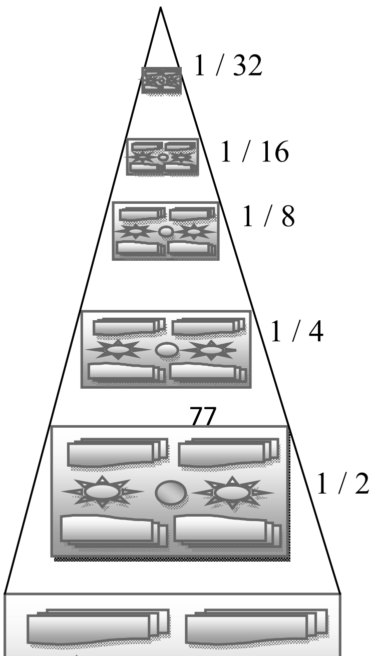


Figure (6.6). Zoom pyramid

5. Measuring

This function contains the3-D measurement system which is also carry out able to the process of measurement for points and features.

6. Super positioning

This function enables the overlap of measured data or digital maps on the displayed images. The measurement is be performed by superimposing a pointing index, whose color will be adjusted automatically to the background image.

6.6 Classification of Digital Photogrammetric Workstations

The widening circle of engineering projects that can be carry out using digital photogrammetric techniques, increased the demand for the use of digital photogrammetric workstations. This lead to an,the is increase in the number of companiesmanufacturing such devicesaround world.

Digital photogrammetric workstations emerged in the year 1955. Since there, the photogrammetric field saw the birth of many digital photogrammetric workstation systems,including low quality commercial devices, withlow prices. On the other hand, also there are also high efficiency devices with high costs.

Photogrammetrists are diligent in setting a clear criterion for the classification of these devices.They classified them into two main classes.The first category is based onfunctionality and Performance and the second category is based on the installation of hardware components (Schenk, 1998).

6.6.1 Category Based onFunctionality and Performance

a. Performance and function of an analytical plotter with automatic feature extraction.

b. Performance and function of an analytical plotter with computer assisted feature extraction.
c. Systems designed for specific applications with high Performance but limited functionality.
d. Systems designed for specific applications with limited Performance and functionality but have low costs.

6.6.2 Category Based on Installation of the Hardware Components

a. **Stereo DPW:** used for interactive stereo plotting. Include high end and lowend system.
b. **Mono DPW:** used for planimetric plotting for example, by digitizing orthophoto. High information may come from DEMs.
c. **Aerial triangulation DPW:** have a specific functionality to perform point transfer and the measurement of features in multiple images as automatically as possible.
d. **DTM DPW:** provide for automatically derived DTM with the possibility of interactive editing and quality control.
e. **Orthoimage DPW:** have special module for orthoprojection and mosaicking. Such modules are usually added to systems developed for remote sensing applications.

6.7Applied Functionalities

Each functional application that can be applied using the techniques of e conventional or analytical photogrammetry, are now available for application in the mosteasiest and quickest way. This is achived by using the techniques of digital photogrammetry.Moreover, there has become a possibility for job re-use at any time without any geometric changes.to the opposite of that, there has been addition of more new functions in the points and features measurement, improved visibility, resampling of images geometry for the conjugate points…etc, which profit from the digital nature of the image.

The geometric quality of the photogrammetric products such as vector data base, DTM, orthophotos, are calculated in an independent shape on the digital photogrammetric workstation.Target quality, when implementing those products, is affected by the quality of the following basic components:

- Specificationsfor the used films.
- Specificationsfor the used digital camera.
- Type and resolution of the used scanner to digitize analogue images.
- Geometric distribution of the control points in the target area.

- Quality of the control points.
- Accuracy of points used for relative and absolute orientations.

Digital photogrammetric workstations are, generally, considered as total photogrammetric work devices able to carry out all kinds of photogrammetric applications, including basic and advanced applications,starting from the management of data until the final outputs required.

6.7.1 Data Management

Digital photogrammetric workstations are characterized by their ability to interact withall kinds of black and white and color images, no matter the source the way acquiring the digital images. They are able to deal with various kinds of scanned analogue aerial images, various classifications of satellite images, and the images coming from various types of digital cameras. The main factor which is based upon the integration of digital photogrammetric workstations and digital images is the image resolution which depends on the size of the pixel and, its number of bits which are digitally detected. Therefore, the black and white 8 bits and color 24 bits images can easily be read by the various digital photogrammetric workstation systems.(Jasim.(2006)).

6.7.1.1 Format of used Images in Digital Photogrammetric Workstation

There is more than one preservation of the digital image file formats, absorbed in digital photogrammetric workstation systems, as a result of different techniques used to get the digital image. The following images represent the most used images in digital photogrammetric systems.

- **Images Saved as A JPEG File**

The term JPEG is an abbreviation designed as an image compression system which is known as the Joint Photographic Experts Group. It is one of the most common formats used with digital cameras. Of the most important advantages of using JPEG format are:

a) All programs dealing with images are able to open image files of type JPEG.
b) JPEG image file is relatively small which means the possibility of storing a large number of images in memory available.
c) JPEG image file take a short time to save in a digital camera this allows a large number of images to acquired quickly
d) JPEG image file does not require many processingsoftwares.

- **Images Saved as TIFF File**

TIFF is an abbreviation of Tagged Image File Format where the image taken by a digital camera is stored. In this case, the file is not compressed but there is possibility of compression after processing. One of the most important advantages of using TIFF formula is suitable formula to deal with the photographs need to processing

- **Images Saved as RAW File**

The word RAW is a photographic term which meansthe exhibition of a film to light before acidification process. The file RAW is opened through a program that contains natural file converter, which is available in many image processing programs. After conducting the necessary processing, the file can be stored in another format such as JPEG or TIFF file. The disadvantage of a RAW file format is thatthe file size is large which means a large memory is need. On the other hand one of the most important advantages of RAW format is that the image is saved without any processingwhich means that the RAW file remains as it is without any changes even if the images are processed once or more.

6.7.2 Basic Photogrammetric Operations

Basic operation contain all the primary procedures required for the adjustment and rectification of e models.

6.7.2.1 Interior(Inner) Orientation

The main goal of the interior orientation is to make the measured image coordinates system parallel to the space coordinates system.Therefore, inner orientation concernswith the work of reestablishingthe relationship between image coordinate system and pixel coordinate system (always necessary for images coming from a digitized classical aerial image). This requires the definition of the internal geometry of a camera to conform with the geometry that exists at the time of image acquisition. The actual basic parameters which are required to implement the internal orientation procedure are:

a. The focal length of the used camera.
b. Perspective centrecoordinates of the used camera.
c. The calibrated coordinates of the principal point (x_o, y_o). i.e. Coordinates of the principle point at the moment of image acquisition.
d. The coordinates of the fiducial marks.
e. Lens distortions.

The actual values of these parameters are associated with the internal geometry of the image acquired by an aerial camera as illustrates in figure (6.7) where,*o*,represents the principal point and,*a* , represents an image point.

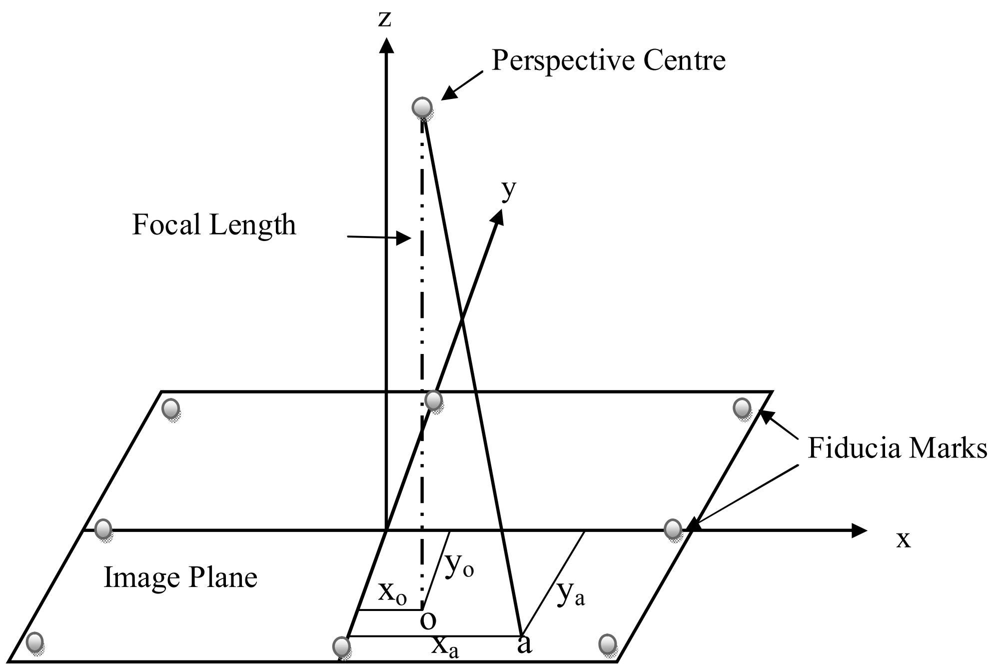


Figure (6.7) internal image geometry

The relationship between pixel coordinates system and image space coordinates systemis depends on the method used for digital image acquisition which may be either direct or indirect.

1- Indirect method

An indirect method means that the digital image is obtained from the scanning process using a scanner. The mathematical model that relates the two types of coordinates is carried out by computing a six parameter, 2-D affine transformation,as in the following equations.

$$x = a_1 + a_2 X + a_3 Y$$
$$y = b_1 + b_2 X + b_3 Y \qquad (6.1)$$

Where

a_1, a_2, a_3, b_1, b_2, and b_3 are the 2- D affine transformation parameters those are two scale factors, two translation and two rotations.

x, y are the image coordinates carried out from the coordinates of the image fiducial marks.

X, Y are the pixel coordinates obtained from the matrix of grey values; X coordinate is the column and Y coordinate is the raw of the grey matrix.

Therefore, these parameters of transformation include the angle of image rotation resulting from the scanning process as shown in Figure (6.8) below.

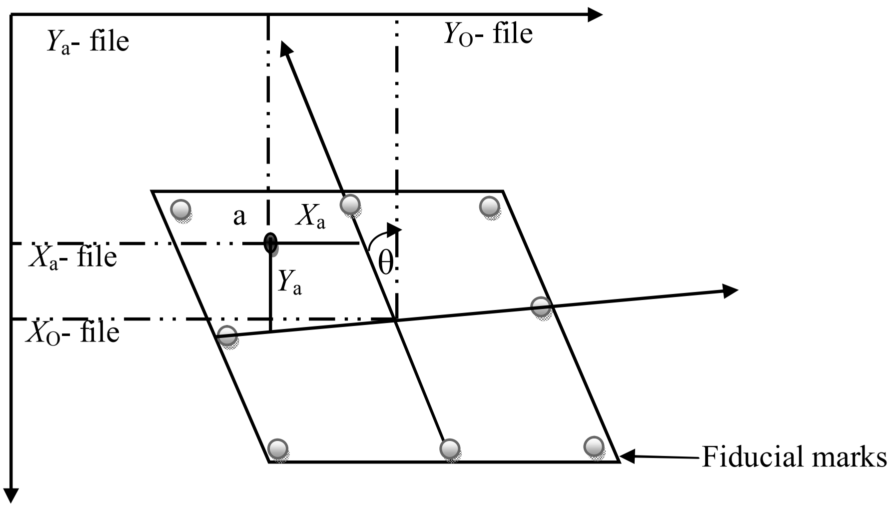


Figure (6.8) Pixel coordinates system versus image coordinates system

2- Direct method

The direct method means a digital image obtained using digital camera. The relationship between the pixel coordinates system and image coordinates system is constant and is determined during the camera calibration procedure.

The basic interior orientation variables which have been mentioned before, it can be defined as follows:

- **Lens Distortion**

Lens distortion happens when light rays, passing through the lens intersect the image plane at positions deviant from the norm. There are two types of distortion that may occur:

i. Radial lens distortion (Δr).

ii. Tangential lens distortion (Δt)

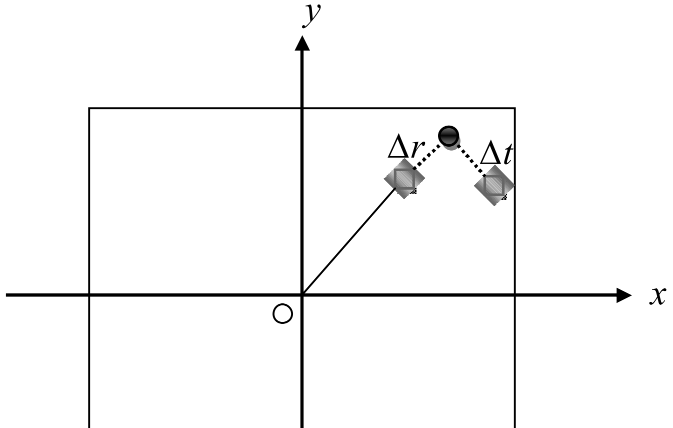


Figure (6.9) Radial and tangential lens distortions

Radial lens distortion (Δr) shown in Figure (6.9), causes distortion along radial lines from the principal point (o). On the other hand tangential lens distortion happensat right angles to the radial lines from the principal point (Lieca, 2008).
Usually the tangential lens distortion is very small in value, so always be ignored except in the jobs that require high accuracy such as medicine and industry. The radial distortion effects are the most serious and there,have to be corrected using different methods .

1. **Graphical methods**

The required correction is readdirectly from the radial lens distortion curve drawn from the calibrated focal length and the radial distance as shown in figure (6.10)

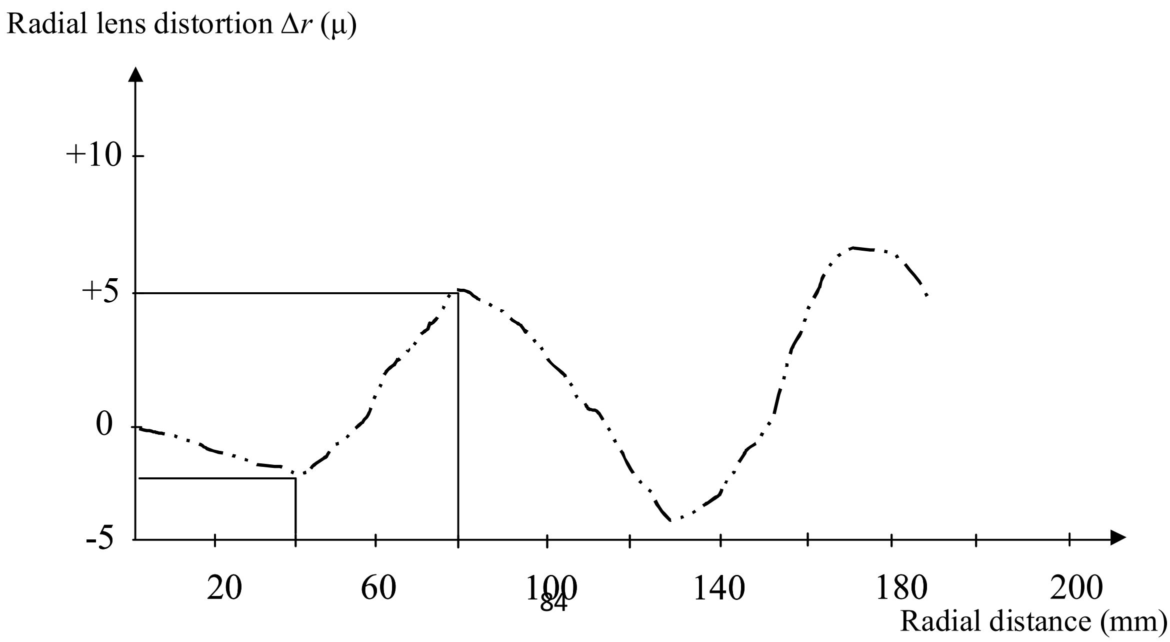


Figure (6.10) radial lens distortion curve

$$\bar{r} = r - \Delta r \quad (6.2)$$

r :Measured radial distance.

$\bar{r}$: Corrected radial distance.

Δr: Radial lens distortion.

2. Interpolation method

The radial lens distortion can also be obtained from interpolated corrections extracted from a table containing measured radial distances and their corresponding Δrs.

3.**Numerical method**

The radial lens distortion can be carried out numerically using anapproximate polynomial of the form:

$$\Delta r = k_1 r + k_2 r^3 + k_3 r^5 + k_4 r^7 \quad (6.3)$$

r :Measured radial distance

K_1, k_2, k_3, k_4…etc are coefficients of approximate polynomial that are to be determined.

$\Delta r$is the Radial lens distortion.

6.7.2.2 Exterior Orientation

The exterior (outer) orientation process contains the relative and absolute orientations' procedures. Both types of orientation are required to adjust, level, and scale the created 3-D model.

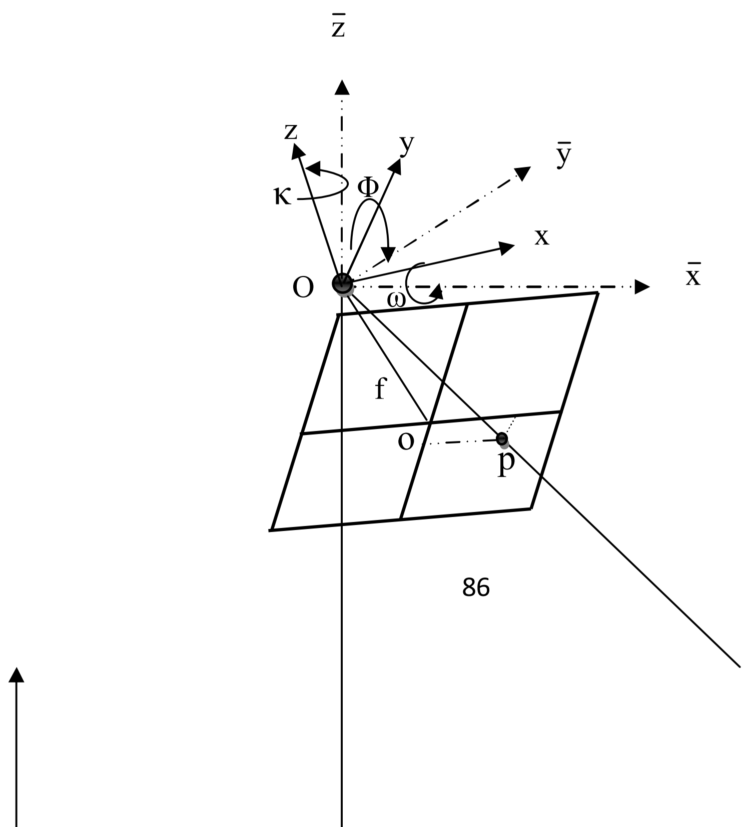
6.7.2.2.1 Automatic Relative Orientation

The relative orientation of two overlapping images describes the relative position and attitude of two photographs with respect to one another. It is 5 parameters all photography rays of conjugate features intersect, and these intersections from the model surface. After interior orientation is completed for both photographs separately. The two photograph coordinate systems are explicitly is known. Therefore, relative orientation is non semantic task, and arbitrary conjugate features can be used for the computation of the orientation parameters.

Automatic relative orientation, can be defined as the process which is describe the located x_o, y_o, and z_o, beside to the angular rotation ω, Φ, and κ for the camera at the moment of image acquired. As shown in Figures (6.11) and (6.12) below. (Tang and Heipke, (1993)).

Automatic relative orientation approach should be ideally work with multi-temporal, multi-spectral and multi- sensor imagery. The input should only consist of the photographs themselves and the result of interior orientation, the output are the five orientation parameters, the 3-d of the conjugate features and corresponding accuracy measures.

A generally, automatic relative orientation softwares should be fast, accurate, robust and reliable. Further, it should not require any approximate values.(Heipke, (1996).



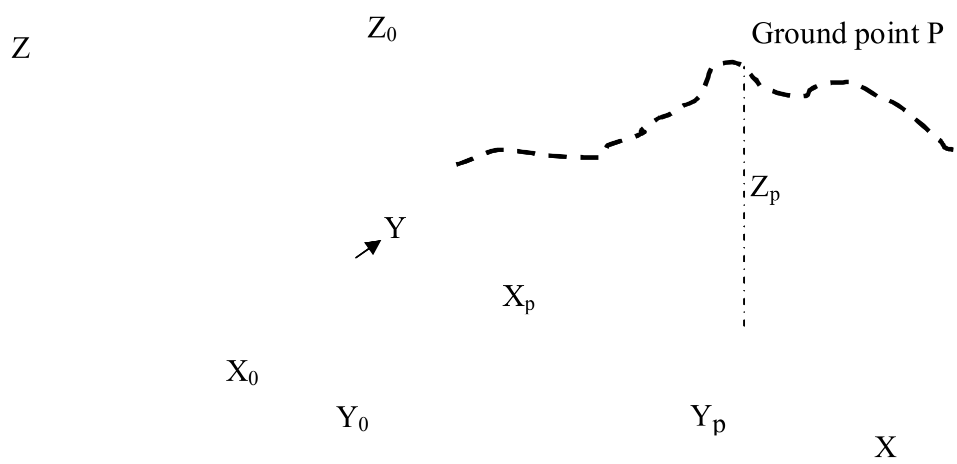


Figure (6.11) elements of exterior orientation

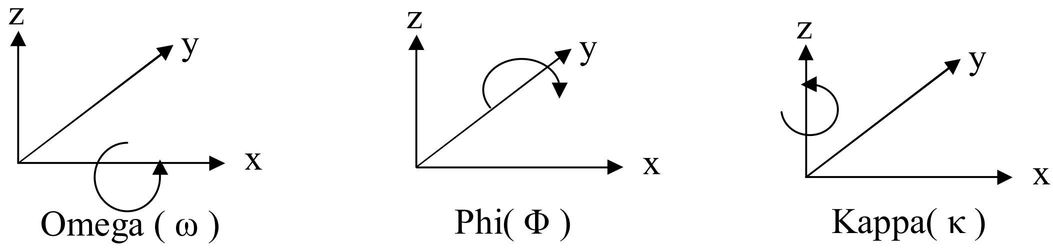
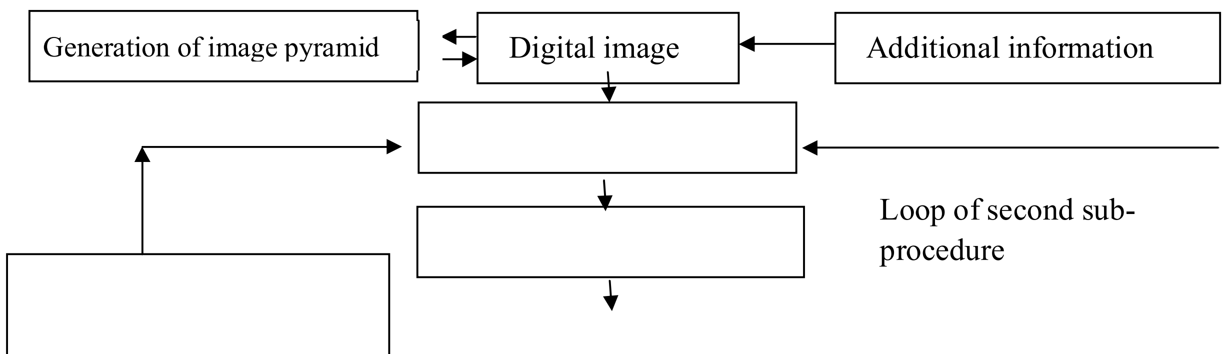


Figure (6.12) rotation elements omega, phi, and kappa

Omega is a rotation about the image x-axis, phi is a rotation about the image y-axis, and kappa is a rotation about the image z-axis. Rotation sign depends on the direction of the rotation .i.e. rotation being positive if they are takenwith clockwise and being negative if they are taken anticlockwise. Image z axis equivalent to the camera focal length. The $\bar{x}$, $\bar{y}$, and $\bar{z}$ coordinates are parallel to the ground coordinates system.

In digital relative orientation, the process of re-correcting conjugate rays coming from a pair of overlapping images automatically happens. The parameters of relative orientation are needed for epipolar resampling of digital images. Therefore, automatic relative orientation is an essential procedure for the automation of further procedures in photogrammetric stereo processing. The procedure is completed by fixing one cursor of a stereo positionwhile moving the second cursor.

Figure (6.13) gives the algorithms used for a practical application of automatic relative orientation by using digital photogrammetric workstation systems (Tank and Heipke, 1994).



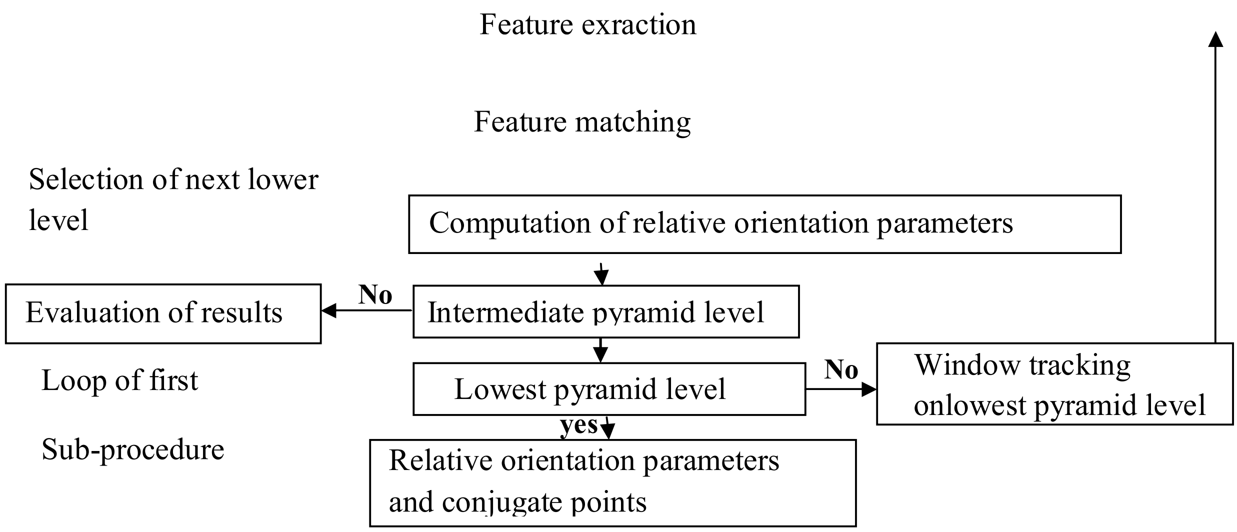


Figure (6. 13) Concept of the algorithm for automatic relative orientation

Where:

- **Additional information:** Additional information is used to derive initial values for the unknown orientation parametersusing the method of local forward intersection.
- **Feature extraction:**is the determinationof imagesof distinct points, edges (or lines), and areas.
- **Feature Matching**: is the process of finding the corresponding feature pairs.
- **Computation of relative orientation Parameters**:After feature matching, the parameters of relative orientation are calculated in each pyramid level in a least-squares bundle adjustment using the candidates for conjugate points as observations.
- **Evaluation of results:** results are evaluated by computing theoretical standard deviation values of the six orientation parameters.
- **Pyramid levels:**The relative orientation procedure starts from the highest pyramid level with the smallest image size and the lowest resolution, and ends at the lowest level with the original size and resolution.
- **Window Tracking:**The idea of window tracking is based on the consideration that a feature from a given level can only be one of the following:

➢ An indication for a good feature on a lower level,

➢ a representative of several good features on a lower level, or

➢ a pseudo-feature which disappears later.

6.7.2.2.2 Automatic Absolute Orientation

Most systems calculate the relative and absolute orientations by the simultaneous use of the collinearity equations, illustrated in Chapter Two. After relative orientation, the three dimensional model surface is available through the stereo viewing. An automatic module, however, obviously does not have stereo viewing capabilities and thus, unless the surface has been explicitly extracted, for example as in the form of DTM, it is not available. Therefore, there are two basic purposes are achievable where carrying out the process of absolute orientation in general photogrammetric idea.

- It assists in leveling of the model.
- It assists in the process of model scalling.

Automatic absolute orientation demonstrates the relations between images or model coordinates system and the object coordinatessystem. Therefore, there must be found a number of ground control points, to complete the absolute orientation process.

6.7.3 Advanced Photogrammetric Applications

Advanced photogrammetric applications include all extra techniques which are used as assistance methods to improve the photogrammetric applications, such as automatic aerial triangulation, digital terrain models, ortho-images… etc.

6.7.3.1 Automatic Aerial Triangulation

The main goal of the aerial triangulation isto increase the least number of control points, physically located in the overlapping area between the images, to assist in the process of georeferencingof images in a form of blocks or image sets.

In digital photogrammetric system the same calculations and formulae are the same as those used to complete the aerial triangulation in analytical photogrammetric systems.

On the other hand, in automatic aerial triangulation, the reference points can be measured automatically and interactively with the assistance of a multi windowing design. Each point is measured automatically on the image where it appears. All images containing the same point are displayed in mini windows, directly zoomed on the area concerned. Therefore, all points' positions can be measured from the window where it appears.

In automatic aerial triangulation, the measurement of any tie point, identifiable on a pair of or more, overlapping images, whose ground coordinates are not known,is very automated.

There are many types of modern softwares, designed by multi different companies, are used in digital photogrammetric workstation systems.These have been developed to carry out the automatic aerial triangulation more effectively to meet the shortfalls increase the reliability and effectiveness of the traditional systems. The Leica Photogrammetry Suite (LPS) is one of these softwares which works in integration with ERDAS software. This software has manyadvantages and characteristics, when applied to carry out aerial triangulation such as(LPS Users Guide, 2008):

- **Automatic block configuration:**Based on the initial input requirements, this software automatically detects the relationship of the block with respect to image adjacency.
- **Automatic tie point extraction:**Extraction of the candidates of tie points.
- **Point transfer:** All conjugate points are automatically identified on the image where they appear.
- **Gross error detection:**The gross errors in measured points are automatically identified and removedbefore they are used in the solution.
- **Tie point selection:**The intended number of tie points defined by the user is automatically selected as the final number of tie points.

6.7.3.2 Digital Terrain Models (DTMs)

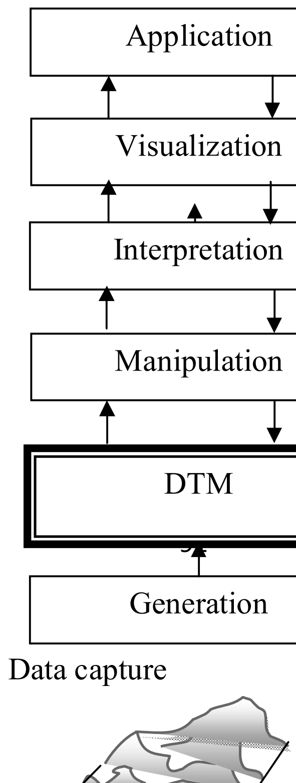
The term DTM refers to those datasets which originate as point features while the term DEM refers to those datasets which originate as continuous surfaces. Therefore, Digital Terrain Models (DTM), is a representation process, to dipict the terrain reliefsand the relative heights of a part or all of the earth's surface in digital forms.

Terrain or etherrelief, means the physical shape of the earth surface in the vertical and horizontal dimension levels. Therefore, there are many expressions that can be used to illustrate the concept of terrain, or earth, relief. These may be in terms of elevations, slopes, and orientation of terrain features on the surface of the earth. Generally, the terms Digital Terrain Models (DTM) and Digital Elevation Models (DEM) are often used interchangeably in Geographical Information System (GIS) sciences.

Representation of the terrain is one of the arduous tasks that are difficult to produce manually. Therefore the Digital Terrain Models are used as supporting data to the restitutions and or as a product.(Weib and Heller (1990)).

All of digital photogrammetric workstations are perfectly designed and adapted to control and correct DTMs obtained from automatic techniques.   In addition to that there a possibility of modifying the existing digital terrain models, by fixing the DTM measure mark, which leads to save effort evolved.However, this process is of limited benefit for many reasons; such as the frequently excessive generalization which may lead to non-representation of the objects over the ground surface and false correlation may happen especially when the signal noise ratio is slow.So, to complete the process of a DTM, and outlook to a really represents the terrain and to give a real shape of the surface of the earth these the created Digital Terrain Models must includes the following tasks, as illustrated in Figure (6.14)below (Weibel and Heller, 1990).

- **DTM generation:**Sampling of original terrain data among the diverse observationsformation of relations.
- **DTM manipulation:**Rectification refinement of DTM**.**
- **DTM interpretation:**DTM analysis, and information extraction from DTMs.
- **DTM visualization**:Graphical rendering of DTMs and derived information.
- **DTM application**:Development of appropriate application models for specific disciplines.



For the purposes of enhancement, DTM correction and system controlling, there are some measures that must be done manually. The control is often performed visually by stereoscopic observation of level lines calculated from the DTM superimposed onto the couple of images. The correction process can be done using different solutions from local recalculations with different parameters.

CHAPTER SEVEN

EVALUATION OF PHOTOGRAMMETRIC SURVEYS

7.1 Introduction

Photogrammetry is a surveying and mapping method that has many applications in civilian, include topographic mapping, site planning, earthwork volume estimation for proposed roads, compilation of digital elevation models (DEM), and image base mapping (orthophotography).

The term “photogrammetry” is composed of the words “photo” and “meter” meaning measurements from photographs. From the classical definition of photogrammetry that illustrated in Chapter One. Photogrammetry is an art, because obtaining reliable measurements requires certain skills, techniques and judgments to be made by an individual. It is a science and a technology because it takes an image and transforms it, via technology, into meaningful results. Modern photogrammetry includes image sources and image forms other than photographs, such as radar images.

Images used for photogrammetry can originate from an analogue camera, digital sensors, or image can be recorded from a device mounted on a satellite,

7.1.1 Advantages and Disadvantages.

Some advantages of photogrammetry over conventional surveying and mapping methods are:

1- Provides a permanent photographic record of conditions that existed at the time the aerial photographs were taken. Since this record has metric characteristics, it is not only a pictorial record but also an accurate measurable record.

2- If informationhas to be re-surveyed or re-evaluated, it is not necessary to perform expensive field work. The same photographs can be measured again and new information can be compiled in a very timely fashion.

3- Provide a large mapped area so alternate line studies can be made with the same data source can be performed more efficiently and economically then other conventional methods.

4- Provides a broad view of the project area, identifying both topographic and cultural features.

5- Used in locations that are difficult, unsafe, or impossible to access. Photogrammetry is an ideal surveying method for toxic areas where field work may compromise the safety of the surveying cadre.

6- An extremely important advantage of photogrammetry is that road surveys can be done without closing lanes, disturbing traffic or endangering the field crew. Once a road is photographed, measurement of road features, including elevation data, is done in the office, not in the field.

Some disadvantages are:

1- Weather conditions such as, winds, clouds, haze… etc. affects the aerial photography process and the quality of the images.

2- Seasonal conditions affect the aerial photographs, i.e., snow cover will obliterate the targets and give a false ground impression. Therefore, there is only a short time is ideal for general purpose aerial photography.
3- Hidden grounds caused by man-made objects, such as an overpass and a roof, cannot be mapped with photogrammetry. Therefore the information hidden from the camera must be mapped with other surveying methods.
4- The accuracy of the mapping contours and cross sections depends on flight height and the accuracy of the field survey.

7.2 Evaluation of Photogrammetric Components Processes

Evaluation of the photogrammetric process include of project planning, image acquisition, image processing, and control data for image orientation, data compilation and presentation of ouput product formed in coordinate values of individual points, topographic map, or ortho-photographs.

7.2.1 Image Acquisition

Image acquisition includes planning the over flight, selecting an appropriate frame or digital camera system, photo taking film processing, film inspection and annotation, printing of paper prints and diapositives, and image scanning if necessary.

7.2.1. 1 Flight Planning

A flight plan generally consists of two items:

A flight map which shows where the photos are to be taken. It consists of flight lines, showing the starting and ending points of each line. It is used by the pilot for navigation and by the photographer for taking the pictures. Usually, there are enough topographical features in the flight area to assist the pilot in flying the designated flight lines. Otherwise, a large arrow on the ground at the beginning and end of each flight strip is necessary to aid the pilot and photographer. The number of flight lines, their location, the spacing between them, and their orientation depends on the characteristics of the project to be mapped and on the specifications of the flight mission.

Specifications which outline how to take the photographs, including camera and film or sensors requirements, scale, flying heights, end lap, side lap… etc.

7.2.1.2 Aerial Cameras

Aerial mapping cameras are perhaps the most important photogrammetric instruments, since they record the image on which the photogrammetric principles will be applied. Aerial cameras must be able to produce very sharp images, almost distortion free, in rapid succession under the adverse conditions of a moving aircraft. Any error, distortion, or compromise in the clarity of the image will result in mapping and positioning errors.(Wolf,(1983)).

7.2.1.3 Aerial Films

Aerial films are fine grained, high speed photographic emulsion on a stable polyester film base. The fine grain is necessary for identifying features as small as 1 micron on the negative. High speed film permits short exposure time which is necessary to prevent image smearing and displacement that may result from the movement of the aircraft. The image must be recorded on a stable film to prevent it from irregular shrinkage or expansion. Any change in the dimension of the film results in a measurement error and less accurate product. Aerial films come in a roll of about 200 exposures of 9x9 inches (23x23 cm) each.

To insure dimensional stability, the film should not be stretched or deformed in any way. It should not be subjected to extreme changes in humidity and temperature. The film should be sealed in its container and stored at a temperature recommended by the manufacturer at all times, except when in actual use during the flight mission or when being processed.

When we used a digital camera to obtain digital image directly, number and size of the sensitive sensors such as a CCD, CID, or CCTV, illustrated in Chapter two are having an impact.

7.2.1.4 Image Scanning

Sometimes, photogrammetric products were developed from diapositives or paper prints. With the emergence of digital photogrammetry, photographs are now scanned into a digital format that is compatible with digital image processing software. Scanners for digital photogrammetry are precision devices that maintain the radiometric and geometric integrity of the scanned image.

7.2.2 Control for Photogrammetry

The second element of the evaluation of photogrammetric process is control, which is used to establish the position and orientation of the camera at the instant of exposure. The necessity, accuracy and the rigor of photogrammetric control depends on the particular product sought. Photograph mosaics used for annotation, cultural studies, public meetings, and other varied purposes may not require any control. Rectified aerial photographs, used mainly for photograph plan sheets, may require partial control in the form of measured distances. Field measured distances are scaled down to match corresponding distances on the photograph. However, most common photogrammetric products, such as mapping and ortho-photography, require full control information. As illustrated in Chapter Two.

Photographs can be controlled using three different methods:

1- Ground control points that were surveyed on the ground using ordinary surveying techniques.
2- Bridging control through aerial triangulation. Bridging is accomplished by measuring on the photographs common points that appear in three consecutive photographs or in two adjacent strips and computing their 3-D coordinate values.
3- Aerial photography control through kinematic GPS technique in which the position and the attitude of the camera are computed without ground control.

In most photogrammetric projects, combinations of all or some of these methods are utilized.

7.2.2.1 Ground Control

Ground control can be classified as targeted and photograph-identifiable control points, and can also be classified as horizontal control, vertical only control, or as 3-D control. Horizontal and vertical controls require different configurations to make them serve their intended purposes. The use of only ground control is now limited to small projects, such as bridge sites, borrow areas and where only one or two models are needed. Photograph identifiable control points are rarely needed.

7.2.2.2 Targeting

Targeting operations are an essential part of photogrammetric mapping to be considered prior to establishing a control survey. Preflight targeting is performed to make ground locations of control points visible on the photographs. Easy identification and clear image of the control points on the photograph increases the accuracy and efficiency ofthe photogrammetricprocess. Photographic targets should be of symmetrical shape, adequate size, and appropriate photographic contrast and resolution. As shows in Figure (7.1) below,(Department of Transportation. (2009)).

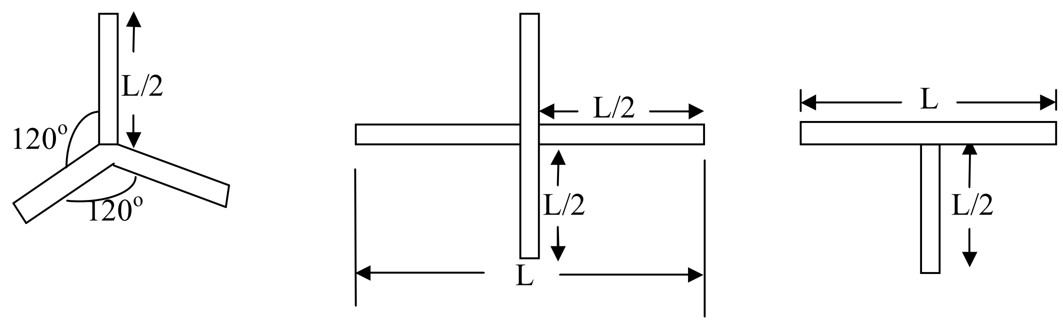


Figure 7.1 Photogrammetric ground control targets

7.2.2.3 Field Survey of Photogrammetric Control

Field surveys for photogrammetric control should be treated as ordinary surveys. Photogrammetric control points are usually spaced widely around, or in the project area. For large projects, this spacing could be extensive enough to require a significant surveying effort. Therefore, GPS is the better suited surveying method for most large photogrammetric projects.Ground control that is to be used in successive photogrammetric projects or field surveys should be monumented accordingly.

7.2.2.4 Aerial Triangulation

Aerial triangulation is the process of determining X, Y, and Z ground coordinates of individual points based on measurements from photographs. Aerial triangulation is used extensively for many purposes. One of the principal applications is densifying ground control through strips or a block of photos to be used in subsequent photogrammetric operations. When used for this purpose it is often called bridging, because it allows the computation of necessary control points between those measured in the field. In a large project, with dozens of photographs, the effort and cost of providing the needed control using field surveys is prohibitive. (Leica, 2008) Aerial triangulation is used to provide the necessary control for each stereo model with only a limited number of field surveyed control point. Referred to Chapter Four.

7.2.2.5 GPS as Control for Photogrammetry

In recent years, GPS has been demonstrated to be able to replace, partially or entirely, the need for ground control. The basic concept of GPS controlled photogrammetry is to use GPS equipment to determine the position and orientation of the camera at the instant of exposure. The only reason for using ground control in photogrammetry is to recover the position and orient a photograph in space at the time that the photograph was taken. If the values of these parameters can be resolved at the time of photography with GPS and/or additional instruments, there is no need for ground control to compute them. Even if GPS controlled photography is not yet at a level of maturity to be able to completely replace the need for ground control, it does reduce the number of field surveyed control points in a given project.(Kasser, et al, 2002).

7.2.3 Product Compilation

These kinds of evaluation include photogrammetric plotters, data collection, and mapping.

7.2.3.1 Photogrammetric Plotters

The most commonly used photogrammetric instrument is the stereo plotter. A stereo plotter is used to reconstruct the actual orientation and geometric integrity of an image at the instant of exposure and to collect three dimensional (3- D) data. Data collection with a stereo plotter is a two stage process. The first stage is orientation, which consists of:

1. **Inner orientation** – Orient each photograph with respect to the geometry of the camera.
2. **Relative orientation** – Orient two photographs with respect to each other to form a stereo model.
3. Absolute orientation – Orient and scale the stereo model to the ground. In some instruments the relative and absolute orientation are performed simultaneously. The simultaneous solution of these orientations is called exterior orientation. As illustrated in Chapter Six.

In the second stage, the operator views the image of the ground in 3-D. Data collection is performs by placing a floating mark on the images of the feature that is surveyed and record its X,Y,Z coordinates. Line features, such as roads or contours, can be digitized, point by point, or traced and recorded continuously,(Atkinson, K.B, 1997).

There are different types of stereo plotters, analog, analytical, and digital (softcopy.) Each of these types of plotters are classified according to their accuracy characteristics as first, second, or third order stereo plotters. Another classification of stereo plotters is as precision, topographic, or simple plotters. Table (7.2) summarizes the differences between the various types of photogrammetric stereo plotters.(Department of Transportation. (2009)).

Table (7.2) Characteristics of photogrammetric stereo plotters.

Characteristics	Analog	Analytic	Digital
Image	Film	Film	Pixels
Plotter	Analog	Analytical	Computer
Model Construc.	Mechanical	mechanic/computer	Computer
Stereo Viewing	Optical	Optical	Varies
Output	Mech./CAD	Mech./CAD	CAD
Aero-triangulation	Very limited	On/Off Line	Semi-automatic*
Ortho-photo	Very limited	Unavailable	Automatic**
Limitations	Focal length Film format	Film Format	None
Accuracy	Average up to ±15μm(microns)	Very high up to ±3μm	Same as scanning accuracy
Cost	Very high	Very high	Reasonable to high

7.2.3.2 Data Collection and Mapping

Photogrammetry can be used to collect a variety of data, presented in the following formats:

Planimetric maps – Planimetric maps are maps that represents only the horizontal features of the mapped area. Planimetric maps display features such as roads, sidewalks, buildings, river banks, shore lines, manholes, trees etc. No elevation information appears on planimetric maps.

Topographic maps – Topographic maps are maps on which both horizontal and vertical features of the mapped are represented. In addition to the above mentioned planimetric features, a topographic map depicts elevation information as contours and/or as spot elevations.

DEMs – Digital Elevation Model (DEM) or Digital Terrain Model (DTM) are dense networks of spot elevations represented by X,Y,Z coordinates. The DEM points are collected in a regular grid with break points which depict the characteristics of the topography. DEM's are used to draw contours and are an essential ingredient for the production of orthophotos.

Special purpose maps – Special purpose maps are maps that are designed to meet special needs or depict a special theme. The rule is that if you can see it on the aerial photograph, you can map it with photogrammetry.

7.3 Accuracy and Errors

The attainable accuracy of a photogrammetric product depends on two main factors. The first is the scale of the photographs from which the product is derived and the second is related to errors in the photogrammetric process.

The scale of the photograph determines the ground resolution. If the smallest identifiable ground feature on the photograph is a 0.1 m^2 object, then the mapping accuracy from this photograph, assuming perfect data compilation, is limited to no better than 0.3 m (±1 ft). Selecting the appropriate photo scale for a particular product depends on product specifications. For example, the photo scale for topographic mapping is a function of the required map scale, the contour interval, and the quality of the photogrammetric plotter. A required accuracy can be met by either using smaller scale photographs and high quality equipment or larger scale photos with less accurate photogrammetric equipment. The photo scale is always smaller than the map scale but the ratio between these two scales should never be larger than eight.

The second factor controlling the accuracy of a photogrammetric product is the total amount of errors accumulated during its derivation. In photogrammetry, as in any other surveying and mapping procedures, there are systematic errors and random errors, assuming all blunders have been removed.

CHAPTER EIGHT

TESTS AND RESULTS

8.1 Introduction

From a photogrammetric point of view there are several potentials of the new modern technology of digital photogrammetry which support the development of a real time conventional photogrammetric system. The evaluation of these potentials includes three basic aspects. Starting from the acquisition of digital image stage using electronic cameras embodied in intelligent sensors, such as Closed Circuit Television (CCTV) and broadcasted television systems, or Charge-Coupled Device (CCD) sensors, due to their higher spatial resolution, in addition to their low cost and low noise. Moreover, these sensors are characterized by their high reliability compared to other system.

The second evaluation of the modern photogrammetric potential comprise the updated softwares, such as ERDAS IMAGINE which is regarded as a comprehensive photogrammetric package useful in many photogrammetric applications, such as aerial triangulation or ortho-rectification of images acquired from different systems, either directly from digital cameras or indirectly from scanned analogue photogrammetric images or even images coming from satellites.

Finally the evaluation of the modern photogrammetric technology potential contains a group of hardware devices, working in an integrated manner with the software packages, such as the Digital Photogrammetric Work station (DPWs) or softcopy workstation. These are characterized by their high capabilities, represented in their functionality for processing, displaying, roaming, measuring, supper positioning, and archiving, besides their large storage capacities, and huge memories.

These capabilities led to an increase of the number of project areas that can be applied in the field of photogrammetry, for an obvious reason; the precession of any project implementation can easily be secured. This was reflected, clearly, in photogrammetric application in the following surveying fields:-

Determining ground coordinates of any point whose coordinates in a created three – dimensional model are known.

Production of thematic maps that represent a three – dimensional model area.

3- Production of topographic maps that represent a three – dimensional model area.

8.2 The Study Area

In order to find out the extent of potential, reliance and reliability of the new modern technologies associated with a digital photogrammetric field, two types of Khartoum topographic maps, planned to be produced, using digital photogrammetric methods, were used in this research.

Khartoum state is the most important state in the country of Sudan. Its importance comes from the fact that it is the capital of Sudan. In addition, it is the foal point of Sudan industry and economy. It is approximately located between longitudes 31º 45´ 00”, and 34º 30´ 00" in east west direction and latitudes 15º 30´00", and 16º 30´ 00" in north south direction. The survey Authority of Khartoum state planed to produce two types of topographic maps. The first one is to cover the centre of the state with a scale 1:1000 to be prepared from digital images taken at 1:5000 scale. The second project is designed to produce new topographic maps for the rural areas of the state at a scale of 1:10000 from digital images taken at a scale of 1:20000. The photogrammetric technical specifications to be considered in the implementation of these projects were suggested by a high technical committee. These are as shown in Table (8.1) below.

Table (8.1) part of technical specifications for the projects

Elements	Parameters	Requirements
Digital Camera	Lens	Focal length to subtend a normal angle for 1:5,000 scale& a wide angle for 1:20000 scale
	Geometric Precision	$\leq 2\ \mu m$
	Geometric Resolution(Physical Pixel Size)	$\leq 15\ \mu m$
	Radiometric Resolution	≥ 12 bits
	Shutter Speed	1/500 or faster
Aerial Triangulation	Tie points on each Image	Not less than 9 points appearing in a minimum of 3 Photographs
	A Control Diagram	Should show the location of all control points using appropriate symbols

	RMSE of Residuals in E, N and h at control points	≤ 1/10,000 of the flying height above ground
	Average standard deviation and σ of E, N and h	≤ 1/10,000 of the flying height above ground
	Maximum residuals in any Control point & σ in E, N, h of Pass points	≤2.5RMSE of Control Points Residuals
	RMSE of Tie Point	≤1/ 20,000 of the flying height above ground
	Maximum Residual in any Tie point	≤2.5RMSE of Tie Points Residuals
	Average Adjustment to Photo-coordinates in a block	± 10 μm
	Max Adjustment to Photo-coordinates Values	± 20 μm

8.3 Measurements and Results

The research work aims to make a technical evaluation of the products concentrating on some parameters. Those include camera specifications, scale of photography, besides making some field observations concerned with the collection of coordinates of ground control points, and some office investigations.

The digital photographic coverage of the project was executed using UltraCamD, manufactured by Vexcel Imaging GmbH, Austria. The following Tables ((8.2) and (8.3)) are parts of the calibration reports of the used panchromatic and multispectral cameras respectively.

Table (8.2) part of the calibration report of a Large Format Panchromatic camera.

	A long track	67.5mm	7500 pixels
	Cross track	103.5 mm	11500 pixels

Image Format			
Image Extent		(-33.75, -51.75) mm	(33.75, 51.75) mm
Pixel Size		9.000 µm X 9.000 µm	
Focal Length	Ck	105.200 mm	± 0.002 mm
Principal point (Level 2)	X ppa	0.000 mm	± 0.002 mm
	Y ppa	0.000 mm	± 0.002 mm
Lens Distortion	Remaining Distortion less than ± 0.002 mm		

Table (8.3) part of the calibration report of a medium format multispectral camera.

Image Format	Along track	67.5mm	2400 pixels
	Cross track	103.5 mm	3680 pixels
Image Extent		(-33.75, -51.75) mm	(33.75, 51.75) mm
Pixel Size		28.125 µm X 28.125 µm	
Focal Length	Ck	105.200 mm	± 0.002 mm
Principal point (Level 2)	X ppa	0.000 mm	± 0.002 mm
	Y ppa	0.000 mm	± 0.002 mm
Lens Distortion	Remaining Distortion less than ± 0.002 mm		

A sample area selected from the centre area of Khartoum state topographic maps project was chosen. The selected area is covered by 32 digital photographs, taken from four adjacent strips (numbers 38, 39, 40, and 41) comprising a block shown in Figure (8.1) below.

Figure (8.1) centre of Khartoum state study area image block.

A digital airborne imaging system was integrated with a flight control system consisting of Global Positioning System (GPS), Inertial Measurement Unit (IMU), and an Inertial Navigation System (INS). The resultant IMU file of the selected photographs contains photograph numbers, easting, northing, and ellipsoidal height of the camera at the moment of exposure. Added to these are the rotations about the axis. All these are shown in Table (8.4) below:

Table (8.4) IMU file of the selected center of Khartoum State study area.

NO	Image ID	E (m)	N (m)	H (m)	Omega^{o}	Phi^{o}	Kappa^{o}
1	38-08281	448790.811	1725270.859	1602.606	0.18067	0.11479	٩٠.٦٦٢٢٩
2	38-08282	448792.748	1724999.366	1600.537	0.16774	0.13713	90.67694
3	38-08283	448794.556	1724727.808	1599.753	0.18455	0.11108	90.64428

4	38-08284	448795.752	1724456.970	1600.585	0.15520	0.13028	90.25298
5	38-08285	448795.611	1724184.605	1602.610	0.16647	0.10943	89.87967
6	38-08286	448794.587	1723912.834	1605.266	0.16496	0.13458	89.85954
7	38-08287	448793.099	1723639.417	1607.355	0.16860	0.11611	89.74474
8	38-08288	448791.264	1723367.457	1607.448	0.15970	0.11127	89.71868
9	39-08021	449634.219	1723326.613	1602.461	-0.17043	-0.07834	-90.59829
10	39-08022	449636.343	1723598.519	1602.638	-0.17534	-0.10700	-90.14487
11	39-08023	449637.189	1723871.223	1604.625	-0.17953	-0.10763	-90.03777
12	39-08024	449637.618	1724143.356	1607.540	-0.17465	-0.09316	-89.93163
13	39-08025	449636.686	1724415.635	1608.616	-0.16362	-0.10281	-89.49022
14	39-08026	449634.260	1724686.588	1606.883	-0.17774	-0.10162	-89.37464
15	39-08027	449631.282	1724958.423	1603.242	-0.16730	-0.10592	-89.29397
16	39-08028	449628.453	1725229.401	1600.141	-0.16436	-0.09872	-89.37066
17	40-05370	450472.663	1723303.126	1595.371	-0.16798	-0.10185	-89.62783
18	40-05371	450472.333	1723574.764	1594.505	-0.16719	-0.10402	-89.45963
19	40-05372	450470.684	1723846.815	1594.069	-0.17341	-0.09312	-89.17806
20	40-05373	450467.735	1724119.637	1594.124	-0.18638	-0.08552	-89.12423
21	40-05374	450463.884	1724391.272	1594.650	-0.18672	-0.09574	-88.72759
22	40-05375	450459.669	1724662.770	1595.356	-0.17466	-0.09909	-88.73162
23	40-05376	450455.371	1724935.167	1596.016	-0.16677	-0.09528	-88.69266
24	40-05377	450451.185	1725207.356	1596.497	-0.15849	-0.09890	-88.81016
25	41-05030	451290.777	1724907.095	1607.832	0.17081	0.10269	89.84162
26	41-05031	451289.333	1724635.759	1605.810	0.14634	0.06526	89.92647
27	41-05032	451288.923	1724364.043	1603.945	0.15488	0.10390	90.20696
28	41-05033	451288.998	1724091.971	1602.738	0.17059	0.09677	90.12815
29	41-05034	451289.344	1723820.203	1602.174	0.15063	0.09287	90.14999
30	41-05035	451290.079	1723548.987	1602.265	0.15663	0.10381	90.39027
31	41-05036	451290.892	1723276.981	1603.046	0.17141	0.07918	90.26049
32	41-05037	451291.541	1723005.245	1604.316	0.16492	0.09857	90.19906

Referring to the calibration report of the used camera, it can be noted that it is a large format wide angle camera while a normal angle was suggested to be used in the project specification.

The average flying height is the average distance between the position of the camera at the time of exposure and the average ground elevation (LPS, user guide, 2008). Accordingly, the average flying height, computed using equation (8.1) below, was found to be approximately equal 1220m above average terrain elevation.

Average flying height (H′) = $\overline{\sum H}$ - average height of all control points above datum (8.1)

The image scale can simply be computed as a ratio of the focal length of the camera used to the average flying height. Applying this relation to the available data of photographic coverage, image scale is then computed from equation (8.2) hereunder.

$$\text{Image scale} = \frac{\text{focal length}}{\text{average flying height}} \qquad (8\text{-}2)$$

The image scale computed was found to be equal 1:11579 or, approximately, equal 1:12000. Compared with the suggested scale of photography, it is found that there is a disagreement. It is 2.4 times smaller than the required scale of 1:5000.

The Ground Resolution Distance (GRD) is the smallest area of the earth's surface that can be clearly distinguished by the camera. This value can be obtained by multiplying the dimensions of a Charge Coupled Device (CCD) by the scale of photography. Mathematically, it can be derived from equation (8.3), below, as following.

$$\text{GRD} = \frac{H'}{f} \cdot \rho^s \qquad (8.3)$$

Where

f is the used digital camera focal length.

H′ is the average flying height above the earth's surface.

ρs is the pixel size.

Referring to the used camera specifications and the above computed scale, the ground resolution distance will be 0.108m for the panchromatic photography and 0.3375m for the multispectral photography. This value was suggested to be less than 0.075m in the specification.

8.3.1 Accuracy Evaluation of the Center of Khartoum State Project

In order to evaluate the precession of the project, were a selected number of 18 well distributed points covering the study area, these points were then observed in the field using Differential Global Positioning System (DGPS). The observations were made using a GPS receiver model R8- GNN from Trimble Company. In a static mode. Each point was observed for 45 minutes. The expected accuracy was equal to 0.5 cm + 1ppm. Points are taken based on Universal Transverse Mercator (UTM) projection, at zoon 36 north and the World Geodetic System 1984 (WGS84) datum. The result is a three dimensional coordinates shown in Table (8.5) .

Table (8.5) Coordinates of observed points

Point	E (m)	N (m)	H (m)
1	449101.669	1725509.714	383.113
2	448340.140	1725365.933	383.415
3	448412.645	1724739.837	383.519
4	448367.877	1724260.062	381.851
5	448470.900	1723645.658	382.161
6	448400.810	1723172.145	383.810
7	449144.144	1724130.761	381.782
8	449152.327	1723066.223	384.543
9	450199.025	1725462.274	381.784
10	450159.446	1724744.166	383.997
11	450067.027	1724230.469	385.429
12	450198.86	1723497.647	385.493
13	450078.078	1722963.961	383.832
14	450921.739	1725231.631	386.380
15	450718.066	1724957.814	383.806
16	450877.109	1724054.616	383.764

17	450775.234	1723581.077	383.200
18	451003.688	1723088.568	385.259

Ground control points , which were observed above plus 63 tie points were used to carry out aerial triangulation , using LPS package. For practical applications, LPS package was used for a number of reasons that can be summarized as:-

It has a high capacity to accept all kinds of digital images in spite of the different acquiring media

tends to reduce the time, effort, and cost required to conduct an aerial triangulation process, and / or ortho -rectification of images.

has the ability to:-

Connect data coming from the airborne Global Positioning System with their image ID

ii- carry out the aerial triangulation automatically and

iii- connect the ground coordinates points with their image coordinates system in a unified file

it contains two different methods to find the tie points from a 3-D model, manually, or automatically by the system itself and

it works to create mathematical relationships between overlapped images, type of used camera, and the ground coordinates. This relationship is called Block triangulation.

When the orientation and aerial triangulation processes were completed, the ground coordinates and tie points (points whose ground coordinates are not known, but are visually recognizable in the overlap area between two or more images) coordinates were computed from the created three-dimensional model. The values of these coordinates were recorded as shown in Table (8.6) below.

Table (8.6) computed control and tie points coordinates for centre of Khartoum state study area

NO	POINT ID	TYPE	USAGE	E (m)	N (m)	H (m)
1	1	Full	Control	448340.993	1725366.027	382.935
2	2	Full	Control	448411.933	1724739.471	383.910
3	3	Full	Control	448367.271	1724260.281	382.413
4	4	Full	Control	448470.591	1723645.576	382.306
5	5	Full	Control	448400.810	1723172.145	383.810
6	6	Full	Control	449100.781	1725509.974	383.190
7	7	Full	Control	449144.659	1724130.966	382.074
8	8	Full	Control	449151.904	1723065.882	384.163
9	9	Full	Control	450199.077	1725461.984	382.365
10	10	Full	Control	450159.455	1724743.812	383.890
11	11	Full	Control	450066.896	1724230.507	384.831
12	12	Full	Control	450198.724	1723497.933	385.339
13	13	Full	Control	450077.872	1722963.676	384.399
14	14	Full	Control	450922.081	1725231.845	386.009
15	16	Full	Control	450877.031	1724054.627	383.985
16	18	Full	Control	451003.956	1723088.538	385.159
17	17	Full	Check	450774.581	1723580.787	384.918
18	15	Full	Check	450718.076	1724958.052	384.722
19	19	None	Tie	449266.742	1724969.748	377.082
20	20	None	Tie	449154.964	1725178.616	374.635
21	21	None	Tie	448314.323	1724957.084	377.739
22	22	None	Tie	449297.309	1725598.812	377.005
23	23	None	Tie	448860.604	1724988.393	385.964
24	24	None	Tie	448737.523	1725219.659	379.182
25	25	None	Tie	448302.614	1725143.969	379.501

26	26	None	Tie	448283.128	1724708.657	378.493
27	27	None	Tie	448388.670	1724701.778	370.749
28	28	None	Tie	449305.829	1724629.654	379.896
Table (8.6) continued						
29	29	None	Tie	448372.730	1724358.396	382.387
30	30	None	Tie	448915.412	1724352.037	377.765
31	31	None	Tie	449288.830	1724426.426	380.346
32	32	None	Tie	448730.992	1724087.408	380.765
33	34	None	Tie	449206.240	1724132.288	377.897
34	35	None	Tie	448260.172	1723809.767	381.554
35	36	None	Tie	448848.308	1723809.143	380.346
36	37	None	Tie	449294.917	1723803.486	380.361
37	38	None	Tie	448201.168	1723548.126	381.768
38	39	None	Tie	448827.669	1723537.281	382.598
39	40	None	Tie	449305.528	1723540.738	380.978
40	41	None	Tie	448231.344	1723296.836	379.632
41	42	None	Tie	448900.985	1723310.533	381.911
42	43	None	Tie	449322.215	1723285.018	381.350
43	56	None	Tie	446547.270	1723572.062	381.830
44	57	None	Tie	450216.258	1723490.671	385.337
45	54	None	Tie	449700.712	1723789.656	379.844
46	55	None	Tie	450192.246	1723942.715	378.029
47	52	None	Tie	449575.910	1724086.415	382.234
48	53	None	Tie	450212.242	1724052.375	376.623
49	50	None	Tie	449526.878	1724380.064	381.918
50	51	None	Tie	450027.717	1724419.159	383.965
51	48	None	Tie	449758.413	1724570.748	379.054
52	49	None	Tie	450100.787	1724588.147	381.373
53	46	None	Tie	449485.228	1724920.040	382.059
54	47	None	Tie	450180.300	1724958.106	381.454
55	44	None	Tie	449569.969	1725181.309	382.263
56	45	None	Tie	450144.922	1725220.272	372.997

57	68	None	Tie	450470.678	1723493.269	381.436
58	69	None	Tie	450957.617	1723535.348	383.919
59	70	None	Tie	450591.809	1723212.455	381.164
Table (8.6) continued						
60	71	None	Tie	451033.660	1723242.359	385.336
61	66	None	Tie	450300.471	1723763.840	376.448
62	67	None	Tie	450959.909	1723823.900	384.476
63	64	None	Tie	450332.530	1724023.685	382.560
64	65	None	Tie	450988.734	1724112.910	383.870
65	62	None	Tie	450495.066	1724283.180	383.717
66	63	None	Tie	451043.407	1724415.959	384.413
67	60	None	Tie	450419.975	1724559.526	383.629
68	61	None	Tie	450985.932	1724639.249	384.754
69	58	None	Tie	450658.334	1724881.128	384.251
70	59	None	Tie	450969.899	1724922.797	385.133
71	72	None	Tie	451099.487	1725097.938	383.765
72	73	None	Tie	451867.912	1725109.639	387.881
73	74	None	Tie	451844.686	1724800.962	387.157
74	75	None	Tie	451571.072	1724272.719	385.552
75	76	None	Tie	451232.376	1724314.817	384.331
76	77	None	Tie	451799.108	1723792.177	385.371
77	78	None	Tie	451110.268	1723714.628	385.006
78	79	None	Tie	451205.855	1723526.012	385.115
79	80	None	Tie	451237.528	1723465.998	381.376
80	81	None	Tie	451446.073	1723172.514	384.747
81	82	None	Tie	450.876.954	1723286.312	385.586

In addition to the ground coordinates values, the error in the calculated coordinates ΔE, ΔN, and Δh has been found. Moreover, the Root Mean Square Error (RMSE), were computed for each control point from the aerial triangulation process. The results are recorded as shown in Table (8.7) below.

Table (8.7) Root Mean Square Errors (RMSE) for center of Khartoum study area coordinates

NO	POINT ID	TYPE	USAGE	ΔE (m)	ΔN (m)	ΔH (m)	Total RMSE
1	1	Full	Control	0.853	0.094	-0.480	0.983
2	2	Full	Control	-0.712	-0.366	0.391	0.891
3	3	Full	Control	-0.606	0.219	0.562	0.855
4	4	Full	Control	-0.309	-0.082	0.145	0.352
5	5	Full	Control	0.000	0.000	0.000	0.000
6	6	Full	Control	-0.888	0.260	0.077	0.929
7	7	Full	Control	0.515	0.205	0.292	0.626
8	8	Full	Control	-0.423	-0.341	-0.380	0.663
9	9	Full	Control	0.052	-0.290	0.581	0.651
10	10	Full	Control	0.009	-0.354	-0.107	0.370
11	11	Full	Control	-0.131	0.038	-0.598	0.613
12	12	Full	Control	-0.136	0.286	-0.154	0.352
13	13	Full	Control	-0.206	-0.285	0.567	0.667
14	14	Full	Control	0.342	0.214	-0.371	0.548
15	16	Full	Control	-0.078	0.011	0.221	0.235
16	18	Full	Control	-0.268	-0.030	-0.100	0.288
17	17	Full	Check	-0.653	-0.290	1.718	1.861
18	15	Full	Check	0.010	0.238	0.916	0.947

The total Root Mean Square Error (RMSE) for the total images are computed by the LPS software and was found to be 0.0625m as illustrated in Figure (8.2).

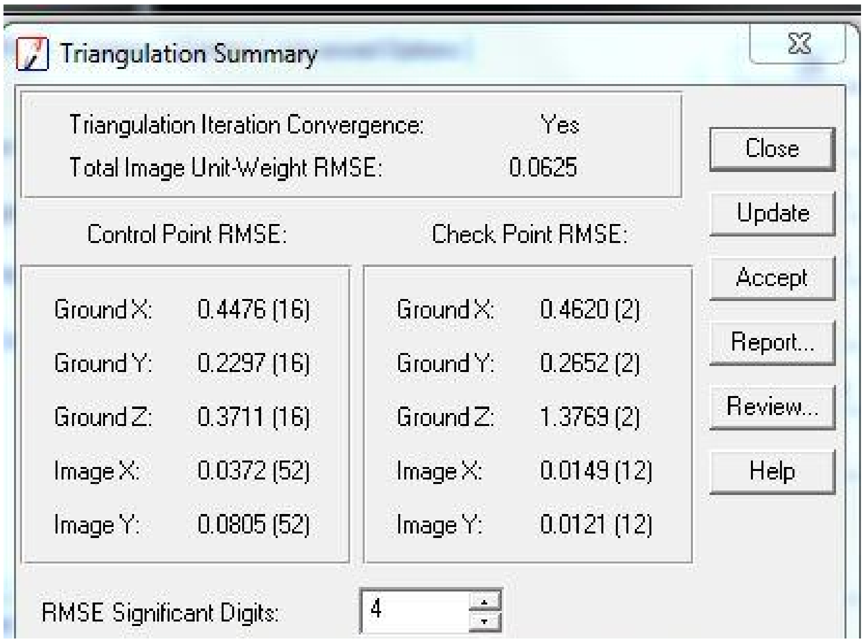


Figure (8.2) triangulation summary of the centre of Khartoum state study area

From the above triangulation summary result, a linear accuracy indicator was calculated from equation (7.4) hereunder.

$$\text{Linear accuracy} = \sqrt{(\text{RMSE (E)})^2 + (\text{RMSE (N)})^2 + (\text{RMSE (H)})^2} \qquad (8.4)$$

Accordingly, for the check points the liner accuracy indicator was found to be;

$$\sqrt{(0.4620)^2 + (0.2652)^2 + (1.3769)^2} = 1.4764\text{m}.$$

The existing topographic maps, which were produced from the covered digital image, were a subject to accuracy evaluation. This was done by measuring the map coordinates of seven control points and comparing the results with their “actual” ground coordinates.

Table (8.8) below is a list of the coordinates of control of seven points measured from the existing topographic maps.

Table (8.8) measured coordinates for the centre of Khartoum study area from an existing topographic map

NO	POINT ID	TYPE	USAGE	E (m)	N (m)
1	1	Full	Control	448340.175	1725366.322
2	2	Full	Control	448412.502	1724739.010
3	3	Full	Control	448368.047	1724260.351
4	6	Full	Control	449101.930	1725509.777
5	7	Full	Control	449144.572	1724131.203
6	10	Full	Control	450159.885	1724743.852
7	11	Full	Control	450067.143	1724230.490

The differences between "actual" ground coordinates of control point and their map coordinates were found to be as shown in Table (8.9) below.

Table (8.9) difference between "actual" ground coordinates and map coordinates for the centre of Khartoum state study area.

NO	POINT ID	TYPE	USAGE	ΔE (m)	ΔN (m)	ΔE2 (m)	ΔN2 (m)
1	1	Full	Control	0.035	0.389	0.0010	0.1510
2	2	Full	Control	0.143	0.827	0.0210	0.6840
3	3	Full	Control	0.170	0.289	0.0290	0.0840
4	6	Full	Control	0.261	0.063	0.0681	0.0040
5	7	Full	Control	0.428	0442	0.1832	0.1950
6	10	Full	Control	0.439	0.314	0.1930	0.0990
7	11	Full	Control	0.116	0.021	0.0140	0.0004

From the above results, the Root Mean Square Error in E-coordinates was calculated as 0.269m, while the RMSE of N-coordinates was found to be 0.417m. Consequently, the Planmetric accuracy was calculated from equation (8.5), hereunder as:-

$$\text{Planmertric accuracy} = \sqrt{(\text{RMSE (E)})^2 + (\text{RMSE (N)})^2} \quad (8.5)$$

Therefore,

planmertric accuracy = $\sqrt{(0.269)^2 + (0.417)^2}$

Accordingly the planmetric accuracy of the produced topographic map for the centre of Khartoum state was found to be 0.496m.

Also from the above results we can calculation of suitable test statistic from the Gauss Markov Model (GMM) using the actual observations. The statistic is selected in such a way that is distributional properties are known by definition if HO is true and that it is as sensitive as possible to departures from HO. there is a large number of test statistic, such as t –distribution (Caspary .(1998)), that as folws:

$$t = d' \Big/ \frac{S}{\sqrt{n}} \qquad \text{———————} \qquad (8.6)$$

$$S = \sqrt{\frac{\sum (x_i - x')^2}{n-1}} \qquad \text{———————} \qquad (8.7)$$

Whete :

t : test statistic.

S: standard deviation.

d′: average value of the different between actual and observed coordinates.

x: observation value.

n: number of points.

i: 1, 2, 3…n.

Therefore, for the centre of the Khartoum state projects the test statistic in E-coordinates was calculated as 3.006m. while the test statistic of N-coordinates was found to be 2.495m.

8.5 Accuracy Evaluation of The Rural Areas of Khartoum State Project

In order to evaluate the accuracy of the rural area of Khartoum state topographic maps project, a sample area south of Khartoum, covered by 8 photographs, taken from two adjacent strips(numbers 55, and 56) illustrated in Figure(8.3) below is used.

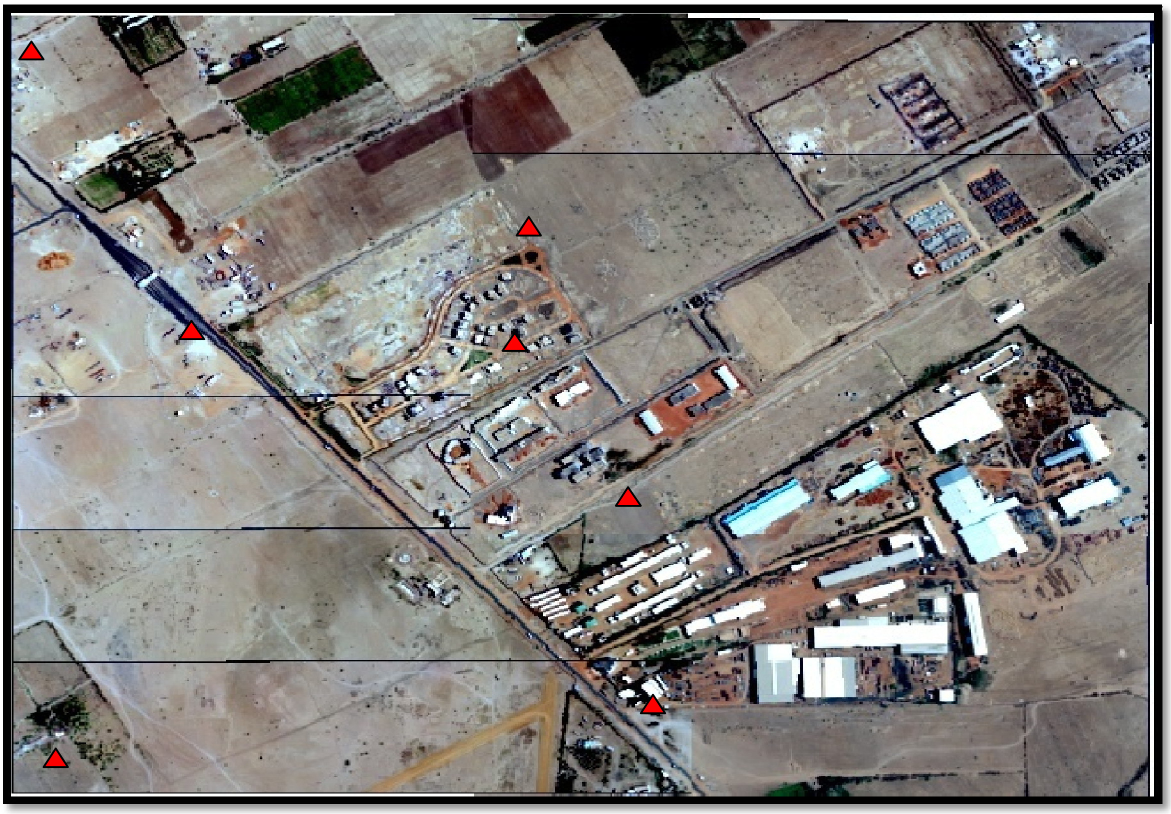


Figure (8.3) Study area image of selected rural areas of Khartoum State

Referring to the calibration report of the camera used (Tables (8.2) and (8.3)) it is clear that the camera used is a large format which means a wide angle lens. Therefor, for the suggested technical specification were not satisfied. The resultant IMU file of the selected photographs, shown in Table (8.10) below, contains photograph numbers, easting, northing, and ellipsoidal height of the camera at the moment of exposure. Added to these are the rotations about the three axis

Table (8.10) IMU file of the photograph of the selected rural area of Khartoum state

NO	Image ID	E (m)	N (m)	H (m)	Omega°	Phi°	Kappa°
1	55-03804	462974.312	1711228.157	1606.376	0.14998	0.09112	٩٠.٢٥٧٩٩
2	55-03805	462975.44	1710956.660	1608.249	0.15760	0.10999	90.29637
3	55-03806	462976.471	1710683.897	1608.849	0.15674	0.09648	90.16161
4	55-03807	462977.277	1710412.073	1608.045	0.16161	0.11533	89.95021
5	56-03446	463785.458	1710408.799	1601.310	-0.16818	-0.09235	-89.67367
6	56-03447	463784.344	1710680.897	1603.610	-0.16836	-0.07865	-89.70219
7	56-03448	463784.706	1710953.048	1607.124	-0.17011	-0.10183	-90.23025
8	56-03449	463786.164	1711225.282	1608.468	-0.16209	-0.08032	-90.31148

Analyzing the data in Table (8.10) above, the computed flying height above ground was found to be , approximately equal 1220m. which when used with the camera focal length value, an image scale of 1:12000, resulted.

Depending on available calibration data of the camera used and applying the above computed scale, ground resolution distance (GRD) will be 0.108m for panchromatic and 0.3375m for multispectral cameras respectively..

When the computed values of flying height, image scale, and ground resolution distance were compared with those for the centre of Khartoum state study area, they were found to be the same.

In order to evaluate the accuracy of the project, a seven well distributed points were selected to cover the chosen area. These points were then field observed using Differential Global Positioning System (DGPS) model R8- GNN from Trimble Company. A static mode is used, every 45 minutes, to observe each point. Unexpected accuracy was equal to 0.5 cm + 1ppm. Points are taken based on Universal Transverse Mercator (UTM) projection, at zone 36 north and the World Geodetic System 1984 (WGS84) datum. Table (8.11) below shows the observed control points coordinates results of the rural study area.

Table (8.11) observed coordinates of control points of the rural study area

NO	E cords(m)	N cords(m)	H cords(m)	REMARKS
1	462452.600	1711316.563	384.013	Full point
2	463230.526	1711107.382	383.482	Full point
3	462465.290	1710147.500	385.072	Full point
4	462700.003	1710913.440	383.900	Full point
5	463209.022	1710914.899	382.461	Full point
6	463416.010	1710678.511	381.387	Full point
7	463430.331	1710306.879	383.140	Full point

Ground control points, which were observed above plus 14 tie points were used to carry out aerial triangulation, using LPS package. After orientation procedures and aerial triangulation processes were done, the coordinates of the ground and tie points were computed from the created 3-D model, the results were shown in Table (8.12) below.

Table (8.12) computed control and tie points coordinates for the study area

NO	POINT ID	TYPE	USAGE	E cords(m)	N cords(m)	H cords(m)
1	1	Full	Control	462452.231	1711316.066	383.895
2	2	Full	Control	463230.323	1711107.000	382.973
3	3	Full	Control	462465.557	1710147.260	385.247
4	4	Full	Control	462700.085	1710913.895	383.737
5	5	Full	Control	463209.898	1710915.310	383.033
6	6	Full	Control	463416.974	1710679.054	382.162
7	7	Full	Control	463428.715	1710306.588	382.409
8	8	None	Tie	462656.462	1710867.023	383.930
9	9	None	Tie	462984.046	1710867.650	383.407
10	19	None	Tie	463315.155	1711097.368	382.693
11	21	None	Tie	463214.278	1710932.442	383.040

12	10	None	Tie	462984.970	1710868.042	383.281
13	11	None	Tie	463155.763	1710572.328	381.042
14	12	None	Tie	463124.374	1710606.490	380.749
15	18	None	Tie	463239.880	1710603.844	379.488
16	20	None	Tie	463399.003	1710288.182	378.671
17	13	None	Tie	464315.099	1710724.275	378.048
18	14	None	Tie	464200.198	1710704.612	376.666
19	15	None	Tie	464238.697	1710596.396	377.387
20	16	None	Tie	464158.569	1711032.896	379.772
21	17	None	Tie	464074.891	1710896.038	379.897

The errors in the calculated coordinates for the rural study area ΔE, ΔN, and ΔH were found. Accordingly the RMSE for each individual point were computed from the aerial triangulation process. The results are recorded as shown Table (8.13) below .

Table (8.13) Root Mean Square Error (RMSE) for rural study area coordinates

NO	POINT ID	TYPE	USAGE	ΔE	ΔN	ΔH	Total RMSE
1	1	Full	Control	-0.369	-0.497	-0.118	0.630
2	2	Full	Control	-0.203	-0.382	-0.509	0.668
3	3	Full	Control	0.267	-0.240	0.175	0.399
4	4	Full	Control	0.082	0.455	-0.163	0.490
5	5	Full	Control	0.876	0.411	0.572	1.124
6	6	Full	Control	0.964	0.543	0.775	1.351
7	7	Full	Control	-1.616	-0.291	-0.731	1.798

The RMSE for the total images is computed by the LPS software and was found to be 0.0061m. As in Figure (8.4) hereunder.

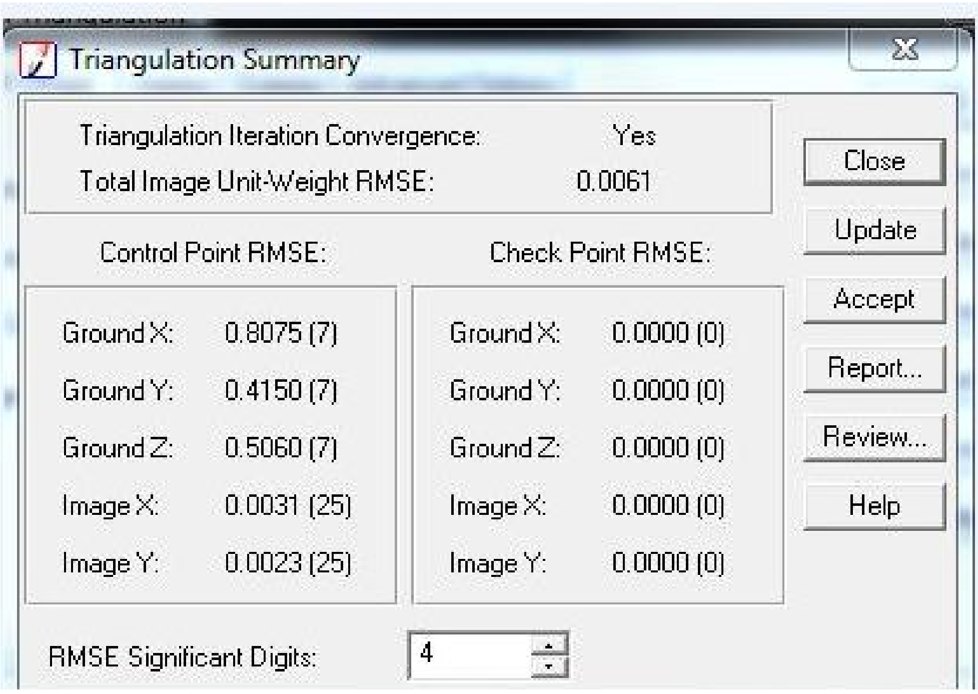


Figure (8.4) triangulation summary of the rural areas of Khartoum state study area

The linear accuracy calculated from the above triangulation summary result was found to be $\sqrt{(0.8075)^2 + (0.4150)^2 + (0.5060)^2}$= 1.039m.

Distributed ground control points in the rural areas of Khartoum study area, were measured from the existing topographic map prepared from the digital images, resulted as shown in Table (8.14) below.

Table (8.14) existing topographic map coordinates of control points for the rural study area.

NO	POINT ID	TYPE	USAGE	E cords (m)	N cords (m)
1	1	Full	Control	462452.245	1711316.446
2	2	Full	Control	463230.669	1711107.240
3	3	Full	Control	462465.265	1710147.529
4	4	Full	Control	462700.015	1710914.146
5	5	Full	Control	463210.711	1710915.542
6	6	Full	Control	463415.686	1710679.372
7	7	Full	Control	463427.506	1710307.975

Differences between actual ground coordinates and rural map coordinates were found to be as shown in Table (8.15) below.

Table (8.15) difference between "actual" groundinates coordinates and map coordinates for Khartoum state rural study area.

NO	POINT ID	TYPE	USAGE	ΔE (m)	ΔN (m)	ΔE2 (m)	ΔN2 (m)
1	1	Full	Control	0.355	0.117	01260	0.014
2	2	Full	Control	0.140	0.142	0.0200	0.020
3	3	Full	Control	0.025	0.029	0.0010	0.001
4	4	Full	Control	0.012	0.706	0.0001	0.498
5	5	Full	Control	1.689	0.643	2.8530	0.414
6	6	Full	Control	0.324	0.861	0.1050	0.741
7	7	Full	Control	2.825	1.096	7.9810	1.201

From the above results, RMSE in E-coordinates was calculated as 1.259m, while the RMSE of the N-coordinates was found to be 0.642m. Consequently, Planmetric accuracy was found to be

$\sqrt{(1.259)^2 + (0.642)^2} =$ 1.413m.

Accordingly, the planmetric accuracy of the produced topographic map for the rural area of Khartoum state was found to be 1.413m.

While, the test statistic in E-coordinates was calculated as 3.875m, and in N-coordinates was found to be 3.724m

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Despite the multiplicity of different surveying methods for data collection to produce topographic maps, photogrammetric techniques remain the most widely used, especially for mapping vast areas. This is due to a number of reasons; firstly the overall cost of projects is reduced; Secondly, the effort and manpower are also reduced. And thirdly time is saved. In addition, the great developments that has been occurred in turning the conventional photogrammetric system to digital photogrammetric systems, due to the great developments that has occurred in the fields of computer science and softwares.

Moreover, the availability of softwares related to surveying sciences, such as ERDAS IMAGINE, and Aig software, led to implement the most complex applications of surveying, such as aerial triangulation, Digital Terrain Modeling (DTM) or Digital Elevation Modeling (DEM), and ortho-rectification. In addition, it provides statistical values to assess errors in measurements, by computing the Root Mean Square Errors (RMSE) and other statistics.

The combinationof all these led to an increase in the reliability of produced topographic maps prepared from digital photogrammetric images.

The aim of this research work is to make some sort of technical evaluation for the centre and rural areas of Khartoum state topographic mapping project executed in 2012. Based on the available data of the project and measurements carried out, conclusions can be summarized in the following points:

- The used camera for both, centre and rural areas of Khartoum state to produce topographic maps was a wide angle camera. This did not comply with the suggested technical specifications.
- The average flying height used for both topographic maps does not satisfy the suggested technical specifications.
- The scale of photography for the centre of Khartoum state was about 2.5 times smaller than the required scale.

- Photographic scale of the rural area of Khartoum state was about 0.5 times greater than the required scale.
- Resolution of the used digital camera for both projects was found to be 0.108m is lower than the specified.
- Linear accuracy of the photographic coverage of centre of the Khartoum state was found to be 1.476m. This accuracy is suitable for the production of maps at scale 1:14760. This did not comply with the suggested technical specifications for the production of centre maps.
- Linear accuracy of the photographic coverage of rural areas of Khartoum state was found to be 1.039m. This accuracy is suitable for the production of maps at scale 1:10390. This scale satisfies the specifications for the production of rural maps.
- Planmetric accuracy of topographic maps produced for the centre of Khartoum state was found to be 0.496m. This accuracy is suitable for the production of maps at scale 1:2480 or smaller. This did not comply with the suggested technical specifications for the production of centre maps.
- Planmetric accuracy of topographic maps produced for the rural areas of Khartoum state was found to be 1.413m. This accuracy is suitable for the production of maps at scale 1:7065 or smaller. This scale satisfies the specifications for the production of rural maps.

9.2 Recommendations

This research work concentrated on the evaluation of Khartoum state mapping project (2012) concerned with the utilization of digital photogrammetric methods to produce topographic maps. So further studies may be extended to:

1- Evaluate other mapping projects that may be executed for the state regardless of whether GPS mapping projects or satellite imagery mapping projects or the techniques are employed.

2- Examine the accuracy of satellite mapping techniques and making some sort of comparison between these satellites.

3- Other photogrammetric softwares such as Agisoft photo scan can be used for aerial triangulation or mapping.

4- Digital terrain models can be generated from aerial photographs and subject to accuracy evaluation.

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APPENDIX (A)

AERIAL SURVEY PROJECT SPECIFICATION KHARTOUM STATE

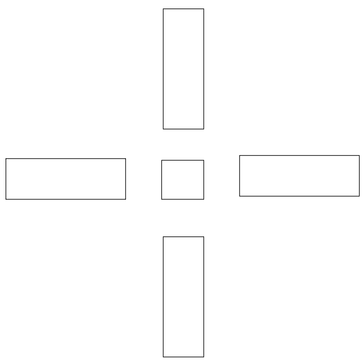
Elements	Parameters	Tolerance	Requirements
Digital Camera	Lens	Focal length to suspend: normal Angle for 1:5,000 wide Angle for 1:20,000	
	Geometric Precision	≤ 2 µm	
	Geometric Resolution (Physical Pixel Size)	≤ 15 µm	
	Radiometric Resolution	≥ 12 bit	
	Shutter Speed	1/500 or Faster	
	Image Motion	≤ 20 µm	Image motion compensation tool is necessary
	Certificate of Camera Calibration	< 4 Months	
	Image Quality	Using adequate filters Image, should be with a brightness, contrast and illumination satisfactory	

Photography	Endlap	≥60 %	Cross strips are recommended the first and the last photo of each strip should cover area outside the mapping limits
	Sidelap	≥30 %	
	Tilt	Tilt < 3º	
	Drift	Drift < 5º	
	Solar altitude	≤ 30º	
	Cloud and haze	≤ 5 %	
	Flying Height	± 5 % of Indicated flying Plan	
Ground Control	Primary Ground Control Station	Accuracy ≤ 0.05m (WGS), Spacing ~ 50Km	Base stations ≥ 2 stations PDOP ≤ 4º Satellite configuration ≥ 5 satellites mast ≥ 10º
	Secondary Ground Control Stations	Accuracy ≤ 0.10m (WGS), Spacing ~ 20-50 Km	
Signalization	Number	At least 4 at the corners of the block other locations depend on the shape of the area	
	Shape	Cross Shape with the Dimensions as Attached	
	Tolerance	Standard Deviation σ ≤ 0.05m for both image scales	
Aerial Triangulation	Tie points	Tie points not less than 9 point appearing in a minimum of 3 Photos	
	A Control diagram should be prepared showing the locations of all types of control points by different symbols		
	Interior Orientation	Average Residual ≤ 0.5 Pixel Size	

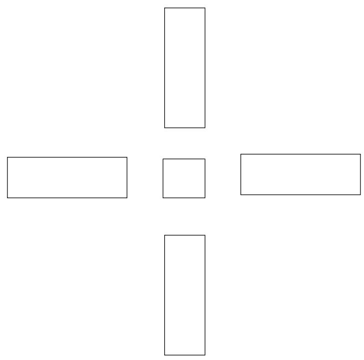
	Relative Orientation	σ x,y ≤ 0.4 Pixel Size σ z ≤ 0.7 Pixel Size	
	Bundle Adjustment Should be Used	σ 0 ≤ 0.3 Pixel Size	PAT- M & BLUH or Equivalent Software
	Max-y-Parallax at any Model	≤ 15 µm	
	RMSE of Residuals in E, N, h at control points	$\leq$ 1/10,000 of the flying height above ground	
	Average σ in Computed E, N, h	$\leq$ 1/10,000 of the flying height above ground	
	Max Residuals in any Control point & σ in E, N, h of Pass points	$\leq$2.5RMSE of Control Points Residuals	
	RMSE at any Mean Tie Point	$\leq$1/ 20,000 of the flying height above ground	
	Max Residuals in any Tie point	$\leq$2.5RMSE of Tie Points Residuals	
	Average Adjustment to Photo-coordinates. in Block	± 10 µm	
	Max Adjustment to Photo-coords. Value	± 20 µm	
	Aerial Triangulation Residuals should be submitted as Report including: - Adjusted Positions and Altitude for Camera Stations (Camera Orientation Parameters) - Adjusted Coords. Of All Points - Differences Between Given and Adjusted Coords. For Control Points Together with the RMSE - Residual for all Image Coords. Differences Between Measured and Adjusted Coords. Together with the RMSE		

DTM	DTM Has To be Generated With 0.30 & 0.15m Intervals	0.15 &0.30m Resolution	Grid points at 20m (Scale1:1000) & 100m (Scale 1:5000) Spacing have to be Measured and Recorded
	Accuracy	0.02% Flying Height	
Orthophotos	Rectifications Accuracy	$\Delta r < 1/3\ \Delta H$ (ΔH is DTM Accuracy)	
Contouring	1m Contour Interval For Scale 1:5,000 0.25m Contour Interval For Scale 1:1,000	Accuracy ≤ 50% of Contour interval	
Vectorisation	Accuracy	$\sigma 2x,y = \sigma 2CTL + \sigma 210 + \sigma 2AT + \sigma 2VECT$ $\sigma 2z = \sigma 2CTL + \sigma 210 + \sigma 2AT + \sigma 2DTM + \sigma 2VECT$ σCTL = Control $\sigma 10$= 0.5 Pixel Size (RMS) σAT= Arial Triangulation σDTM = DTM $\sigma VECT$= 50 µm (Vectorisation)	Roads, Rivers, Water Feature, Drains, Buildings, Bridges, Culverts, Fences, Electric Power Station, Substation, Poles and Lines, Railways, Trees Coverage and Vegetation, Gardens, Cemetery, Communication Towers and Poles, Radio and Television Microwaves Antennas, Canals, Tracks, Traffic Control Signals and Control points
Cartography	Grid Line	250mX250m For Scale 1:20,000 & 50mX50m For Scale 1:1,000	
	Marginal Information	Title, Sheet Name, Sheet No., Sheet Index, Scale Line, Date of Photography, Location in The Map Series, Legend and Symbols table, North & Deviation, Projection & Datum	
	Lettering	Information Should be Written in Arabic & English	

	Test Layout	Has to be approved by The Clint
Printing	Plotter	Minimum 3 colour plotter such as Hp 800 ps or Better
	Paper	Dimensionally Stable Polyester film with Minimum Thickness of 0.15mm such as Hp High – Gloss Photo Paper Q1430A 1,524mm X 30m or Better



Signal (A)



Signal (B)

Note:

Signal (A) For 1:5,000 Photography

Signal (B) For 1:10,000 Photography

ABANDIX (B)

Triangulation Analytical Report with LPS System for Centre of Khartoum State Project

The Triangulation Report With LPS

The output image x, y units: millimeters
The output angle unit: degrees
The output ground X, Y, Z units: meters

The Input Image Coordinates

image ID = 1

Point ID	x	y
1	-8.3239	-38.6224
6	-19.9901	27.2779
19	27.3029	41.7069
20	8.8707	32.1747
21	27.4706	-41.8566
22	-27.7714	44.6472
23	24.9748	5.9973
24	4.7898	-4.4727
25	11.0125	-42.4893

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2 -33.7455
0.009000	-0.000000	51.7455	0.000000	-0.009000	

image ID = 2

Point ID	x	y
1	-31.7779	-38.5211
2	22.4616	-32.9004
19	3.4662	41.8904
20	-15.0924	32.3518
21	3.5674	-41.7617
23	1.4827	6.1284
24	-18.9146	-4.3424
25	-12.7812	-42.3773
26	25.3460	-44.6761
27	26.5618	-36.1118
28	33.1064	44.6351

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 3

Point ID	x	y
2	-0.9771	-32.8417
19	-20.3728	41.9401
21	-20.2647	-41.7176
23	-21.9768	6.1704
26	1.5853	-44.6233
27	2.3411	-36.0638
28	9.4435	44.6889

29	32.0383	-36.6658
30	33.4171	10.4739
31	27.0265	42.9048

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 4

Point ID	x	y
2	-24.1948	-32.7813
3	17.1731	-36.8404
7	28.6232	30.2830
26	-21.8670	-44.5205
27	-21.6445	-35.9727
28	-14.4918	44.7295
29	8.7048	-36.3497
30	9.5304	10.7212
31	3.1632	43.0554
32	32.3387	-5.4731
34	28.7497	36.0028

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 5

Point ID	x	y
3	-6.1166	-36.7459
7	4.8501	30.3229
29	-14.6217	-36.3281
30	-14.3166	10.6507
31	-20.6540	42.8962
32	8.7158	-5.3321
34	4.7467	36.0236
35	32.8866	-46.0749
36	32.8337	4.8768
37	33.1213	43.5747

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 6

Point ID	x	y
3	-29.5099	-36.5839
4	23.4101	-27.6379
7	-18.5881	30.3102
32	-14.7890	-5.2530
34	-18.8983	35.9978
35	9.3282	-45.8631
36	9.2274	4.9377
37	9.5357	43.5358
38	31.9694	-50.9676
39	32.6450	3.1885
40	32.3245	44.6019

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 7

Point ID	x	y
4	-0.1001	-27.5546
35	-14.1499	-45.7688
36	-14.4086	4.9189
37	-14.1386	43.4230
38	8.4340	-50.8156
39	9.0368	3.2253
40	8.5301	44.5074
41	30.3315	-48.4789
42	28.6390	9.6714
43	30.7088	46.1653

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 8

Point ID	x	y
4	-23.4844	-27.5119
5	17.2511	-33.3131
8	26.0696	31.4224
38	-15.0037	-50.7508
39	-14.3668	3.2524
40	-15.0187	44.5141
41	6.6818	-48.4117
42	5.1183	9.7020
43	7.1093	46.1781

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 9

Point ID	x	y
8	-22.6474	41.5361
12	15.5944	-48.5400
13	-30.6529	-38.5504
40	18.6535	28.8679
43	-3.5469	27.1812
56	21.5962	7.8831
57	14.9796	-50.0419

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 10

Point ID	x	y
12	-8.2867	-48.4430

37	18.0505	29.7695
40	-4.6948	28.8759
43	-26.8970	27.3794
54	16.9942	-5.3826
55	30.7150	-48.7147
56	-1.9396	7.8803

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 11

Point ID	x	y
7	22.7143	42.7715
12	-31.8561	-48.2459
34	23.0065	37.6035
37	-5.4812	29.7189
40	-28.2296	28.8725
52	18.9555	5.4610
53	16.3081	-50.5676
54	-6.7173	-5.3505
55	6.5985	-48.6004
56	-25.5317	7.9328
57	-32.4823	-49.7486

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 12

Point ID	x	y
7	-0.5614	41.6530
11	7.7396	-36.8002
31	24.6797	30.1149
34	-0.5860	37.4841
37	-28.8601	29.6760
50	20.6363	9.6145
51	24.0330	-33.4666
52	-4.5819	5.4488
53	-7.7664	-50.4070
54	-30.2934	-5.2663
55	-17.3557	-48.4294

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 13

Point ID	x	y
7	-23.8072	42.7190
10	28.1220	-45.0892
11	-15.9852	-36.6471
28	18.9550	28.5482
31	1.4190	30.0261
34	-23.8940	37.5838
48	13.6170	-10.5800
49	14.8078	-40.1325

50	-2.7413	9.5891
51	0.2765	-33.4571
52	-28.0038	5.6285
53	-32.0813	-50.0917

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 14

Point ID	x	y
10	4.7394	-45.1159
19	25.3140	31.9743
28	-4.3975	28.5776
31	-21.8532	30.0755
46	20.5221	12.7584
47	23.3564	-47.4248
48	-9.9135	-10.5627
49	-8.7369	-40.1493
50	-26.0041	9.6437
51	-23.1073	-33.4395

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 15

Point ID	x	y
10	-18.8090	-45.2088
19	1.5123	32.0349
20	20.1470	41.9233
28	-27.9727	28.6795
44	19.5848	5.1950
45	22.9603	-45.6413
46	-2.9645	12.8039
47	-0.3018	-47.5264
48	-33.6679	-10.5582
49	-32.2197	-40.3441

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 16

Point ID	x	y
6	25.0571	45.4714
9	19.8585	-49.4127
19	-22.2245	32.1243
20	-3.8044	42.0394
22	32.9023	28.8556
44	-3.8612	5.2285
45	-1.0022	-45.7028
46	-26.4974	12.8198
47	-23.8289	-47.6188

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2

-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 17

Point ID	x	y
12	17.3172	23.9690
13	-29.0997	34.6269
17	24.3821	-26.1821
18	-18.4984	-45.9484
57	16.6813	22.4571
68	17.0147	0.3121
69	20.4488	-42.1867
70	-7.6803	-10.2582
71	-5.1298	-48.5732

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 18

Point ID	x	y
12	-6.2538	24.0458
17	0.6761	-26.1259
55	33.1070	24.8370
57	-6.9070	22.5340
66	17.2420	15.3858
67	21.7397	-42.3682
68	-6.8625	0.3825
69	-3.3788	-42.1211
70	-31.6201	-10.1107
71	-28.8630	-48.4312

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 19

Point ID	x	y
16	17.9930	-35.4195
17	-23.1131	-26.0179
53	18.8884	22.9829
55	9.0895	24.7732
57	-30.4660	22.6608
64	15.9395	12.0969
65	22.9675	-45.2019
66	-6.9015	15.4012
67	-2.1474	-42.3651
68	-30.7519	0.5103
69	-27.2986	-41.9967

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 20

Point ID	x	y
11	10.4108	34.9869
16	-5.7769	-35.3905

51	26.9390	38.2808
53	-5.3864	22.9420
55	-15.0600	24.7628
62	14.5524	-2.3681
63	25.4545	-50.2223
64	-7.9299	12.1114
65	-0.8246	-45.1715
66	-31.1224	15.4394
67	-25.8961	-42.3105

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 21

Point ID	x	y
10	31.5938	26.1388
11	-13.0072	35.0182
16	-29.6315	-35.1662
49	18.1729	31.7603
51	3.4942	38.1882
53	-29.3719	23.0954
60	15.0393	3.7511
61	20.9410	-45.6174
62	-9.1680	-2.3460
63	1.4438	-50.2039
64	-31.6135	12.2949
65	-24.7695	-44.9732

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 22

Point ID	x	y
10	7.8774	26.1941
15	25.5444	-22.7842
47	26.6832	24.1422
49	-5.6799	31.8014
51	-20.1730	38.2339
58	18.9466	-17.4754
59	21.9973	-44.6464
60	-8.6368	3.8351
61	-2.7044	-45.4758
62	-32.8145	-2.2498
63	-22.1529	-50.0548

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 23

Point ID	x	y
10	-15.8090	26.2487
15	1.7847	-22.6988
45	26.3317	27.3657
47	2.8379	24.1786

49	-29.2855	31.8353
58	-4.7965	-17.3764
59	-1.7564	-44.5233
60	-32.3101	3.9320
61	-26.3977	-45.3307

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 24

Point ID	x	y
9	22.7936	21.6934
14	1.6571	-40.7239
15	-21.8259	-22.6034
45	1.9685	27.4464
47	-21.0362	24.2267
58	-28.4308	-17.3042
59	-25.3350	-44.4094

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 25

Point ID	x	y
14	-27.5389	-31.6451
15	-3.9110	-49.1075
59	-0.8957	-27.4759
61	23.5395	-26.0383
72	-16.1444	-16.3830
73	-17.1947	50.3255
74	9.6152	48.2532

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 26

Point ID	x	y
15	-27.4288	-49.1540
59	-24.3857	-27.4759
61	0.0762	-26.0693
63	19.3092	-21.1347
74	-13.8567	48.3090
75	31.7778	24.3472
76	28.0871	-4.8598

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 27

Point ID	x	y
16	26.8808	-35.5090
61	-23.4848	-25.9050

63	-4.2378	-21.0518
65	21.8919	-25.8880
75	8.3102	24.4253
76	4.5550	-4.8091

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 28

Point ID	x	y
16	3.4484	-35.4462
63	-27.6763	-21.0279
65	-1.5692	-25.8309
67	23.3900	-28.3456
75	-15.3345	24.4681
76	-18.9884	-4.7676
77	26.2845	44.3376
78	32.8504	-15.3576

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 29

Point ID	x	y
16	-20.0981	-35.4206
17	20.8204	-44.3509
65	-25.1136	-25.7898
67	-0.1706	-28.3198
69	24.8546	-28.6540
77	2.6507	44.3532
78	9.2863	-15.3502
79	25.6570	-7.0945
80	31.1631	-4.4111

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 30

Point ID	x	y
17	-2.8114	-44.2879
67	-23.7029	-28.1716
69	1.2020	-28.6064
71	26.6169	-22.1179
77	-20.6805	44.4418
78	-14.2177	-15.2367
79	2.1241	-7.0826
80	7.4177	-4.4064
81	32.9965	13.6349
82	22.6999	-35.5893

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 31

Point ID	x	y
17	-26.1529	-44.2474
18	16.4570	-24.6574
69	-22.2582	-28.5845
71	3.1600	-22.0343
79	-21.3635	-7.0730
80	-16.3201	-4.3845
81	9.3613	13.6903
82	-0.6920	-35.5133

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 33

Point ID	x	y
14	-4.0375	-31.8370
15	19.6574	-49.2310
59	22.6047	-27.5905
72	7.5008	-16.5489
73	6.2226	50.1305
74	32.9582	48.1496

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

THE OUTPUT OF SELF-CALIBRATING BUNDLE BLOCK ADJUSTMENT

```
the no. of iteration =1    the standard error =  0.0625
the maximal correction of the object points =  28.17783

the no. of iteration =2    the standard error =  0.0625
the maximal correction of the object points =   1.69656

the no. of iteration =3    the standard error =  0.0625
the maximal correction of the object points =   0.00859

the no. of iteration =4    the standard error =  0.0625
the maximal correction of the object points =   0.00003

                    The exterior orientation parameters   image ID
XYsZs  OMEGA       PHI  KAPPA8        -765.072-831.2242     -23.7780   -
0.2674   -0.0306   89.7834  7        -764.3240 -558.7380     -24.6799   -
0.2301    0.0062   89.8085 6        -764.290-284.6075     -24.3648   -
0.1351    0.0271   89.9453  5        -764.2936 -11.5396     -23.6746   -
0.0229    0.0939   89.98544        -764.5205262.3244    -22.5578
0.1264    0.0356   90.3426 3        -766.5514  533.7249     -21.4720
0.0841    0.0853   90.7567
2       -768.8008  804.2579     -21.7023   -0.0467    0.0390   90.7868
1     -764.3231  1052.3190    -827.8619  -1.1326   -0.2835   90.7423  9
80.9850   -874.1659    -20.6154    0.0955    0.0038  -90.4488
10        85.4895   -603.6402    -21.8406   -0.0593   -0.2323  -89.9590
11        85.4035   -330.0288    -22.7590    0.0445   -0.2187  -89.8676
```

12	87.1502	-58.1686	-25.6808	-0.0224	-0.4827	-89.7677
13	83.3848	214.8507	-24.8066	-0.0532	-0.2141	-89.3532
4	79.6696	487.4817	-24.2128	0.1540	-0.1314	-89.2865
15	75.2719	758.7942	-22.4958	0.0471	-0.0381	-89.2604
16	70.8503	1028.3223	-21.7190	-0.1410	0.0748	-89.2837
17	921.5437	-896.0250	-17.7183	0.0723	-0.0277	-89.6921
18	919.6512	-624.9327	-17.0494	-0.0288	0.0935	-89.5330
19	917.0020	-352.8766	-17.2874	-0.0390	0.1152	-89.2410
20	913.7750	-79.5348	-17.6113	0.0249	0.0906	-89.1745
21	909.4464	192.7413	-17.9070	0.0593	0.0920	-88.7624
22	905.0360	464.9132	-18.0995	0.1066	0.0355	-88.7321
23	900.7426	736.9193	-18.7446	0.0578	-0.0695	-88.6330
24	897.0821	1008.9470	-19.4553	-0.0152	-0.2140	-88.8071
31	1736.3720	-914.9546	-18.8912	-0.0436	-0.1897	90.3153
30	1734.581	-644.3782	-19.5258	-0.1664	-0.1274	90.4157
29	1734.188	-373.2707	-20.1328	-0.2015	-0.1355	90.1780
28	1733.84	-100.0382	-20.8155	-0.1366	-0.1561	90.1657
27	1733.3129	174.1334	-21.1401	0.0202	-0.1642	90.3495
26	1734.2834	448.8707	-20.1822	0.2740	-0.2873	90.1984
25	1733.2790	720.1376	-19.3085	0.2239	-0.2685	90.0855
33	1745.4087	999.0636	-830.0803	0.4193	-0.5669	89.8882

The accuracy of the exterior orientation parameters

image ID	mXs	mYs	mZs	mOMEGA	mPHI	mKAPPA
8	0.9352	0.9115	0.3625	0.0912	0.0667	0.0429
7	0.9360	0.8188	0.4361	0.0914	0.0641	0.0446
6	0.7493	0.6545	0.3028	0.0616	0.0538	0.0347
5	0.8524	0.7343	0.3348	0.0811	0.0613	0.0421
4	0.8861	0.7488	0.3065	0.0754	0.0644	0.0366
3	1.0106	0.7942	0.4279	0.0876	0.0718	0.0385
2	0.9065	0.7066	0.4248	0.0645	0.0666	0.0375
1	4.1341	5.7130	0.9368	0.2594	0.1772	0.0479
9	0.9732	0.7561	0.3445	0.0739	0.0599	0.0364
10	1.0201	0.9203	0.4563	0.1000	0.0730	0.0444
11	0.7666	0.6887	0.2779	0.0706	0.0520	0.0295
12	0.8300	0.8256	0.2960	0.0929	0.0577	0.0328
13	0.7132	0.6244	0.2749	0.0625	0.0482	0.0306
14	0.9277	0.9569	0.4388	0.1053	0.0704	0.0390
15	0.9146	0.8472	0.4990	0.0865	0.0631	0.0378
16	0.9202	0.8348	0.4242	0.0915	0.0521	0.0343
17	0.8243	0.8867	0.3857	0.0885	0.0582	0.0399
18	0.9952	0.8887	0.5167	0.0971	0.0851	0.0450
19	0.9194	0.8471	0.4584	0.0886	0.0811	0.0413
20	0.8663	0.7966	0.3379	0.0941	0.0667	0.0362
21	0.7684	0.7274	0.3005	0.0720	0.0603	0.0334
22	0.8459	0.9356	0.4296	0.1025	0.0687	0.0420
23	0.9888	1.0641	0.5964	0.1200	0.0810	0.0501
24	1.1337	1.3218	0.4827	0.1521	0.0921	0.0481
31	3.0996	3.5407	2.5302	0.3102	0.4109	0.1827
30	2.2526	2.6575	1.8486	0.2029	0.2833	0.1517
29	2.2783	1.7210	2.0174	0.1414	0.2902	0.0998
28	2.5328	2.3810	1.7389	0.2021	0.2891	0.1500
27	2.5764	1.8635	1.8483	0.1695	0.2902	0.1091

26	2.4056	2.6127	1.8132	0.2205	0.2954	0.1285
25	2.2502	2.4220	2.0491	0.2012	0.2915	0.1287
33	11.0841	16.1628	4.6294	0.7092	0.5070	0.1984

The interior orientation parameters of photos

image ID	f(mm)	xo(mm)	yo(mm)
8	35.0000	0.0000	0.0000
7	35.0000	0.0000	0.0000
6	35.0000	0.0000	0.0000
5	35.0000	0.0000	0.0000
4	35.0000	0.0000	0.0000
3	35.0000	0.0000	0.0000
2	35.0000	0.0000	0.0000
1	105.2000	0.0000	0.0000
9	35.0000	0.0000	0.0000
10	35.0000	0.0000	0.0000
11	35.0000	0.0000	0.0000
12	35.0000	0.0000	0.0000
13	35.0000	0.0000	0.0000
14	35.0000	0.0000	0.0000
15	35.0000	0.0000	0.0000
16	35.0000	0.0000	0.0000
17	35.0000	0.0000	0.0000
18	35.0000	0.0000	0.0000
19	35.0000	0.0000	0.0000
20	35.0000	0.0000	0.0000
21	35.0000	0.0000	0.0000
22	35.0000	0.0000	0.0000
23	35.0000	0.0000	0.0000
24	35.0000	0.0000	0.0000
31	35.0000	0.0000	0.0000
30	35.0000	0.0000	0.0000
29	35.0000	0.0000	0.0000
28	35.0000	0.0000	0.0000
27	35.0000	0.0000	0.0000
26	35.0000	0.0000	0.0000
25	35.0000	0.0000	0.0000
33	105.2000	0.0000	0.0000

The residuals of the control points

Point ID	rXrYrZ		
1	0.8528	0.0961	-0.4801
2	-0.7114	-0.3681	0.3913
3	-0.6072	0.2176	0.5617
4	-0.3094	-0.0827	0.1451
5	0.0000	0.0000	0.0000
6	-0.8894	0.2585	0.0767
7	0.5142	0.2064	0.2918
8	-0.4228	-0.3418	-0.3797
9	0.0524	-0.2895	0.5813
10	0.0102	-0.3540	-0.1073
11	-0.1312	0.0376	-0.5980
12	-0.1364	0.2857	-0.1535
13	-0.2054	-0.2862	0.5669
14	0.3412	0.2151	-0.3706
16	-0.0785	0.0107	0.2212
18	0.2681	-0.0295	-0.1002

aXaYaZ

-0.0908 -0.0265 0.0404

mXmYmZ

0.4477 0.2300 0.3711

The coordinates of object points

Point ID	X	Y	Z	Overlap
1	-1218.9263	1166.0151	383.1913	2
2	-1145.0070	539.8131	383.3933	3
3	-1188.7338	59.7352	381.7400	3
4	-1084.3102	-554.7025	382.0446	3
5	-1153.3848	-1028.5718	383.6223	1
6	-457.3913	1311.5405	382.9610	2
7	-411.8512	-67.9062	381.7683	6
8	-401.3144	-1132.8801	384.4292	2
9	640.5374	1266.5056	381.6254	2
10	602.5287	548.0035	383.9449	6
11	511.2051	33.8828	385.4084	4
12	644.7128	-698.9616	385.4219	5
13	525.0572	-1233.1422	383.6905	2
14	1364.0710	1037.3620	386.1493	3
16	1322.0218	-140.2563	383.6255	6
18	1450.7883	-1106.4390	384.9975	2
19	-291.0546	771.7080	377.0288	6
20	-403.3408	980.4179	374.5467	4
21	-1243.8492	756.9341	377.5728	3
22	-261.8648	1401.1074	376.8446	2
23	-697.4067	789.4652	385.8765	3
24	-821.0502	1020.5569	379.0471	2
25	-1255.9765	943.8734	379.3067	2
26	-1274.5089	508.3337	378.3458	3
27	-1168.9056	501.6838	370.6217	3
28	-251.1992	431.5568	379.8760	6
29	-1184.0957	158.1213	382.2756	3
30	-641.1691	152.9592	377.7310	3
31	-267.7561	228.2046	380.3363	6
32	-825.0835	-112.1901	380.7105	3
34	-349.7319	-66.2413	377.8875	6
35	-1295.4904	-390.9890	381.4107	3
36	-707.1023	-390.3140	380.2951	3
37	-260.2907	-394.9878	380.3439	6
38	-1353.9416	-652.8712	381.5902	3
39	-727.1504	-662.3379	382.5219	3
40	-249.0952	-657.8240	380.9391	6
41	-1323.1972	-904.2015	379.4301	2
42	-653.3026	-889.0199	381.8147	2
43	-231.8369	-913.6164	381.2798	4
56	-7.3202	-625.9534	381.7995	3
57	662.1338	-705.9022	385.2632	5
54	145.7069	-407.9276	379.8288	3
55	637.1122	-253.7176	377.9922	6
52	20.1963	-111.3174	382.2329	3
53	656.8743	-143.9669	376.5875	6
50	-29.5047	182.3487	381.9152	3
51	471.4619	222.5668	383.9436	6
48	201.7078	373.6255	379.0398	3

49	544.1889	391.7878	381.3381	6
46	-72.3661	722.4623	382.0170	3
47	622.9182	762.0812	381.3778	6
44	11.8345	984.0307	382.1866	2
45	586.9452	1024.2789	372.8868	4
17	1220.4961	-614.5149	384.7716	6
68	916.6561	-702.7404	381.3314	3
69	1403.7113	-659.5686	383.7308	6
70	1038.4586	-983.4072	381.0036	2
71	1480.4339	-952.5158	385.0930	4
66	745.7788	-432.4298	376.3897	3
67	1405.3666	-370.8881	384.3103	6
64	777.2776	-172.4029	382.5099	3
65	1433.5658	-81.6912	383.7084	6
62	939.3106	87.5620	383.6472	3
63	1487.5931	221.6092	384.2352	6
60	863.5766	363.8606	383.5605	3
61	1429.6005	444.8675	384.5781	6
15	1160.9251	763.2151	384.5708	6
58	1101.3271	686.1261	384.1192	3
59	1412.9343	728.5023	384.9344	6
72	1542.1897	904.0045	383.5142	2
73	2310.9205	917.4091	387.3961	2
74	2288.3662	608.5477	386.7174	3
75	2015.8011	79.4733	385.2330	3
76	1676.8659	120.8411	384.1095	3
77	2244.9965	-400.7719	384.9637	3
78	1556.0313	-479.8752	384.7984	3
79	1652.0767	-668.3612	384.8663	3
80	1683.8939	-728.3306	381.1123	3
81	1893.1776	-1021.4803	384.3837	2
82	1323.5635	-908.8903	385.3837	2

The total object points = 81

The accuracy of object points

Point ID	mXmYmZmP	Overlap			
19	0.5629	0.4981	0.6890	1.0196	6
20	0.5714	0.5435	0.7141	1.0639	4
21	1.3109	0.5739	1.2169	1.8785	3
22	0.8066	0.9634	1.0088	1.6113	2
23	0.6196	0.5515	1.3783	1.6087	3
24	0.7105	0.8089	1.9908	2.2632	2
25	1.4059	0.7072	1.4210	2.1204	2
26	1.3471	0.5735	1.0420	1.7970	3
27	1.0798	0.5405	0.9593	1.5422	3
28	0.4955	0.4661	0.5487	0.8740	6
29	1.2327	0.5968	1.1437	1.7843	3
30	0.6124	0.5370	0.9359	1.2407	3
31	0.4743	0.4325	0.4738	0.7978	6
32	0.5569	0.5263	0.8687	1.1583	3
34	0.3869	0.3803	0.3431	0.6419	6
35	1.5509	0.6447	1.2474	2.0921	3
36	0.5749	0.5476	0.9536	1.2408	3
37	0.4765	0.4412	0.4844	0.8102	6
38	1.5895	0.6479	1.1656	2.0748	3
39	0.5886	0.5527	0.9208	1.2247	3
40	0.5084	0.4792	0.4979	0.8579	6

41	2.8205	1.2009	2.1022	3.7171	2
42	0.8356	1.0116	1.7537	2.1902	2
43	0.5817	0.6013	0.5989	1.0289	4
56	0.6306	0.5320	0.9014	1.2219	3
57	0.4541	0.4331	0.4045	0.7466	5
54	0.5838	0.5268	0.9362	1.2227	3
55	0.4804	0.4283	0.4719	0.7981	6
52	0.5493	0.4880	0.8510	1.1243	3
53	0.4542	0.4102	0.4440	0.7561	6
50	0.6057	0.5037	0.9296	1.2185	3
51	0.4118	0.3857	0.3954	0.6890	6
48	0.6061	0.5309	0.8738	1.1886	3
49	0.3921	0.3803	0.3532	0.6505	6
46	0.6938	0.5598	1.0566	1.3824	3
47	0.4995	0.4180	0.5323	0.8411	6
44	0.7715	0.7092	1.7424	2.0332	2
45	0.5967	0.5454	0.6099	1.0126	4
17	0.6924	0.4575	0.7515	1.1196	6
68	0.5690	0.5270	0.9206	1.2038	3
69	0.6500	0.5596	0.6659	1.0858	6
70	0.8313	1.0992	1.8335	2.2936	2
71	0.6701	0.6482	0.6757	1.1515	4
66	0.6730	0.5645	0.9715	1.3097	3
67	0.5720	0.4700	0.5820	0.9417	6
64	0.6064	0.5540	0.8892	1.2105	3
65	0.5130	0.4382	0.4677	0.8210	6
62	0.5384	0.5299	0.9538	1.2167	3
63	0.8022	0.5746	0.8108	1.2772	6
60	0.5396	0.5329	0.8970	1.1746	3
61	0.7604	0.6478	0.8489	1.3109	6
15	0.7363	0.4859	0.9077	1.2657	6
58	0.7241	0.5689	1.0594	1.4037	3
59	0.6437	0.5650	0.7861	1.1626	6
72	1.0823	1.1271	2.1846	2.6859	2
73	4.3821	3.1786	4.8987	7.3010	2
74	5.5678	2.0787	4.8324	7.6599	3
75	2.6048	1.4213	3.8613	4.8698	3
76	0.9247	0.8463	2.0471	2.4004	3
77	4.6450	1.7909	4.7728	6.8966	3
78	0.8276	0.8623	1.5472	1.9551	3
79	0.7669	1.1819	1.9176	2.3795	3
80	0.7904	1.2739	2.0264	2.5206	3
81	2.2225	3.0873	4.1753	5.6483	2
82	2.0049	0.9052	2.0064	2.9774	2

amXamYamZ

1.0119	0.7485	1.2808

The residuals of image points

Point	Image	VxVy	
1	2	0.0026	0.0189
1	1	0.0536	-0.1055

Point	Image	VxVy	
2	4	-0.0533	0.0306
2	3	-0.0348	0.0367

```
   2        2     -0.0080       0.0233

Point    Image       VxVy
   3        6     -0.0052       0.0135
   3        5     -0.0234      -0.0160
   3        4      0.0599       0.0073

Point    Image       VxVy
   4        8     -0.0120       0.0075
   4        7     -0.0145       0.0129
   4        6      0.0048       0.0299

Point    Image       VxVy
   5        8      0.0227      -0.0221

Point    Image       VxVy
   6        1     -0.0387       0.0983
   6       16     -0.0789      -0.0484

Point    Image       VxVy
   7        6     -0.0023      -0.0222
   7        5      0.0154       0.0042
   7        4      0.0004      -0.0183
   7       11     -0.0040      -0.1134
   7       12     -0.1093       0.4851
   7       13      0.0077      -0.1113

Point    Image       VxVy
   8        8     -0.0582       0.0070
   8        9      0.0467      -0.0749

Point    Image       VxVy
   9       16      0.0389      -0.0662
   9       24      0.0729       0.0349

Point    Image       VxVy
  10       13     -0.0205       0.0071
  10       14      0.0005      -0.0132
  10       15      0.0929      -0.0004
  10       21      0.0237       0.0296
  10       22      0.0093       0.0168
  10       23      0.0682      -0.0242

Point    Image       VxVy
  11       12      0.0032       0.0538
  11       13      0.0310       0.0336
  11       20     -0.0247      -0.0570
  11       21     -0.0069      -0.0722

Point    Image       VxVy
  12        9     -0.0437       0.0393
  12       10     -0.0243      -0.0340
  12       11     -0.0068       0.0083
  12       17     -0.0305      -0.0375
  12       18     -0.0136       0.0015

Point    Image       VxVy
```

```
  13       9     -0.0150     -0.0716
  13      17     -0.0195      0.0310

Point   Image       VxVy
  14      24     -0.0497      0.0802
  14      25      0.0044      0.0170
  14      33      0.0285     -0.0242

Point   Image       VxVy
  16      19      0.0330     -0.0264
  16      20     -0.0067     -0.0266
  16      21     -0.0527     -0.0173
  16      29      0.0008     -0.0056
  16      28      0.0039     -0.0172
  16      27     -0.0102     -0.0068

Point   Image       VxVy
  18      17      0.0090      0.0347
  18      31     -0.0051     -0.0170

Point   Image       VxVy
  19       3     -0.0094      0.0057
  19       2     -0.0079     -0.0533
  19       1     -0.0038      0.0665
  19      14     -0.0328     -0.0355
  19      15      0.0608     -0.0028
  19      16     -0.0481      0.0569

Point   Image       VxVy
  20       2      0.0203      0.0830
  20       1     -0.0614     -0.0915
  20      15     -0.0459     -0.0265
  20      16      0.0045      0.0181

Point   Image       VxVy
  21       3      0.0312     -0.0438
  21       2      0.0402      0.0044
  21       1     -0.0709      0.0398

Point   Image       VxVy
  22       1      0.0722     -0.0377
  22      16      0.0711     -0.0376

Point   Image       VxVy
  23       3      0.0168      0.0130
  23       2     -0.1002     -0.0404
  23       1      0.0818      0.0269

Point   Image       VxVy
  24       2     -0.0022      0.0163
  24       1      0.0022     -0.0163

Point   Image       VxVy
  25       2      0.0341     -0.0192
  25       1     -0.0340      0.0193

Point   Image       VxVy
```

26	4	-0.0004	0.0094
26	3	0.0008	-0.0005
26	2	-0.0005	-0.0089

Point	Image	VxVy	
27	4	0.0021	0.0106
27	3	-0.0043	0.0110
27	2	0.0020	-0.0216

Point	Image	VxVy	
28	4	-0.0386	-0.0135
28	3	-0.0146	-0.0222
28	2	0.0173	-0.0029
28	13	0.0110	-0.0569
28	14	0.0137	-0.0071
28	15	-0.0604	0.0250

Point	Image	VxVy	
29	5	-0.0052	0.0173
29	4	0.0104	-0.0023
29	3	-0.0054	-0.0150

Point	Image	VxVy	
30	5	-0.0059	0.0169
30	4	0.0115	-0.0229
30	3	-0.0057	0.0061

Point	Image	VxVy	
31	5	-0.0657	-0.0397
31	4	-0.0215	0.0185
31	3	0.0254	0.0094
31	12	-0.0716	-0.1451
31	13	0.0382	0.0650
31	14	-0.0286	0.0667

Point	Image	VxVy	
32	6	-0.0071	-0.0255
32	5	0.0140	0.0137
32	4	-0.0069	0.0118

Point	Image	VxVy	
34	6	-0.0202	-0.0252
34	5	0.0181	-0.0056
34	4	0.0361	-0.0311
34	11	0.0686	0.0855
34	12	0.0296	-0.2268
34	13	-0.0638	0.0765

Point	Image	VxVy	
35	7	0.0072	0.0064
35	6	-0.0144	-0.0199
35	5	0.0072	0.0134

Point	Image	VxVy	
36	7	0.0009	-0.0338
36	6	-0.0017	0.0036
36	5	0.0009	0.0300

Point	Image	VxVy	
37	7	0.0081	0.0060
37	6	0.0516	0.0463
37	5	0.0445	-0.0344
37	10	0.0201	0.0470
37	11	-0.0440	0.0746
37	12	0.1293	-0.1068

Point	Image	VxVy	
38	8	0.0025	0.0116
38	7	-0.0050	-0.0113
38	6	0.0025	-0.0002

Point	Image	VxVy	
39	8	-0.0034	-0.0274
39	7	0.0069	-0.0004
39	6	-0.0034	0.0277

Point	Image	VxVy	
40	8	0.0375	0.0118
40	7	0.0189	0.0135
40	6	-0.0045	-0.0278
40	9	0.0534	0.0796
40	10	-0.0139	-0.0334
40	11	0.0110	-0.0495

Point	Image	VxVy	
41	8	0.0000	0.0023
41	7	-0.0000	-0.0023

Point	Image	VxVy	
42	8	0.0000	-0.0109
42	7	0.0000	0.0109

Point	Image	VxVy	
43	8	0.0108	0.0201
43	7	-0.0225	-0.0020
43	9	-0.0433	0.0337
43	10	0.0316	-0.0163

Point	Image	VxVy	
56	9	0.0121	-0.0229
56	10	-0.0241	0.0200
56	11	0.0122	0.0031

Point	Image	VxVy	
57	9	-0.0104	0.0159
57	11	0.0005	-0.0151
57	17	0.0011	-0.0264
57	18	0.0206	0.0090
57	19	-0.0118	0.0165

Point	Image	VxVy	
54	10	0.0213	-0.0192
54	11	-0.0431	-0.0124
54	12	0.0220	0.0318

Point	Image	VxVy	
55	10	-0.0107	0.0354
55	11	0.0176	0.0049
55	12	-0.0105	-0.0457
55	18	-0.0092	0.0011
55	19	0.0065	-0.0071
55	20	0.0061	0.0115

Point	Image	VxVy	
52	11	-0.0178	-0.0040
52	12	0.0360	0.0124
52	13	-0.0179	-0.0082

Point	Image	VxVy	
53	11	0.0052	0.0165
53	12	-0.0081	-0.0330
53	13	-0.0008	0.0028
53	19	-0.0246	-0.0228
53	20	0.0057	0.0248
53	21	0.0228	0.0119

Point	Image	VxVy	
50	12	-0.0115	-0.0016
50	13	0.0228	0.0168
50	14	-0.0115	-0.0153

Point	Image	VxVy	
51	12	-0.0097	-0.0182
51	13	-0.0240	-0.0267
51	14	0.0563	0.0313
51	20	0.0171	0.0227
51	21	-0.0294	0.0193
51	22	-0.0095	-0.0283

Point	Image	VxVy	
48	13	0.0029	0.0325
48	14	-0.0061	0.0135
48	15	0.0031	-0.0458

Point	Image	VxVy	
49	13	0.0138	-0.0320
49	14	0.0554	0.0046
49	15	-0.0827	0.0927
49	21	0.0377	-0.0057
49	22	0.0380	-0.0215
49	23	-0.0630	-0.0373

Point	Image	VxVy	
46	14	-0.0077	0.0152
46	15	0.0155	-0.0179
46	16	-0.0077	0.0028

Point	Image	VxVy	
47	14	-0.0386	-0.0594
47	15	0.0022	0.0003
47	16	0.0326	0.0310

47	22	0.0078	0.0576
47	23	-0.0257	0.0020
47	24	0.0215	-0.0320

Point	Image	VxVy	
44	15	-0.0000	0.0178
44	16	0.0000	-0.0178

Point	Image	VxVy	
45	15	0.0152	-0.0408
45	16	-0.0125	0.0588
45	23	0.0394	0.0080
45	24	-0.0428	-0.0259

Point	Image	VxVy	
17	17	0.0320	0.0048
17	18	-0.0003	0.0042
17	19	-0.0091	0.0007
17	31	0.0097	-0.0101
17	30	0.0140	0.0151
17	29	-0.0007	0.0047

Point	Image	VxVy	
68	17	-0.0056	0.0085
68	18	0.0111	-0.0064
68	19	-0.0056	-0.0021

Point	Image	VxVy	
69	17	0.0114	-0.0339
69	18	-0.0010	0.0127
69	19	0.0003	0.0272
69	31	-0.0026	-0.0034
69	30	0.0082	0.0063
69	29	0.0050	0.0030

Point	Image	VxVy	
70	17	-0.0000	0.0210
70	18	-0.0000	-0.0210

Point	Image	VxVy	
71	17	0.0020	-0.0024
71	18	-0.0080	0.0056
71	31	-0.0070	0.0034
71	30	0.0010	-0.0002

Point	Image	VxVy	
66	18	-0.0006	0.0062
66	19	0.0012	0.0001
66	20	-0.0006	-0.0063

Point	Image	VxVy	
67	18	0.0010	-0.0127
67	19	-0.0037	0.0006
67	20	-0.0152	0.0221
67	30	-0.0148	-0.0047
67	29	-0.0003	0.0020
67	28	-0.0032	0.0125

Point	Image	VxVy	
64	19	0.0041	0.0003
64	20	-0.0081	0.0047
64	21	0.0041	-0.0051

Point	Image	VxVy	
65	19	0.0101	0.0137
65	20	0.0012	-0.0056
65	21	-0.0208	0.0059
65	29	-0.0065	0.0074
65	28	-0.0063	0.0055
65	27	0.0031	0.0010

Point	Image	VxVy	
62	20	0.0064	-0.0142
62	21	-0.0127	-0.0020
62	22	0.0064	0.0163

Point	Image	VxVy	
63	20	0.0186	0.0232
63	21	0.0155	0.0106
63	22	-0.0185	-0.0209
63	28	0.0035	0.0004
63	27	0.0049	-0.0020
63	26	0.0074	0.0148

Point	Image	VxVy	
60	21	0.0087	-0.0175
60	22	-0.0176	-0.0097
60	23	0.0090	0.0273

Point	Image	VxVy	
61	21	0.0093	0.0424
61	22	0.0216	-0.0076
61	23	-0.0225	-0.0279
61	27	0.0031	-0.0025
61	26	0.0116	-0.0025
61	25	-0.0063	0.0120

Point	Image	VxVy	
15	22	-0.0239	-0.0282
15	23	-0.0063	0.0094
15	24	-0.0015	0.0060
15	26	0.0009	0.0102
15	25	-0.0082	-0.0172
15	33	-0.0244	-0.0068

Point	Image	VxVy	
58	22	-0.0007	-0.0196
58	23	0.0012	0.0086
58	24	-0.0005	0.0110

Point	Image	VxVy	
59	22	-0.0133	0.0448
59	23	-0.0010	0.0341
59	24	0.0007	-0.0733

59	26	-0.0196	-0.0094
59	25	-0.0031	0.0049
59	33	0.0086	0.0095

Point	Image	VxVy	
72	25	0.0144	-0.0253
72	33	-0.0146	0.0254

Point	Image	VxVy	
73	25	0.0086	0.0049
73	33	-0.0086	-0.0049

Point	Image	VxVy	
74	26	-0.0006	-0.0048
74	25	-0.0098	0.0038
74	33	0.0104	0.0010

Point	Image	VxVy	
75	28	0.0025	-0.0035
75	27	-0.0049	0.0017
75	26	0.0025	0.0018

Point	Image	VxVy	
76	28	-0.0020	0.0015
76	27	0.0040	0.0086
76	26	-0.0020	-0.0101

Point	Image	VxVy	
77	30	0.0028	0.0000
77	29	-0.0057	-0.0020
77	28	0.0028	0.0019

Point	Image	VxVy	
78	30	-0.0012	-0.0055
78	29	0.0024	0.0067
78	28	-0.0012	-0.0011

Point	Image	VxVy	
79	31	-0.0006	0.0075
79	30	0.0013	0.0060
79	29	-0.0006	-0.0135

Point	Image	VxVy	
80	31	0.0056	0.0018
80	30	-0.0113	0.0008
80	29	0.0056	-0.0025

Point	Image	VxVy	
81	31	-0.0000	0.0038
81	30	-0.0000	-0.0038

Point	Image	VxVy	
82	31	-0.0001	0.0141
82	30	-0.0000	-0.0140

The image residuals of the control points

```
          The image ID = 8
   Point ID       VxVy
         4     -0.0120      0.0075
         5      0.0227     -0.0221
         8     -0.0582      0.0070
RMSE of 3 points: mx=0.0367, my=0.0141

          The image ID = 7
   Point ID       VxVy
         4     -0.0145      0.0129
RMSE of 1 points: mx=0.0145, my=0.0129

          The image ID = 6
   Point ID       VxVy
         3     -0.0052      0.0135
         4      0.0048      0.0299
         7     -0.0023     -0.0222
RMSE of 3 points: mx=0.0043, my=0.0229

          The image ID = 5
   Point ID       VxVy
         3     -0.0234     -0.0160
         7      0.0154      0.0042
RMSE of 2 points: mx=0.0198, my=0.0117

          The image ID = 4
   Point ID       VxVy
         2     -0.0533      0.0306
         3      0.0599      0.0073
         7      0.0004     -0.0183
RMSE of 3 points: mx=0.0463, my=0.0210

          The image ID = 3
   Point ID       VxVy
         2     -0.0348      0.0367
RMSE of 1 points: mx=0.0348, my=0.0367

          The image ID = 2
   Point ID       VxVy
         1      0.0026      0.0189
         2     -0.0080      0.0233
RMSE of 2 points: mx=0.0059, my=0.0212

          The image ID = 1
   Point ID       VxVy
         1      0.0536     -0.1055
         6     -0.0387      0.0983
RMSE of 2 points: mx=0.0467, my=0.1020

          The image ID = 9
   Point ID       VxVy
         8      0.0467     -0.0749
        12     -0.0437      0.0393
        13     -0.0150     -0.0716
RMSE of 3 points: mx=0.0379, my=0.0640
```

```
          The image ID = 10
   Point ID       VxVy
       12     -0.0243     -0.0340
RMSE of 1 points: mx=0.0243, my=0.0340

          The image ID = 11
   Point ID       VxVy
        7     -0.0040     -0.1134
       12     -0.0068      0.0083
RMSE of 2 points: mx=0.0056, my=0.0804

          The image ID = 12
   Point ID       VxVy
        7     -0.1093      0.4851
       11      0.0032      0.0538
RMSE of 2 points: mx=0.0773, my=0.3451

          The image ID = 13
   Point ID       VxVy
        7      0.0077     -0.1113
       10     -0.0205      0.0071
       11      0.0310      0.0336
RMSE of 3 points: mx=0.0219, my=0.0672

          The image ID = 14
   Point ID       VxVy
       10      0.0005     -0.0132
RMSE of 1 points: mx=0.0005, my=0.0132

          The image ID = 15
   Point ID       VxVy
       10      0.0929     -0.0004
RMSE of 1 points: mx=0.0929, my=0.0004

          The image ID = 16
   Point ID       VxVy
        6     -0.0789     -0.0484
        9      0.0389     -0.0662
RMSE of 2 points: mx=0.0622, my=0.0580

          The image ID = 17
   Point ID       VxVy
       12     -0.0305     -0.0375
       13     -0.0195      0.0310
       18      0.0090      0.0347
RMSE of 3 points: mx=0.0215, my=0.0345

          The image ID = 18
   Point ID       VxVy
       12     -0.0136      0.0015
RMSE of 1 points: mx=0.0136, my=0.0015

          The image ID = 19
   Point ID       VxVy
       16      0.0330     -0.0264
RMSE of 1 points: mx=0.0330, my=0.0264
```

```
          The image ID = 20
   Point ID       VxVy
        11     -0.0247     -0.0570
        16     -0.0067     -0.0266
RMSE of 2 points: mx=0.0181, my=0.0445

          The image ID = 21
   Point ID       VxVy
        10      0.0237      0.0296
        11     -0.0069     -0.0722
        16     -0.0527     -0.0173
RMSE of 3 points: mx=0.0336, my=0.0462

          The image ID = 22
   Point ID       VxVy
        10      0.0093      0.0168
RMSE of 1 points: mx=0.0093, my=0.0168

          The image ID = 23
   Point ID       VxVy
        10      0.0682     -0.0242
RMSE of 1 points: mx=0.0682, my=0.0242

          The image ID = 24
   Point ID       VxVy
         9      0.0729      0.0349
        14     -0.0497      0.0802
RMSE of 2 points: mx=0.0624, my=0.0618

          The image ID = 31
   Point ID       VxVy
        18     -0.0051     -0.0170
RMSE of 1 points: mx=0.0051, my=0.0170

          The image ID = 30
   Point ID       VxVy
 There are no GCPs on this image.
          The image ID = 29
   Point ID       VxVy
        16      0.0008     -0.0056
RMSE of 1 points: mx=0.0008, my=0.0056

          The image ID = 28
   Point ID       VxVy
        16      0.0039     -0.0172
RMSE of 1 points: mx=0.0039, my=0.0172

          The image ID = 27
   Point ID       VxVy
        16     -0.0102     -0.0068
RMSE of 1 points: mx=0.0102, my=0.0068

          The image ID = 26
   Point ID       VxVy
 There are no GCPs on this image.
          The image ID = 25
   Point ID       VxVy
```

```
        14      0.0044      0.0170
RMSE of 1 points: mx=0.0044, my=0.0170

         The image ID = 33
   Point ID       VxVy
        14      0.0285     -0.0242
RMSE of 1 points: mx=0.0285, my=0.0242
```

APPENDIX (C)

TriangulationAnalytical Report with LPS System for Rural of Khartoum State Project

```
The output image x, y units:     millimeters
The output angle unit:    degrees
The output ground X, Y, Z units: meters
```

The Input Image Coordinates

image ID = 1

Point ID	x	y
1	-7.5047	-44.7305
2	10.8707	22.2770
4	27.3303	-23.5363
5	27.3873	20.4427
8	31.3614	-27.3297
9	31.4286	0.9623
19	11.7360	29.5725
21	25.9160	20.8288

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 2

Point ID	x	y
2	-12.5292	22.2700
4	3.8606	-23.4585
5	3.9414	20.4544
6	24.3954	38.2420
8	7.8862	-27.2400
9	7.9524	0.9948
10	7.9260	1.0795
11	33.6633	15.7547
12	30.7116	13.0625
18	31.0579	23.1342
21	2.4726	20.8342

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 3

Point ID	x	y
4	-19.5941	-23.4762
5	-19.6065	20.3784
6	0.7331	38.2002
7	32.8072	39.1492
9	-15.5559	0.9584
10	-15.5945	1.0358
11	9.9190	15.7636
12	6.9724	13.0678
18	7.2475	23.1222
21	-21.0849	20.7565

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 4

Point ID	x	y
3	23.1199	-43.7579
6	-22.8617	38.1357
7	9.2050	39.2094
11	-13.6950	15.7437
18	-16.4975	23.0803
20	10.9070	37.0057

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 5

Point ID	x	y
6	24.0472	32.0598
7	-8.2359	31.1954
13	27.6580	-45.9565
14	26.1128	-36.1266
18	17.7527	47.8375
20	-9.9097	34.1000

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 6

Point ID	x	y
5	20.9003	49.7819
6	0.3944	32.0082
7	-31.7848	31.1107
13	3.9520	-45.8535
14	2.3030	-36.0110
15	-7.1318	-39.2463
16	30.7207	-32.2947
18	-6.0739	47.7166
21	22.3741	49.4020

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 7

Point ID	x	y
2	13.3975	48.1233
5	-3.1261	49.8012
6	-23.4104	31.8826
13	-19.2161	-45.6556
15	-30.3683	-39.1862
16	7.3759	-31.9010
17	-4.4520	-24.7670
18	-30.2121	47.4883
21	-1.6497	49.4265

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

image ID = 8

Point ID	x	y
2	-10.1820	48.0105
5	-26.6844	49.6631
16	-16.0997	-31.8815
17	-27.9210	-24.7394
19	-10.9740	40.7089
21	-25.2006	49.2893

Affine coefficients from file (pixels) to film (millimeters)

A0	A1	A2	B0	B1	B2
-33.7455	0.009000	-0.000000	51.7455	0.000000	-0.009000

THE OUTPUT OF SELF-CALIBRATING BUNDLE BLOCK ADJUSTMENT

the no. of iteration =1   the standard error = 0.2521
the maximal correction of the object points =2196.83266

```
the no. of iteration =2    the standard error =  0.0271
the maximal correction of the object points = 249.27373

the no. of iteration =3    the standard error =  0.0064
the maximal correction of the object points =  11.77096

the no. of iteration =4    the standard error =  0.0061
the maximal correction of the object points =   0.88322

the no. of iteration =5    the standard error =  0.0061
the maximal correction of the object points =   0.00533

the no. of iteration =6    the standard error =  0.0061
the maximal correction of the object points =   0.00002

                     The exterior orientation parameters           image
ID  XsYsZs       OMEGA      PHI      KAP  4        462972.2783
1710414.0965 -22.5990 -0.0460    0.1891   89.8874 3        462972.3271
1710686.4483 -23.3519  -0.0447   0.1322   90.1082 2        462970.8680
1710959.269  -23.1251  -0.1012   0.1606   90.2744 1        462963.9095
1711226.1655 -837.6591 -0.2672   0.3322   90.3045 5        463786.9372
1710403.4319 -22.6788   -0.0121  0.1826  -89.7052
6   463786.0606  1710676.3636 -23.6727    0.0194  0.1583  -89.7270
7   463786.6528  1710949.0353 -25.0506    0.0080  0.1901  -90.2615
8   463787.7672  1711222.4517 -25.7121    0.0360  0.1932  -90.3305

       The interior orientation parameters of photos
image ID     f(mm)        xo(mm)        yo(mm)
            4      35.0000       0.0000       0.0000
            3      35.0000       0.0000       0.0000
            2      35.0000       0.0000       0.0000
            1     105.2000       0.0000       0.0000
            5      35.0000       0.0000       0.0000
            6      35.0000       0.0000       0.0000
            7      35.0000       0.0000       0.0000
            8      35.0000       0.0000       0.0000

      The residuals of the control points
  Point ID      rXrYrZ
       1     -0.3693     -0.4968     -0.1181
       2     -0.2034     -0.3818     -0.5091
       3      0.2669     -0.2400      0.1746
       4      0.0825      0.4552     -0.1627
       5      0.8758      0.4107      0.5721
       6      0.9638      0.5434      0.7745
       7     -1.6164     -0.2907     -0.7313

aXaYaZ
              0.0000     -0.0000     -0.0000
mXmYmZ
              0.8075      0.4150      0.5060

              The coordinates of object points
  Point ID         X              Y              Z       Overlap
       1     462452.2307    1711316.0662      383.8949     1
       2     463230.3226    1711107.0002      382.9729     4
       3     462465.5569    1710147.2600      385.2466     1
```

4	462700.0855	1710913.8952	383.7373	3
5	463209.8978	1710915.3097	383.0331	6
6	463416.9738	1710679.0544	382.1615	6
7	463428.7146	1710306.5883	382.4087	4
8	462656.4618	1710867.0231	383.9302	2
9	462984.0463	1710867.6500	383.4070	3
19	463315.1547	1711097.3680	382.6933	2
21	463214.2783	1710932.4420	383.0403	6
10	462984.9702	1710868.0420	383.2811	2
11	463155.7631	1710572.3277	381.0415	3
12	463124.3744	1710606.4901	380.7489	2
18	463239.8801	1710603.8441	379.4878	6
20	463399.0025	1710288.1816	378.6709	2
13	464315.0991	1710724.2747	378.0484	3
14	464200.1982	1710704.6123	376.6661	2
15	464238.6968	1710596.3957	377.3866	2
16	464158.5692	1711032.8956	379.7724	3
17	464074.8911	1710896.0378	379.8967	2

The total object points = 21

The residuals of image points

Point	Image	VxVy	
1	1	-0.0001	0.0000

Point	Image	VxVy	
2	2	-0.0042	-0.0005
2	1	0.0002	-0.0012
2	7	0.0004	-0.0038
2	8	-0.0043	0.0020

Point	Image	VxVy	
3	4	-0.0000	-0.0000

Point	Image	VxVy	
4	3	0.0003	-0.0001
4	2	0.0004	-0.0005
4	1	-0.0006	0.0006

Point	Image	VxVy	
5	3	-0.0034	0.0023
5	2	0.0009	-0.0030
5	1	0.0031	0.0027
5	6	-0.0029	0.0040
5	7	-0.0025	0.0006
5	8	0.0060	-0.0024

Point	Image	VxVy	
6	4	-0.0018	-0.0015
6	3	0.0028	-0.0008
6	2	0.0038	-0.0027
6	5	0.0056	0.0023
6	6	0.0027	-0.0017
6	7	-0.0035	-0.0055

Point	Image	VxVy	
7	4	0.0042	0.0003

7	3	-0.0011	0.0021
7	5	-0.0027	-0.0009
7	6	0.0058	0.0031

Point	Image	VxVy	
8	2	-0.0025	0.0003
8	1	0.0025	-0.0003

Point	Image	VxVy	
9	3	-0.0004	-0.0019
9	2	0.0046	0.0040
9	1	-0.0042	-0.0021

Point	Image	VxVy	
19	1	0.0015	0.0002
19	8	0.0015	0.0002

Point	Image	VxVy	
21	3	0.0043	0.0020
21	2	-0.0029	-0.0013
21	1	-0.0025	0.0001
21	6	0.0012	-0.0034
21	7	-0.0008	0.0023
21	8	-0.0016	0.0019

Point	Image	VxVy	
10	3	-0.0000	0.0006
10	2	0.0000	-0.0006

Point	Image	VxVy	
11	4	-0.0035	-0.0047
11	3	0.0069	0.0002
11	2	-0.0034	0.0045

Point	Image	VxVy	
12	3	0.0000	-0.0019
12	2	-0.0000	0.0019

Point	Image	VxVy	
18	4	0.0057	0.0058
18	3	-0.0095	-0.0025
18	2	0.0034	-0.0021
18	5	0.0020	-0.0044
18	6	-0.0059	0.0013
18	7	0.0034	0.0044

Point	Image	VxVy	
20	4	-0.0046	0.0000
20	5	-0.0046	0.0001

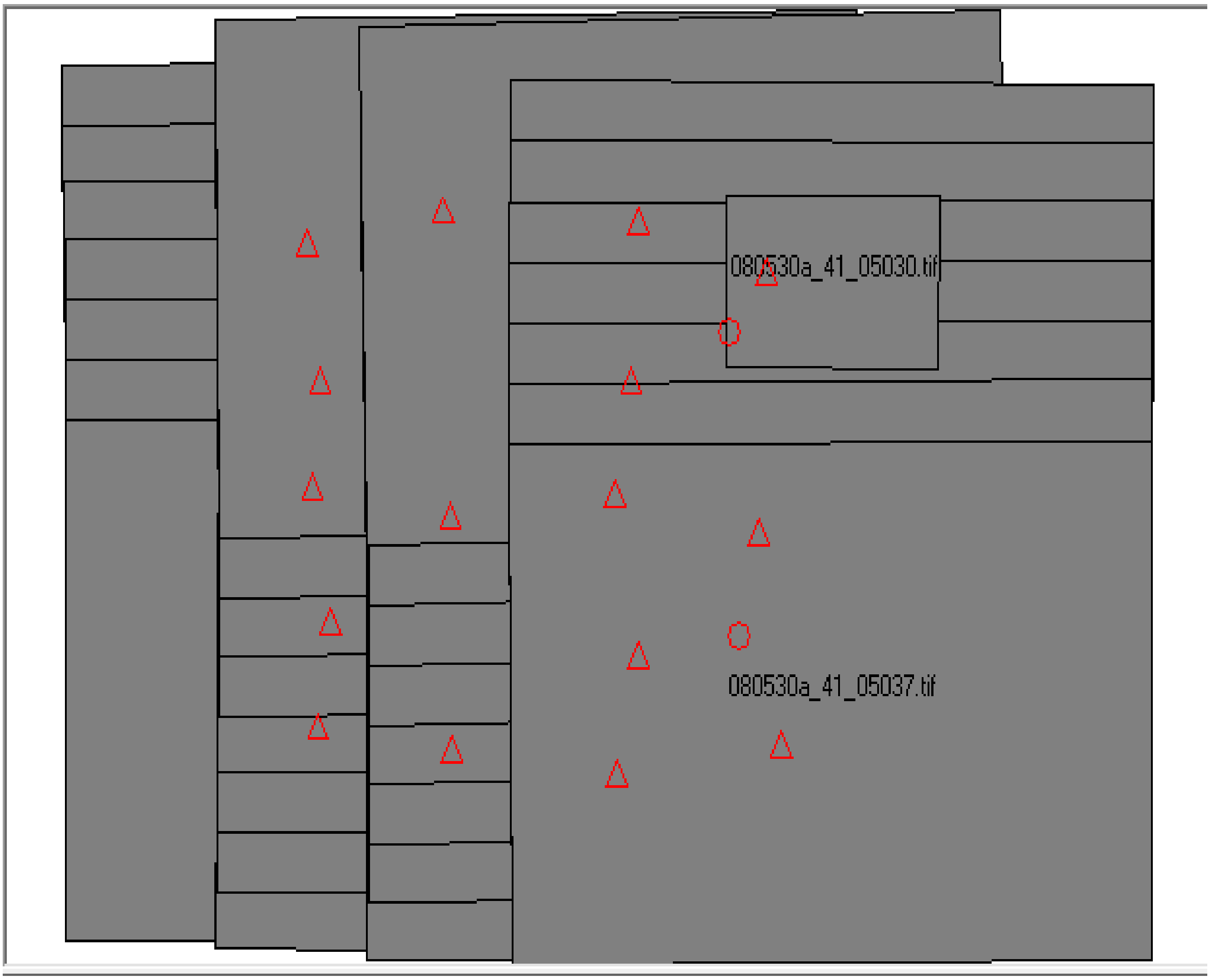
Point	Image	VxVy	
13	5	-0.0004	-0.0050
13	6	0.0008	0.0032
13	7	-0.0004	0.0018

Point	Image	VxVy	
14	5	0.0000	0.0080

```
  14       6     -0.0001     -0.0080

Point   Image        VxVy
  15       6      0.0000      0.0006
  15       7     -0.0000     -0.0006

Point   Image        VxVy
  16       6     -0.0016      0.0009
  16       7      0.0032     -0.0080
  16       8     -0.0016      0.0071

Point   Image        VxVy
  17       7      0.0000      0.0088
  17       8     -0.0000     -0.0088


The image residuals of the control points

            The image ID = 4
     Point ID       VxVy
           3     -0.0000     -0.0000
           6     -0.0018     -0.0015
           7      0.0042      0.0003
  RMSE of 3 points: mx=0.0026, my=0.0009

            The image ID = 3
     Point ID       VxVy
           4      0.0003     -0.0001
           5     -0.0034      0.0023
           6      0.0028     -0.0008
           7     -0.0011      0.0021
  RMSE of 4 points: mx=0.0023, my=0.0016

            The image ID = 2
     Point ID       VxVy
           2     -0.0042     -0.0005
           4      0.0004     -0.0005
           5      0.0009     -0.0030
           6      0.0038     -0.0027
  RMSE of 4 points: mx=0.0029, my=0.0020

            The image ID = 1
     Point ID       VxVy
           1     -0.0001      0.0000
           2      0.0002     -0.0012
           4     -0.0006      0.0006
           5      0.0031      0.0027
  RMSE of 4 points: mx=0.0016, my=0.0015

            The image ID = 5
     Point ID       VxVy
           6      0.0056      0.0023
           7     -0.0027     -0.0009
  RMSE of 2 points: mx=0.0044, my=0.0017

            The image ID = 6
     Point ID       VxVy
```

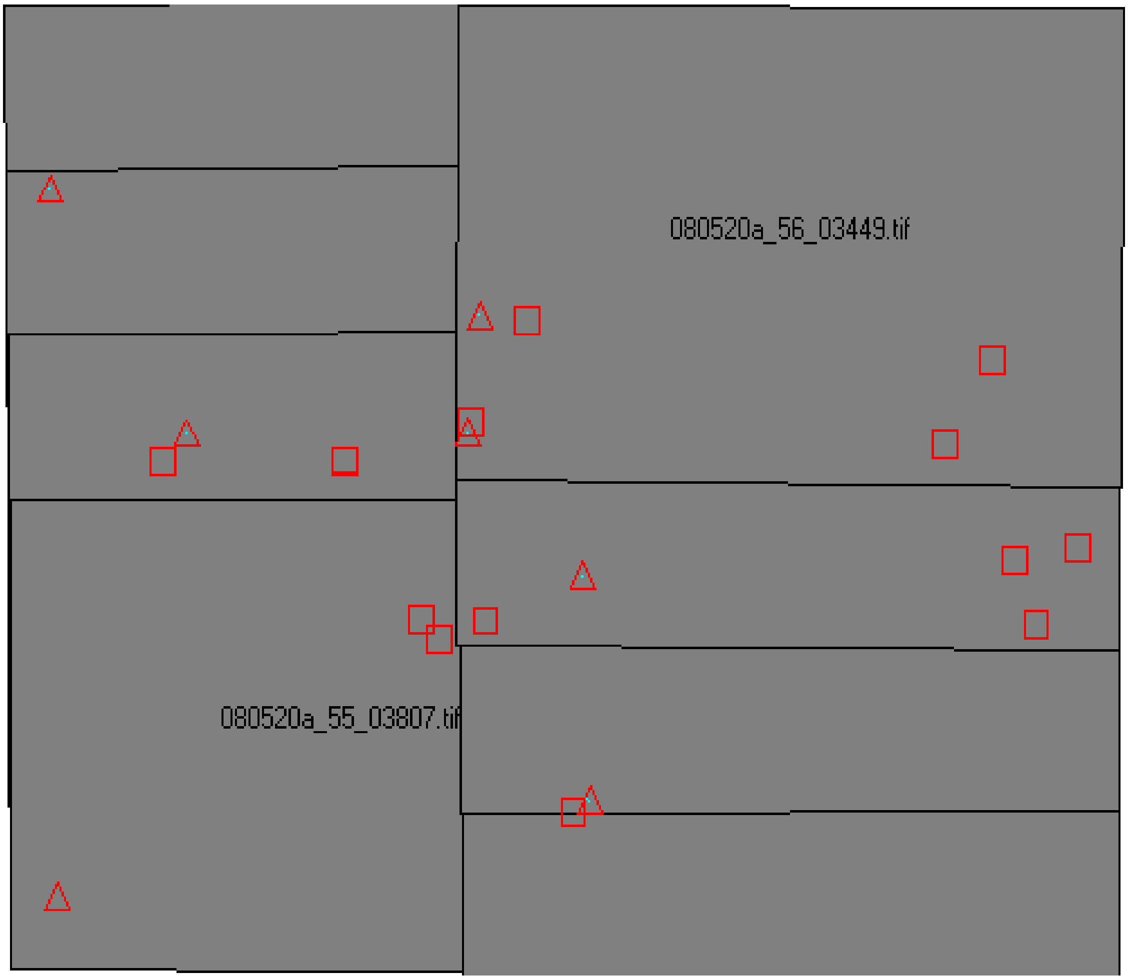
```
          5     -0.0029      0.0040
          6      0.0027     -0.0017
          7      0.0058      0.0031
RMSE of 3 points: mx=0.0041, my=0.0031

          The image ID = 7
   Point ID        VxVy
          2      0.0004     -0.0038
          5     -0.0025      0.0006
          6     -0.0035     -0.0055
RMSE of 3 points: mx=0.0025, my=0.0039

          The image ID = 8
   Point ID        VxVy
          2     -0.0043      0.0020
          5      0.0060     -0.0024
RMSE of 2 points: mx=0.0052, my=0.0022
```

Appendix (D)



Created aerial triangulation block for the central of the Khartoum state project

Appendix (E)



Created aerial triangulation block for the rural area of the Khartoum state project

PUBLICATIONS

1-Paper title: Etrex Garmin GPS Receiver Accuracy Testing

Title of Journal: International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169 Volume:3 Issue: 5 2772 – 2774. May2015.

Published Country: India

Authors: Mohammed Fator&NagiZomrawi

2-Paper title:Technical Evaluation of Khartoum StateMapping Project

Title of Journal: INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY SCIENCES AND ENGINEERING, VOL. 6, NO. 5, MAY 2015.

Published Country: Austria

Authors: NagiZomrawi&Mohammed Fator