ABSTRACT

The global positioning system (GPS) relative observations would provide a powerful and fast tool for obtaining an accurate relative three dimensional position of a point (X,Y and ellipsoidal height h).

The required orthometric height values for most of surveying and engineering applications are not directly provided by GPS observations.

Orthometric heights are normally derived using spirit leveling with standard observation and computation procedures .This requires the spirit level equipment to be setup from point to point along a leveling line which is a time consuming and a tedious task.

The conversion from ellipsoidal to orthometric heights requires a geoid height which can be obtained from a geoid model.

This research presents accurate, relatively simple, and reliable mathematical models for densification of orthometric hights (H) to densify the number of spot heights for contour maps and for the densification of geoidal heights in case of geoid contours when it is needed to draw the contour maps .Also can be used for densification of geoidal heights .

To check the reliability of the model a dense test network was designed. Both precise leveling and GPS observations were carried out and adjusted for common stations to establish precise vertical control networks and it gave a good result of analysis of variance , with standard error not more than 3 Cm.

المستخلص

الأرصاد النسبية لمنظومة تحديد الموقع العالمى (جى،بى،اس) تعطي آلية سريعة للحصول على الإحداثيات ثلاثية الأبعاد(X,Y,h) لنقطة فوق سطح الأرض منسوبة لسطح الإهليليج (إليبسويد) بدقة وسرعة .

قيم الارتفاعات الاورثومترية المطلوبة لأعمال المساحة ومعظم التطبيقات الهندسية لا تتوفر مباشرة من رصد منظومة تحديد الموقع العالمي.

الارتفاعات الاورثومترية عادة يتم إيجادها باستخدام أجهزة الميزان مع الرصد والحسابات بالطرق القياسية وهذا يتطلّب تحويل نصب جهاز الميزان من نقطة إلى أخرى تبعد عن بعضها بمسافات قصيرة ممّا يستهلك زمناً كثيراً و تكلفة أكبر ومشقة.

تحويل الارتفاعات المقروءة على سطح الإهليلج للارتفاعات الاورثوميترية يتطلّب معرفة سطح الجهد المتساوي (الجيويد) باستخدام النماذج الرياضية.

في هذا البحث تم إيجاد أنموذج رياضي دقيق، مطاوع، بسيط وموثوق لتكثيف الارتفاعات الاورثومترية (H)، لتكثيف نقاط الارتفاعات لرسم الخرائط الكنتورية وتكثيف نقاط الجيويد لرسم خرائط الجويد الكنتورية عندما تكون مطلوبة.

لاختبار وثوقية ودقة الأنموذج الرياضي تم تصميم شبكة ذات كثافة من النقاط، حيث تمت قراءتها بواسطة جهاز الميزان الدقيق وجهاز منظومة تحديد الموقع العالمي. تم تصحيح النقاط المشتركة لإنشاء شبكة نقاط ضبط رأسية دقيقة. عند المقارنة كانت النتائج جيدة بحيث لا يتعدّى الخطأ المعياري (أو الإنحراف المعياري) مقدار3 سم.

ACKNOWLEDGMENTS

First, and for most I am indebted to my supervisor Dr. Ali Hassan Fagir. I would like to thank him for his excellent supervision, assistance, patience, constant encouragement and for reading this thesis.

My thanks are extended to Dr. Alhadi A. Ibrahim the head of the Surveying Department, for reading the thesis and making numerous useful suggestions.

I would like to express my thanks to Dr. Mohammed A. Khalid and Dr. Ahmed M. Ibrahim for their help and advice.

I thank Al Nazir A. Hussien for sharing his programming knowledge, and for many useful discussions.

All the staff of the surveying department,for their assistance.

The late engineer Almahi A Omer, Almumaiz Company and Kenana Engineering & Technical Services Limited (KETS) for preparing the study area.

LIST OF CONTENTS

Description	Page no.
Abstract	………………………………………………..……i
المستخلص	…………………………………………….…….ii
Acknowledgements	…………………………………...iii
List of contents	…………………………………...iv
List of tables	...…………………………….....viii
List of figures	…………………………………..ix
List of abbreviations	…..……………………………..xiii

CHAPTER ONE: INTRODUCTION

1.1 Background	……………………………………….1
1.2 Objectives	………………………………..…….2
1.3 Thesis lay out	……………………………………..3

CHAPTER TWO: REFERENCE ELLIPSOIDS AND VERTICAL DATUMS

2.1 Background	………………………….……….4
2.1.1 Spherical earth	……………………………………....4
2.1.2 Ellipsoidal earth	…………………………......5
2.1.3 Geoidal Earth	………………….……....5
2.1.4 The World Geoidetic System	………………..…...…..6
2.2 Reference Ellipsoids	……………….…………....6
2.3 Local Reference Ellipsoids	……….……………..………6

2.4 Equipotential Ellipsoids …………………..8
2.5 Equipotential Ellipsoids as Vertical Datums ……...…………10
2.6 The World Geodetic System 1984(WGS 84) …..…………....10
2.6.1 Adindan Sudan local Datum 11
2.7 Mean Sea Level …..………..…. .11
2.7.1 Sudan Mean Sea Level (M.S.L) Height ………………..…13
2.7.1.1 Irrigation Datum ………………..……..14
2.7.1.2 Sudan Survey Authority Datum ………………….. 14
2.8 Tidal Datums ………..…………14
2.8.1 Principal Tidal Datums …………..……….14
2.8.2 Other Tidal Datums ……..…………….16

CHAPTER THREE: DIGITAL TERRAIN MODELING

3.1 Introduction …………………………………………….17
3.2 Sources of data …..……………………………………….17
3.2.1 Ground survey methods ……..……………………….17
3.2.2 Photogrammetric methods ……………….………………17
3.2.3 Graphics digitizing methods ……...…………….………….17
3.3 Measurement patterns ...…………………………….……..18
3.3.1 Systematic sampling …………………………………..18
3.3.2 Progressive sampling …………………………………..18
3.3.3 Random sampling …....……………………………..……19
3.3.4 Composite sampling ..……………..……………….………19

3.3.5 Measured contours ..…………………….……….…..20

3.4 Modelling techniques ……………………….……….20

3.4.1 Grid-based terrain modelling …...20

3.4.1.1 Point wise methods ..…………….………………..21

3.4.1.2 Global methods ....……………………………22

3.4.1.3 Patch wise methods ..…..…………………….….22

3.4.1.4 Polynomials used for surface representation ………….…..24

3.4.1.5 Contouring from grid data ……………....…………….27

3.4.2 Triangle-based terrain modelling ……………………….…...28

3.4.2.1 Contouring from triangulated data …………..…………29

CHAPTER FOUR: LEAST SQUARES COLLOCATION

4.1: Introduction ……..……………………….…………....….31

4.2 Covariance matrices …..31

4.3 Least squares prediction ……….……..………….………34

4.4 Collocation Mathematical Model ……….………….….……..37

4.4.1 The Signal ………………………..…………….….…….38

4.4.2 The Noise ………………………………….…..………….39

4.4.3 Solution of the Parameters ………………….…..…………43

4.4.4 Special cases ……………………………………………….47

CHAPTER FIVE: THE MODELING PROGRAM

5.1 Study area ……………………………………..…….50

5.2 Data collection for control work ……………………………..51

5.3 Instruments used and methodology ……………………….……..51

5.4 The programming language ………………………..…53

5.4.1 Back ground ……………………………………………....54

5.4.2 Design goals ……………………………………...…56

5.5 About the Program ……………………………………........57

CHAPTER SIX: THE PROGRAM TEST AND RESULTS

6.1 Introduction ...……………………………….…………..71
6.2 Computation and Methodology …...……………….……… .72
6.3 Mapping methodology ………………….……….…… 72
6.4 Map Datum ………………………………..…………. ...72
6.5 Adjustment report for GPS observations and leveling ……… ….73

6.5.1 Quality Assurance and Quality Control (QA/QC) of data and
result achievements ……………..………73

6.5.1.1 Quality Assurance ……………………………73

6.5.1.2 Quality control ……………………………..73

6.6 Least Squares surface fitting ………………………..…...73
6.7 Data points configuration ………………….…..….…..75
6.8 The mathematical modeling program surface fitting ……..……..…79

6.9 Result comparison …………………………………….. …. 82

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions …………………………………….….…... 83

7.2 Recommendations ………………………………….... 84

REFERENCES ……………………………..……….85

APPENDICES ………………………………….....90

APPENDIX A The program Code ……………………………….90

APPENDIX B Analysis of variance …………………………..…..154

LIST OF TABLES

Table 3.1-Polynomial equation used for surface representation ……..….26

Table 5.1-Study area coordinates ……………………………………...50

Table 6.1-Map Datum ………………………………………………..…72

Table 6.2-Gridded observed heights ….…………………..……74

Table 6.3-Application of Polynomials in different area …………..…78

Table 6.4-Comparison of residual according to number of data points 80

Table 6.5-Comparison of residuals between polynomial and mathematical model ……………………………………………………….…..81

LIST OF FIGURES

Figure 2.1: The design of a NOAA tide house and tide gauge used for measuring mean sea level. Source ……………….……..…13

Figure 3.1 Regular grid patterns …..…………………….………18-19

Figure 3.2 Progressive sampling ……………………………….……....19

Figure 3.3 Overall relationships between measured point data, networks and contours in terrain modeling……………………..………...21

Figure 3.4 Sequential steepest slope algorithm showing cross-sections *HH*,*VV*,*UU* and *GG*. And the intersection points in the contours 23

Figure 3.5 Global Interpolation ……………………………………....24

Figure (3.6a) Patch wise Interpolation (Exact Fit Patches) ...…….…25

Figure (3.6b) Patch wise Interpolation(overlapping patches) ..……..…25

Figure (3.7) Surface shapes produced by individual terms in the general polynomial equation …………..……………………….………27

Figure 3.8 Grid contouring: linear contour interpolation in a single cell ….28

Figure 3.9 Grid contouring: ambiguity in contour threading in a single cell ………………………………………………………………..29

Figure 4.1 points with known heights …………………………………...32

Figure 4.2 points for prediction of the unknown height ……….…….. 33

Figure 4.3: concept of collocation …...……………………38

Figure 5.1(Study area location By Google) ……………………..50

Figure 5.2 (Study area Location - Map of Sudan) …………...…51

Figure 5.3(Loops Diagram) ……………….…………..52

Figure 5.4 Program main menu screen ……………………….…...53

Figure 5.5 The main menu and file pull-down menu ……...….54

Figure 5.6 Drive and Geoid –Ellipsoid File selection ..…….. ...55

Figure 5.7 Open Geoids – Ellipsoid data file …..………..……57

Figure 5.8 Select matrices operations form ...………………….58

Figure 5.9 Matrices pull-down menu screen ………..……….59

Figure 5.10 Least Squares pull- down menu ………… …….....61

Figure 5.11 Blank Ordinary Least Squares Entry form ……….. ...…61

Figure 5.12 Blank Weighted Least Squares Entry form …..……....62

Figure 5.13 Blank Geoidal Separation Entry form ...………..…62

Figure 5.14 Blank Densification of Orthometric Heights Entry form …..63

Figure 5.15 Completed Geoidal Separation Entry form before pressing

OK …………………………………………………….…...63

Figure 5.16 Geoidal Separation Result after pressing OK ……..…64

Figure 5.17 Geoidal Separation Prediction Form ……...………64

Figure 5.18 Predicted Geoidal Separation …………………..……..65

Figure 5.19 ANOVA Table (Geoidal Separation ……….……...65

Figure 5.20 The Linear Correlation (Geoidal Separation) ……..…66

Figure 5.21 Graph for Minimum And Maximum (Geoidal Separation)…..66

Figure 5.22 Drive and Densification of Orthometric Heights File selection ……………………………………………………………….…...67

Figure 5.23 Densification of Orthometric Heights Open Data File ……….67

Figure 5.24 Completed Densification of Orthometric Heights Entry form before pressing OK ……………………………………..…68

Figure 5.25 Densification of Orthometric Heights Results after pressing OK ………………………………………………….………....68

Figure 5.26Predicted Orthometric Heights ……….……………..…69

Figure 5.27 ANOVA Table (Orthometric Heights) ………….……….……69

Figure 5.28 The Linear correlation coefficients (Orthometric Heights) …..70

Figure 5.29 Graph for Minimum And Maximum (Orthometric Heights) ...70

Fig 6.1 Master ……………………………….……..……….75

Fig 6.2a-1X1 4pts …………………………………….…….….…75

Fig 6.2b- 1X1 5pts …………………………………….….….…75

Fig 6.2c- 1X1 6pts1 …………………………………….……..….…75

Fig 6.2d- 1X1 6pts2 …………………………………….……….…..…75

Fig 6.3a 1X2 4pts ……………………………….………….….….…75

Fig 6.3b 1X2 5pts …………………………………….……..….…75

Fig 6.3c 1X2 6pts1 …………………………………….………...…75

Fig 6.4a 2X1 4pts …………………………………….………...…76

Fig 6.4b 2X1 5pts …………………………………….…….….….…76

Fig 6.4c 2X1 6pts2 ………………………….…….……………76

Fig 6.5a 2X2 4pts ………………………………….…..……….76

Fig 6.5b 2X2 5pts ………………………………………….……..76

Fig 6.5c 2X2 6pts1 …………………………………………….….76

Fig 6.5d 2X2 6pts2 ……………………………..…………..…76

Fig 6.6a 2X4 4pts …………………………………………….….76

Fig 6.6b 2X4 5pts …………………………….…………….76

Fig 6.6c 2X4 6pts1 ……………………………..…………….76

Fig 6.6d 2X4 6pts2 …………………………….….…………….77

Fig 6.7a 4X2 4pts ……………………………..…………….77

Fig 6.7b 4X2 5pts ……………………………...…………….77

Fig 6.7c 4X2 6pts1 ………………………………….….…………….77

Fig 6.7d 4X2 6pts2 ……………………………….….…………….77

Fig 6.8 a 4X4 4pts ………………………………….…………..77

Fig 6.8b 4X4 5pts ………………………………………..….…….77

Fig 6.8c 4X4 6pts1 …………………………………….………..…77

Fig 6.8d 4X4 6ptsS2 ……………………………….…...………77

Fig .6.9 Enter the dependent by shading the height column ……..…79

LIST OF ABBREVIATIONS

ADO	Active Data Objects
ANOVA	Analyses Of Variance
ASP.NET	Active Server Pages
C#	See Sharp
CLR	Common Language Runtime
COOL	C-like Object Oriented Language
CO-OPS	Center for Operational Oceanographic Products and Services
DEM	Digital Elevation Model
d.f.	Degree of freedom
DGM	Digital Ground Model
DHM	Digital Height Model
DHQ	Diurnal High Water Inequality
DTEM	Digital Terrain Elevation Model
DLQ	Diurnal Low Water Inequality
DMA	Defense Mapping Agency
DTL	Diurnal Tide Level
DTM	Digital Terrain model
EGM 2008	Earth Gravitational Model 2008
GDR	Great Diurnal Range
GIS	Geographical Information System
GPS	Global Positioning System
GRS 80	Geodetic Reference System 1980
HZ	Horizontal
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
LINQ	Language Integrated Query
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MR	Mean Range
MSL	Mean Sea Level
MTL	Mean Tide Level
NAD 27	North American Datum of 1927
NAD 83	North American Datum of 1983
NGA	National Geospatial-Intelligence Agency

NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NSA	National Surveying Authority
NTDE	National Tidal Datum Epoch
Pts	points
QA/QC	Quality Assurance and Quality Control
RMS	Root Mean Square
RTK	Real Time Kinematic
SMC	Simple Managed C
SSA	Sudan Survey Authority
TBC	Trimble Business Center
USA	United States of America
UTM	Universal Transverse Mercator
V	Vertical
VLBI	Very Long Baseline Interferometry
WCF	Windows Communication Foundation
WGS 84	World Geodetic System 1984