Sudan University of Science and Technology

College of Engineering

School of Electrical and Nuclear Engineering

Automated Warehouse Management System (Case Study)

نظام إدارة المخزن الأوتوماتيكي (دراسة حالة)

A Project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering (Control)

Prepared by:

1. Abdalla Abdulhakeem Abdalla
2. Amna Galaleldin Abdelrahim Mohamed
3. Mohamed Abdalwhab Mohamed Ibrahim
4. Ola Azmi Alladeen Yousif

Supervised By:

Dr. Awadalla Taifour Ali

November 2020

الآية

بسم الله الرحمن الرحيم

قال تعالى:

أَفَرَأَيْتَ الَّذِي تَوَلَّىٰ ﴿٣٣﴾ وَأَعْطَىٰ قَلِيلًا وَأَكْدَىٰ ﴿٣٤﴾ أَعِندَهُ عِلْمُ الْغَيْبِ
فَهُوَ يَرَىٰ ﴿٣٥﴾ أَمْ لَمْ يُنَبَّأْ بِمَا فِي صُحُفِ مُوسَىٰ ﴿٣٦﴾ وَإِبْرَاهِيمَ الَّذِي
وَفَّىٰ ﴿٣٧﴾ أَلَّا تَزِرُ وَازِرَةٌ وِزْرَ أُخْرَىٰ ﴿٣٨﴾ وَأَن لَّيْسَ لِلْإِنسَانِ إِلَّا مَا
سَعَىٰ ﴿٣٩﴾ وَأَنَّ سَعْيَهُ سَوْفَ يُرَىٰ ﴿٤٠﴾ ثُمَّ يُجْزَاهُ الْجَزَاءَ
الْأَوْفَىٰ ﴿٤١﴾ وَأَنَّ إِلَىٰ رَبِّكَ الْمُنتَهَىٰ ﴿٤٢﴾ وَأَنَّهُ هُوَ أَضْحَكَ
وَأَبْكَىٰ ﴿٤٣﴾ وَأَنَّهُ هُوَ أَمَاتَ وَأَحْيَا ﴿٤٤﴾

[سورة النجم: الآيات 33-44]

DEDICATIONS

To the souls of the martyrs of the protests, to the missing ones, to the burned ones, to the drowned ones and to the wounded ones. To the white army who stood in the face of this pandemic on the first lines of defense. To our families and friends for their love and support.

ACKNOWLEDGEMENT

We are eternally grateful and thankful to **Dr. Awadalla Taifour Ali**, for being our supervisor and for guiding, encouraging and motivating us in this project through all these circumstances starting from the demonstration that occurred in the country and through this pandemic, to completing this project successfully.

ABSTRACT

The industrial and production sectors in Sudan generally suffer from the lack of modern technologies that support the production process and its development. Automated storage and retrieval systems (ASRS) are one of these technologies that increase the rate of production and accuracy in storage and contribute in reducing time, cost and manual labor. Some areas need to be carefully handled with materials and products, such as medical and chemical fields so the automated storage and recovery system is an excellent alternative to manual labor to reduce the risk of dealing with these substances.

This study discusses the design and simulation of an automated storage and retrieval system (ASRS) controlled by entering the coordinates of the designated shelf to store the particular product. The automated storage and retrieval system consists of a precise control to control the movement of the three stepper motors which responsible from moving the model according to the coordinates entered into it using universal g-code sender platform which connected with Proteus through visual serial port emulator. The steps number, speed and acceleration of the motor can be controlled using universal g-code sender platform allowing for a wide range of choice selections for the system to be controlled.

In this study, the automated storage and retrieval system increase the storing process by 20%, while the retrieving process is increased by 10.1%. The design implemented in this study reduces the total cost of storage and retrieval by at least 60%, time by nearly 16.55%, space by 20% and reduce labor to 80%.

مستخلص

تعاني قطاعات الصناعة والإنتاج في السودان بصورة عامة من الإفتقار للتقنيات الحديثة التي تدعم عملية الإنتاج وتطورها. تعتبر أنظمة التخزين و الإسترجاع الآلي أحد هذه التقنيات التي تزيد معدل الإنتاج والدقة في التخزين وتساهم في تقليل الوقت والتكلفة والعمالة اليدوية. بعض المجالات تحتاج إلى التعامل الدقيق مع المواد والمنتجات مثل المجالات الطبية والكيميائية، بالتالي يكون نظام التخزين والإسترجاع الآلي بديل ممتاز للعمالة اليدوية لتقليل الخطورة من التعامل مع هذه المواد.

تناقش هذه الدراسة تصميم ومحاكاة نظام تخزين وإسترجاع آلي يتم التحكم به عن طريق إدخال إحداثيات الرف المعين لتخزين المنتج المعين. يتكون نظام التخزين والإسترجاع الآلي من متحكم دقيق للتحكم بحركة الموتورات الخطوية الثلاثة المسؤولة من تحريك النموذج حسب الإحداثيات المدخلة إليه بإستخدام منصة (UGS) والتي يتم ربطها مع برنامج (PROTEUS) عن طريق برنامج (VSP). يمكن التحكم في عدد خطوات الموتور الخطوي وسرعته وعجلته باستخدام منصة (UGS) مما يسمح بمدى واسع من الإختيار للنظام الذي سيتم التحكم فيه.

في هذه الدراسة، نظام التخزين والإسترجاع الآلي سيزيد من كفاءة عملية التخزين بنسبة 20%، وعملية الإسترجاع بنسبة 10.1%، ايضاً سيقلل تكلفة التخزين والإسترجاع الكلية بنسبة 60% على الأقل، والزمن بنسبة 16.55% ، تقليل استخدام المساحة بنسبة 20% وتقليل العمالة الى 80%.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

AGVs	Automated Guided Vehicles
WMS	Warehouse Management System
RFID	Radio Frequency Identification
ABS	Anti-lock braking system
I/O	Input Output
CPU	Central Processing Unit
DMA	direct memory access
PWM	Pulse Width Modulation
PC	Personal Computer
SPI	Serial Peripheral Interface
SCI	Serial Communication Interface
IIC	Inter-IC bus
CAN	Controller Area Network
PCI	Parallel Card Interface
USB	Universal Serial Bus
UART	Universal Asynchronous Receiver Transmitter
TXD	Transmit Data
RXD	Receive Data
MOSI	Master Out, Slave In
MISO	Master In, Slave Out
SCK	System Clock
SS	Slave Select
SCL	Serial Clock Line
SDA	Serial Data Line
DC	Direct Current
AC	Alternative Current
3D	Three Dimensions
ASRS	Automated Storage And Retrieval System
DOF	Degree Of Freedom
FIFO	First In First Out
UGS	Universal G-code Sender

LIST OF SYMBOLS

W	Aisle width, mm
x	Depth of a load unit, mm
Y	Length of a load unit, mm
z	Height of a load unit, mm
L	Aisle length, mm
H	Aisle height, mm
a, b, c	Respective tolerances for the rack compartment, mm
n_y	Number of rack compartments along its length
n_z	Number of rack compartments along its height
Ck	Total storage capacity of a single aisle
Tcs	Duration of a single cycle, min per cycle
L_r	Length of a rack, mm
H_r	Height of a rack, mm
v_y	Horizontal velocity of a stacker crane, m/s
v_z	Vertical velocity of a stacker crane, m/s
T_{pd}	Load acceptance or collection time, sec
W	Total weight of the shelf and load, N
m	Total mass of the shelf and load. Kg
F	Force acting on the pelt, N
U	Friction of sliding surface, N
T	Torque around the movable axis, N.m
D	Final pulley diameter, mm

CHAPTER ONE
INTRODUCTION

1.1 Introduction

In today's world storage is becoming a big problem, and finding a suitable area to store at is becoming a challenge. When time and cost are important factors for human life, engineers are looking for solutions. One of these solutions is automated warehouses, it helps to store a lot of goods in small area, reducing the space used and eliminate time and effort. Automated storage/retrieval systems (AS/RSs) are widely used in industry. They are product-to-picker storage systems that consists of one or multiple parallel aisles with two high bay pallet racks alongside each aisle. A storage/retrieval (S/R) machine or automated stacker crane travels within the aisle and performs storages and retrievals. It has three independent drives for horizontal, vertical and fork movement.

1.2 Problem Statement

High Labor Costs, picking time, inventory accuracy and space utilization are big challenges in warehouse management. The problem is to design and simulate a system with an acceptable price and a high quality of working that can improve the process in warehouses.

1.3 Objectives

The main aim of this study is to:

- Design and simulation of Automated Storage and Retrieval System with microcontroller integration.
- Reduce labor cost and time for transporting items into and out of an inventory.
- Provide more accurate tracking of inventory, and space savings.

1.4 Methodology

The study involves heavy reviewing of previously published scientific papers addressing this type of solutions. A microcontroller was used to build a control program. Jog controllers was used to enter the input, integrated with the universal G-code sender platform which sends signals to the microcontroller in order to control position of the stepper motors to the selected rack location.

1.5 Project Layout

The project layout of this thesis is shown below:

- Chapter two consists the historical background of automated storage and retrieval systems and all components and concepts that are used.
- Chapter three clarifies the methodology used to implement the study until the end.
- Chapter four provides a walkthrough of the control system of the main actuators used, simulation of the circuit, controller that have been selected and the simulation results and discussions.
- Chapter five summarizes and discusses the conclusion and the recommendations to improve the project in the future.

CHAPTER TWO
THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

The supply chain activity has changed during the last decades because companies understood the importance of competitive advantage. The change to a more global environment, the need of a higher speed, higher productivity and lower process costs, motivated companies to implement more and more technical solutions for automation, especially in their warehouses [1].

In recent years, the logistics industry known as "the third source of profits" has been concerned widely and has been booming. Warehouse business, an important link in the logistics business, its operational efficiency determines directly the level of the overall operation efficiency of the logistics business [2]. The improved inventory management, space efficiency, reduced labor costs and reduced costs of loss by theft and misplacing are some of the advantages of automated storage and retrieval system through which the efficiency of material handling and inventory control can be enhanced [3].

2.2 Processes within Warehouse

Warehousing operation refers to a series of activities which takes the storage and the safekeeping of goods as the center. It is the whole process starting from the warehouse receiving goods to distributing the goods to customer on demand. It is composed by three major activities: the goods entering, the goods storage and goods distributing [2]. The processes within the warehouse can be divided into main processes and supportive processes, the main processes include the main functionalities of a warehouse, this include inbound storage and outbound process of a warehouse. The ‘supportive’ processes provide the functionalities of the main processes, which cover the areas of the movement and tracking of goods [1].

2.2.1 Main warehouse processes

The operation of the warehouse start with the receiving process, this process contains a few sub-processes, like the inspection of incoming goods, the repacking and the labeling. The Second process is the storage process, the storage area may consist of two parts: the reserve area, where products are stored in the most economical way (bulk storage area) and the forward area where products are stored for easy retrieval by an order picker [4]. The third process has the purpose to fulfil customer orders and is called outbound process. There are three main sub-processes within the outbound process of a warehouse, the order picking, the packing and the shipment.

There are a few different ways of picking an order, which depend on the industry in which the warehouse is used. For instance, the method of single-order picking can be used, which idea is to pick all items for a single order at the same time. Another method is the batch picking, where multiple orders are picked at the same time. A third method is the zone picking, where all items of a certain warehouse zone are collected at the same time. After the items are picked, they have to be packed, which includes the putting of items in a box together with packing material to prevent damages. Before the shipment can start, labels must be put on the boxes to ensure that the right customer gets the right box [1].

2.2.2 Supportive warehouse processes

The presented warehouse processes are dependent on supportive processes within the warehouse, like the movement or the tracking of good. The movement of goods includes the horizontal and vertical movement. The horizontal movement is mainly used for the transportation of goods from one zone of a warehouse to another zone. The vertical movement is mostly used to lift and pick goods in or from the storage area [1].

The need of tracking goods is throughout the whole warehouse, to ensure the availability of the product and to be able to locate this product constantly. Without tracking goods through the whole warehouse, it is not possible to control and therefore to manage the inventory during its journey in the warehouse [1].

2.3 Automation

Automation is the use of logical programming commands and mechanized equipment to replace the decision making and manual command-response activities of human beings. It is believed that the term automation was first coined in the 1940s by a Ford Motor Company engineer describing various systems where automatic actions and controls were substituted for human effort and intelligence. At this time, control devices were electromechanical in nature. Logic was performed by means of relays and timers interlocked with human feedback at decision points. By wiring relays, timers, push buttons, and mechanical position sensors together, simple logical motion sequences could be performed by turning on and off motors and actuators.

Here are some of the pros and cons of automation:

Pros

• Human operators performing tasks that involve hard physical or monotonous work can be replaced.

• Human operators performing tasks in dangerous environments, such as those with temperature extremes or radioactive and toxic atmospheres, can be replaced.

• Production is often faster and labor costs less on a per product basis than the equivalent manual operations.

• Automation systems can easily incorporate quality checks and verifications to reduce the number of out-of-tolerance parts being produced while allowing for statistical process control that will allow for a more consistent and uniform product.

• Automation can serve as the catalyst for improvement in the economies of enterprises or society. For example, the gross national income and standard of living in Germany and Japan improved drastically in the 20th century, due in large part to embracing automation for the production of weapons, automobiles, textiles, and other goods for export.

• Automation systems do not call in sick.

Cons

• The research and development cost of automating a process is difficult to predict accurately beforehand

• Initial costs are relatively high.

• Current technology is unable to automate all desired tasks.

• A skilled maintenance department is often required to service and maintain the automation system in proper working order.

2.4 Automation via Good's Movement

2.4.1 Automated Guided Vehicles

One of the technical solutions for the movement of goods within the warehouse is the automated guided vehicles. AGVs can be used for automatizing movement of goods among different locations within an industrial environment each movement is often referred to a mission, which are controlled by a warehouse management system (WMS). The system assigns each specific AGV with missions that it completes on its own. The main functionality of an AGV is the horizontal movement of goods, they use a lifting mechanism to minimally lift the whole inventory pod and bring it to the picker. The picker then removes or refills the desired item from or of the bin, and then the AGV brings the whole inventory pod back to the warehouse. Figure 2.1 below shows the AGVs [1].

Figure 2.1: Automated guided vehicles

2.4.2 Automated conveyor systems

Automated conveyor system enable faster transports of goods in warehouses, it usually consists of a lane, accumulation conveyor, recirculation conveyor, and exit lanes. Once an order is set the goods get released from its storage position onto the lane at the right times. The goods then travel inside the warehouse in the lane towards a sorting zone as other goods join it on the lane. The sortation then sorts out the goods according to the orders. When orders are sorted, they are removed from the sorting lanes to get checked, packed and delivered [1]. Figure 2.2 below show this type of solution.

Figure 2.2: Conveyer system

2.4.3 Automated forklifts

Another solution for automating the movement of goods in warehouses is automated forklifts. The purpose of this innovation is both for the horizontal (e.g. the movement to different loading zones) and vertical movement (e.g. for collection and storage) of goods.

Figure 2.3: Forklift

2.5 Automation via Good's tracking

2.5.1 Barcodes

Barcode was first used back in the late 1970s and early 1980s. And yet, it is still today the most widely used in designating and identifying products throughout the world. The recent years have seen a new trend of applying mobile readers to these graphic designations. These readers are connected to wireless networks via standard information systems in support of business operations. As an older and simpler technology of designating products by means of a linear code printed on a label or packaging, it facilitates manipulation with a great number of products and their packing. By means of a mobile laser reader the linear code is converted into a range of numbers that serve as a key to interconnection with the database in the central information system for management and identification of products [5].

Bar code is a common international language by which goods may circulate in international markets. It is also the international unified code of the commodity status. The most common theme of technique is bar code technique in the warehouse [2]. There are many sorts of barcodes, we should choice different barcodes in different situation, for example, according to international standards, retail goods should choice such barcode as the EAN-13, EAN-8 or UPCA, UPC-E (Using in USA and Canada), and non-retail goods in the warehouse should select such barcode as EAN-13, UPC-A, ITF-14 or EAN-128.He have mentioned that ,bar code technology can improve the efficiency of logistics operations, reduce management costs; secondly, it can reduce the error rate of data collection and improve the quality of work. Figure 2.4 below shows the process of using barcode in warehouse.

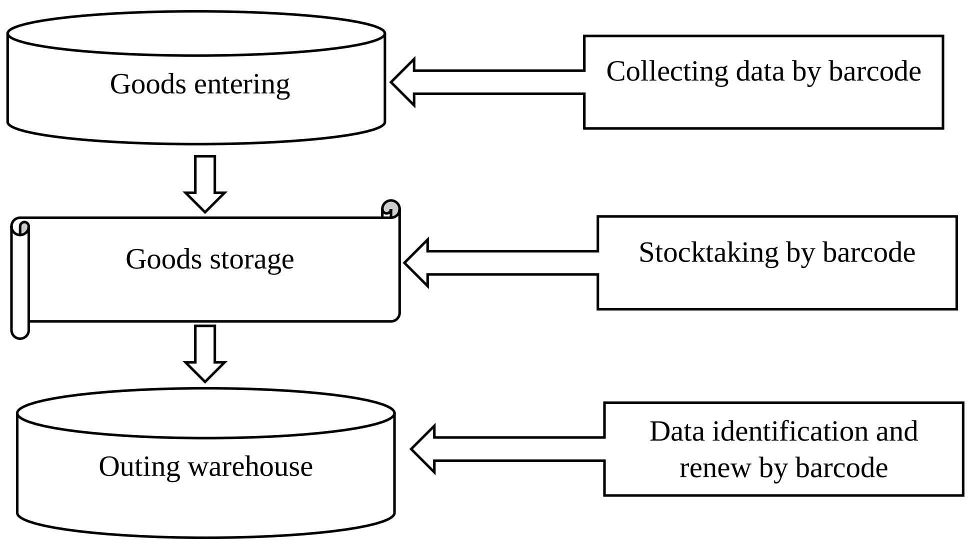


Figure 2.4: The process of using Bar code in warehouse

2.5.2 RFID systems

RFID -as shown in figure 2.5- uses a small tag containing an integrated circuit chip and an antenna, which has the ability to respond to radio waves transmitted from the RFID reader. It is able to send, process, and store information, In addition to bar code technology, RFID is an identification tool that does not need physical contact or particular alignment with the reader. The reading phase is very fast and fully automated. Benefits include accuracy of data, availability of timely data, improved register check-out productivity, increased levels of controls, customer service, reduced physical inventory time, and increased system flexibility. However, real applications of RFID technologies are still limited because of various technical and economical obstacles. Metal and liquid environment can disturb reading performances of RFID technologies. Lack of international standards is another disadvantage [5].

There are two different types of RFID tags, namely active and passive tags. The principle of those tags is the same, but the way of transmitting data differs between these tags. The receiver of the data sends out a signal and the passive RFID tag receives that signal via the antenna, which catches the incoming radio waves, and responds to that and sends the signal with the information back to the receiver. In comparison to that, active RFID-tags contain an internal energy source, like a battery. Therefore, active RFID tags continuously broadcast their own signal to send their information and also their unique serial number all the time. Caused by the internal energy source, the distance for transmitting information is much wider for active RFID tags in comparison to passive RFID tags. Active RFID tags are mostly used in high speed environments to accurately track the real-time location of the item. These tags can cover up to 100 meter for the transmission of data. Passive RFID tags can cover, caused by the lack of an internal energy source, an average distance of about 5 to 6 meters, if they use a specific frequency for the transmission. Regarding the costs of these tags, passive RFID tags cost between 0.20 $ USD and 1.5 $ USD, depending on their features. Active RFID tags cost between 15$ USD and 20$

USD. Passive RFID tags cover the requirements of a standard warehouse in the logistic sector and are regarding the costs of the tags and the needed amount of the tags the only economic reasonable solution for high throughput warehouses [1].

Figure 2.5: Radio frequency identification system

2.6 Frequently Used Term

Real-Time System: Controllers are frequently used in real-time systems, where the reaction to an event has to occur within a specified time. This is true for many applications in aerospace, railroad, or automotive areas, e.g., for brake-by-wire in cars.

Payload: is maximum weight that machine can carry without loss accuracy

Precision (validity): Precision is defined as how accurately a specified point can be reached. This is a function of the resolution of the actuators as well as the robot's feedback devices.

Repeatability (variability): Repeatability is how accurately the same position can be reached if the motion is repeated many times.

2.7 Microcontroller

Microcontroller is a (stripped-down) processor which is equipped with memory, timers, (parallel) I/O pins and other on-chip peripherals. The driving element behind all this is cost: Integrating all elements on one chip saves space and leads to both lower manufacturing costs and shorter development times. This saves both time and money, which are key factors in embedded systems. Additional advantages of the integration are easy upgradability, lower power consumption, and higher reliability, which are also very important aspects in embedded systems. On the downside, using a microcontroller to solve a task in software that could also be solved with a hardware solution will not give you the same speed that the hardware solution could achieve. Hence, applications which require very short reaction times might still call for a hardware solution. Most applications, however, and in particular those that require some sort of human interaction(microwave, mobile phone), do not need such fast reaction times, so for these applications microcontrollers are a good choice.

Today, microcontroller production counts are in the billions per year, and the controllers are integrated into many appliances we have grown used to, like

• Household appliances (Microwave, washing machine, coffee machine,)

• Telecommunication (mobile phones)

• Automotive industry (fuel injection, ABS,)

• Aerospace industry

• Industrial automation.

2.7.1 Architecture of microcontroller

The basic internal designs of microcontrollers are pretty similar. Figure 2.6 shows the block diagram of a typical microcontroller. All components are connected via an internal bus and are all integrated on one chip. The modules are connected to the outside world via I/O pins.

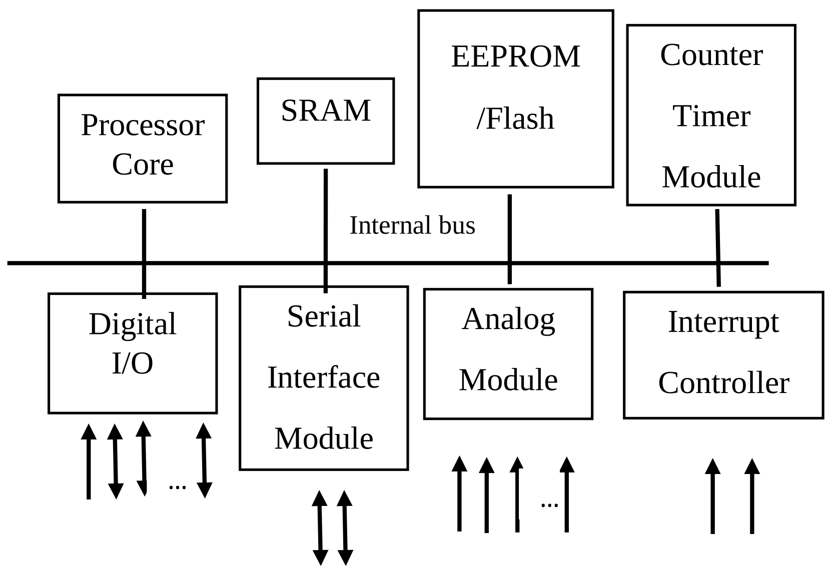


Figure 2.6: Basic layout of a microcontroller

The following list contains the **modules** typically found in a microcontroller:

Processor Core: The CPU of the controller. It contains the arithmetic logic unit, the control unit, and the registers (stack pointer, program counter, accumulator register, register file ...).

Memory: The memory is sometimes split into program memory and data memory. In larger controllers, a DMA controller handles data transfers between peripheral components and the memory.

Interrupt Controller: Interrupts are useful for interrupting the normal program flow in case of (important) external or internal events. In conjunction with sleep modes, they help to conserve power.

Timer/Counter: Most controllers have at least one and more likely 2-3 Timer/Counters, which can be used to timestamp events, measure intervals, or count events. Many controllers also contain PWM (pulse width modulation) outputs, which can be used to drive motors or for safe breaking (antilock brake system, ABS). Furthermore the PWM output can, in conjunction with an external filter, be used to realize a cheap digital/analog converter.

Digital I/O: Parallel digital I/O ports are one of the main features of microcontrollers. The number of I/O pins varies from 3-4 to over 90, depending on the controller family and the controller type.

Analog I/O: A part from a few small controllers, most microcontrollers have integrated analog/digital converters, which differ in the number of channels (2-16) and their resolution (8-12 bits). The analog module also generally features an analog comparator. In some cases, the microcontroller includes digital/analog converters.

Interfaces: Controllers generally have at least one serial interface which can be used to download the program and for communication with the development PC in general. Since serial interfaces can also be used to communicate with external peripheral devices, most controllers offer several and varied interfaces like SPI and SCI. Many microcontrollers also contain integrated bus controllers for the most common (field) busses. IIC and CAN controllers lead the field here. Larger microcontrollers may also contain PCI, USB, or Ethernet interfaces.

Watchdog Timer: Since safety-critical systems form a major application area of microcontrollers, it is important to guard against errors in the program and/or the hardware. The watchdog timer is used to reset the controller in case of software “crashes”.

Debugging Unit: Some controllers are equipped with additional hardware to allow remote debugging of the chip from the PC. So there is no need to download special debugging software, which has the distinct advantage that erroneous application code cannot overwrite the debugger.

2.7.2 Communication interfaces

The basic purpose of any such interface is to allow the microcontroller to communicate with other units. The implementation of such interfaces can take many forms, but basically, interfaces can be categorized according to a hand-full of properties: They can be either serial or parallel, synchronous or asynchronous, use a bus or point-to-point communication, be full-duplex or half duplex, and can either be based on a master-slave principle or consist of equal partners. In most cases, data communication between a controller and its peripherals is bi-directional, that is, both controller and peripheral device will at some time transmit data. For point-to-point connections (and some buses), the question arises whether two devices can transmit at the same time or not. In a full-duplex connection, both sides can transmit at the same time. Naturally, this requires at least two wires, one for each node, to avoid collisions, and allows a maximum overall throughput. The technique is useful if both communication partners have much to transmit at the same time. In half duplex communication, only one node transmits at any time. This saves on wires, because only one wire is required for a half-duplex serial connection. Drawbacks are less overall throughput and the necessity of negotiating access to the single wire. The mode is particularly useful if there is one communication partner (e.g. a sensor device) that has to transmit much data, whereas its peer is mostly receiving.

- **SCI (UART)**

The Serial Communication Interface (SCI) provides an asynchronous communication interface (Universal Asynchronous Receiver Transmitter, UART). The UART module utilizes two wires, a transit (TXD) and receive (RXD) line, for full- or half-duplex communication. The UART is no communication protocol per se, but a module that can be used for asynchronous serial communication. Hence, the UART module within a microcontroller allows the application to control much of its behavior. Configurable parameters include:

Number of Data Bits: Depending on the UART, the number of data bits can be chosen within a more or less wide range. The AT mega series, for example, allows between 5 and 9 data bits. Other UARTs may have a broader or smaller range.

Parity Bit: The user can select whether there should be a parity bit or not, and if yes, whether the parity should be odd or even. If the parity is set to even, the parity bit is 0 if the number of 1's among the data bits is even. Odd parity is just the opposite.

Stop Bits: The user generally can select whether there should be one stop bit or two.

Baud Rate: The UART module contains a register which allows the user to select a certain baud rate (i.e., the transmission speed, given in bits per second (bps)) from a set of possible ones. Possible baud rates generally include the range within 9600 and 115200 baud. However, since the feasible baud rates depend on the frequency of the system clock, different clock speeds imply different sets of available baud rates.

- **SPI**

The Serial Peripheral Interface (SPI) 7 is a simple synchronous point-to-point interface based on a master-slave principle. It provides full-duplex communication between a master (generally a controller) and one (or more) slaves (generally peripheral devices). The interface consists of four single ended lines:

MOSI (Master Out, Slave In): This line is used by the master to transmit data to the slave.

MISO (Master In, Slave Out): This line is used by the slave to transmit data to the master.

SCK (System Clock): This line is used by the master to transmit the clock signal.

SS (Slave Select): This line is used by the master to select a slave.

- **IIC(I2C)**

The Inter-IC bus (IIC) is a synchronous bus that operates on a master-slave principle. It uses two single-ended wires SCL (Serial Clock Line) and SDA (Serial Data Line) for half-duplex communication. The protocol has been developed and is widely used for (short distance) communication between one or more controllers and peripheral devices. The protocol includes bus arbitration mechanisms and thus allows the co-existence of several masters. The role of master normally falls to the microcontroller, with all peripheral devices as simple slaves. In a system with several microcontrollers, you may choose for each controller whether it should be a master or a slave. The only condition is that there must be at least one master in the system.

2.8 Actuators

An actuator is a device that provides the energy to move a load. Motion control systems can be built using hydraulic, pneumatic, or electromechanical (motor) technologies.

2.8.1 Electric drive

Mostly machines are derived by electric actuator cause it make best response and speed control, have a good accuracy and repeatability and more towards precise work such as assembly applications (servomotor or stepper motor). There two type of electric actuators according to supply source DC and AC actuator, most commonly used are DC motor for micro and medium size of robots, and AC motors may be utilized for the large system, and can add gear train to control torque and speed. But in the large applications more expensive and become fire hazard that make hydraulic actuator is great choice.

2.8.2 Transmission mechanisms

A transmission mechanism is used to connect the load to the motor of an axis. It helps meet the motion profile requirements, lead/ball-screw drives, linear belt drives as shown in Figure 2.7, pulley-and-belt drives, and conveyors. When a load is coupled to a motor through a transmission mechanism, the load inertia and torque are reflected through the mechanism to the motor.

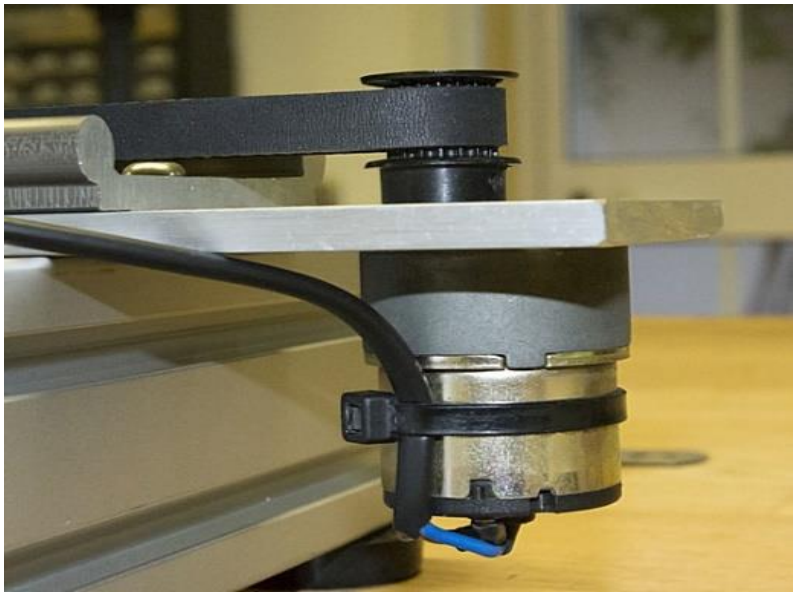


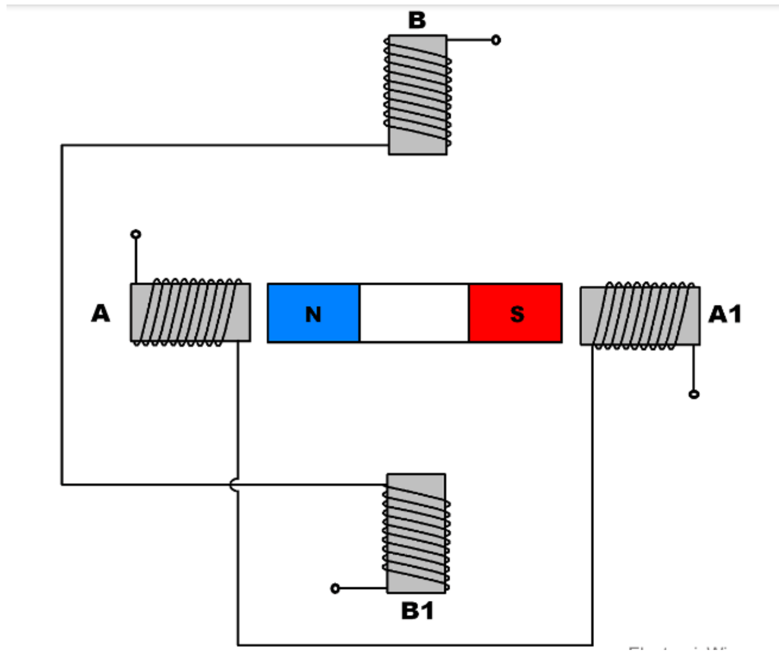
Figure 2.7: Linear belt drives

2.9 Stepper Motors

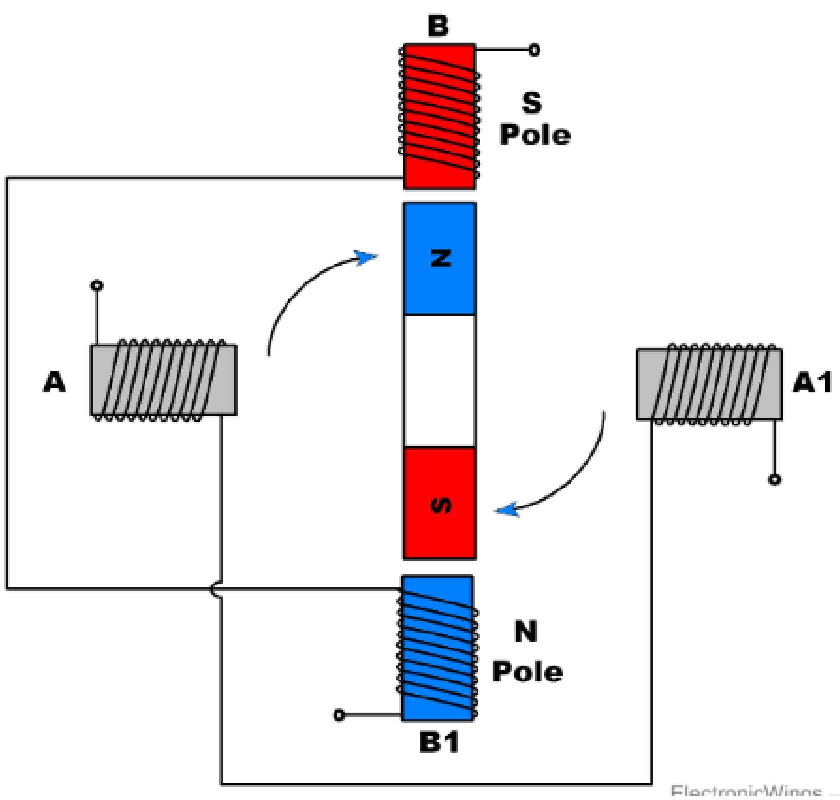
Stepper Motor is a brushless DC Motor that divides the full rotation angle of 360° into a number of equal steps. Control signals are applied to stepper motor to rotate it in steps.

2.9.1 Working principle

Stepper motor rotates in steps. To understand its principle, consider the logical diagram of its construction in figure 2.8 below. Figure 2.9 shows two winding, A and B are the stator of motor. Permanent magnet having North and South poles is rotor of the motor. If we energies winding B, it will create North and South poles on winding B which will attract opposite poles of magnet towards it. This causes rotor (permanent magnet) to rotate by a step. Similarly, for winding A.



FUGURE 2.8: Logical diagram of stepper's structure



FUGURE 2.9: Logical diagram of stepper's structure

2.9.2 Step angle

Step angle is the minimum angle that stepper motor will cover within one move/step. Number of steps required to complete one rotation depends upon step angle. E.g. If step angle is of 45° then 8 steps are required to complete one rotation as shown in figure 2.10 below;

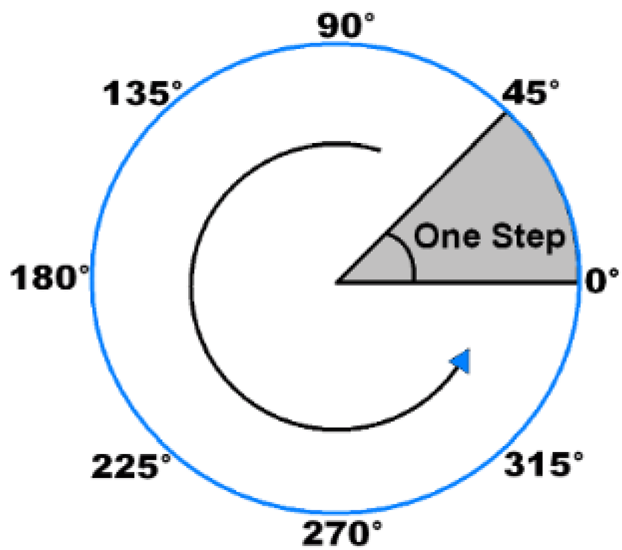


Figure 2.10: Step angle of stepper motor

Depending upon stepper motor configuration, step angle varies e.g. 0.72°, 1.8°, 3.75°, 7.5°, 15° etc.

2.9.3 Stepper classification

Stepper motors are classified depending upon construction and winding arrangement.

- Depending upon winding arrangement

- Unipolar Stepper Motor
- Bipolar Stepper Motor

- Depending upon construction
  - Permanent Magnet Stepper Motor
  - Variable Reluctance Stepper Motor
  - Hybrid Stepper Motor

2.9.4 Difference between unipolar and bipolar stepper motor

- Figure 2.11 shows the difference in the connection of bipolar and unipolar stepper motor
- As per name, they already differ in current direction.
- Also, due to unidirectional arrangement, unipolar stepper motor do not require to control direction of current. So, it does not require H Bridge like circuitry for bidirectional operation. A simple ULN2003 driver circuitry is used to drive it.
- Whereas in bipolar stepper motor, it requires H Bridge driver circuitry e.g. like L293D driver for bidirectional current control.
- Unipolar Stepper Motor has less torque than Bipolar Stepper Motor because in unipolar stepper motor current flows through half of the winding; whereas in bipolar stepper motor current flows through full winding.

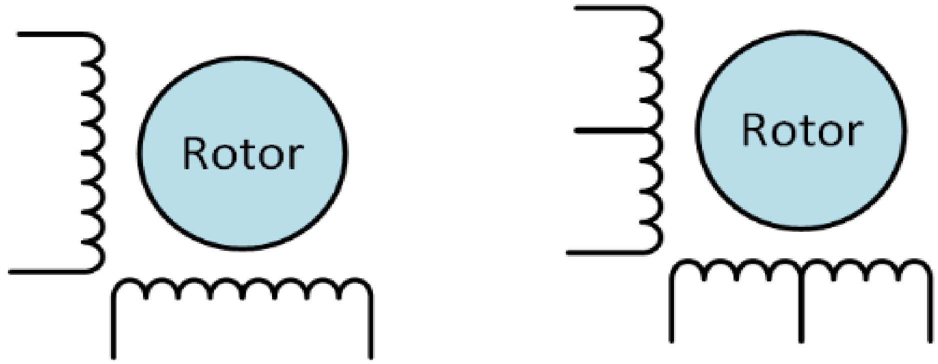


Figure 2.11: The connection of bipolar and unipolar stepper motor

2.9.5 Step sequence modes

Stepper motor rotates in steps and for continuous or limited angle rotation we need to provide sequential steps. Mostly there are two step sequences used to rotate stepper motor.

- Full Step Sequence.

  Here motor moves through its basic step angle.

  At a time two coils are excited.

- Half Step Sequence.

  Here motor moves half of its basic step angle.

  Half step can be achieve by exciting both current and next coil.

CHAPTER THREE
METHODOLOGY

3.1 Introduction

The main purpose of this study is to help the supply chain sector in Sudan by designing a system with an acceptable price and a high quality of working that can improve the process in warehouses. This chapter discusses the methodology that was followed to achieve the goals, starting from the design selection and considerations, walking through the procedure that used in the study.

3.2 Design Steps

- Defining the goals of the study and different constraints i.e. range of motion of the machine, payload, workspace and maximum reach; and the types of the applications that will be done by it.
- Visiting DAL group for heavy machines in order to collect data.
- Assuming the design's dimensions.
- Creating Cad 3D modeling of ASRS using FLEXSIM.
- Selecting the actuators which have to be used depending on the required torque, the torque was determined for the motor depending on speed and payload, a safety factor was implemented, Different options were considered but mainly two were of interest: DC motor and stepper motor. The selection criteria were the accuracy, cost, and controllability. In the final simulation stepper motors were used.
- Implementing of the Electrical circuit using PROTEUS 8.

- Creating control system by designing the actuation circuit to control the motor using an ARDUINO Uno microcontroller, and integrating the overall control using GRBL software.

3.3 Design Selection

The mechanism of automated storage and retrieval system (ASRS) has three degree of freedom (DOF). The horizontal drive is considered as x-axis and vertical drive as y-axis in direction. The griper drive or slider moves along z-axis, is used to store and retrieve objects from the rack. The mechanism of the ASRS has been modelled by using 3D computer aided design software FLEXSIM. Figure 3.1 shows FLEXSIM environment.

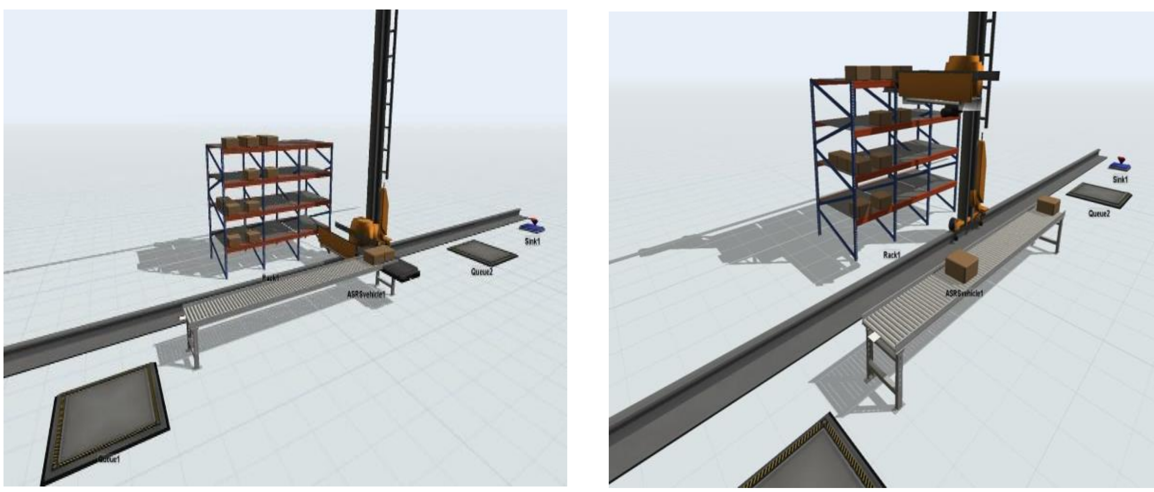


Figure 3.1: FLEXSIM environment

3.4 Transport Processes

The stacker crane may transport at most one pallet. Pallets to be stored are delivered (e.g., by conveyors) to the acceptance station and wait in a buffer (stacking path) until a stacker crane transports them to the specified storage space. Pallets are taken from the buffer on the FIFO (first in, first out) basis: a stacker crane takes this pallet first which has first come into the buffer. At the other end of the warehouse, a pallet, having been located by a stacker crane, is transported to the acceptance/collection station.

If x, y and z stand for the dimensions of a load unit [in mm] (depth, length and height, respectively), then the width, length and height of the aisle can be expressed as follows:

$$W = 3(x + a) \tag{3.1}$$

=3*(400+10) = 1230 mm

$$L = ny\ (y + b) \tag{3.2}$$

=3*(400+10) = 1230 mm

$$H = nz\ (z + c) \tag{3.3}$$

=3*(400+10) = 1230 mm

Where:

W is the aisle width [in mm],

L is the aisle length [in mm],

H is the aisle height [in mm],

a, *b*, *c* are respective tolerances for the rack compartment [in mm],

n_y is the number of rack compartments along its length,

n_z is the number of rack compartments along its height.

The total storage capacity of a single aisle depends on the number of compartments along the rack length and the number of compartment levels, can be expressed as:

$$Ck = ny\,nz \qquad (3.4)$$

= 3*3 = 9

A stacker crane has been assumed to operate in single (simple) cycle mode, Figure 3.2 shows the Stacker crane travel trajectories for a single cycle, where a crane exclusively stores a load unit in a rack or exclusively retrieves a load unit from a rack. The storage method has been assumed to be dedicated storage where goods are assigned to specified compartments.

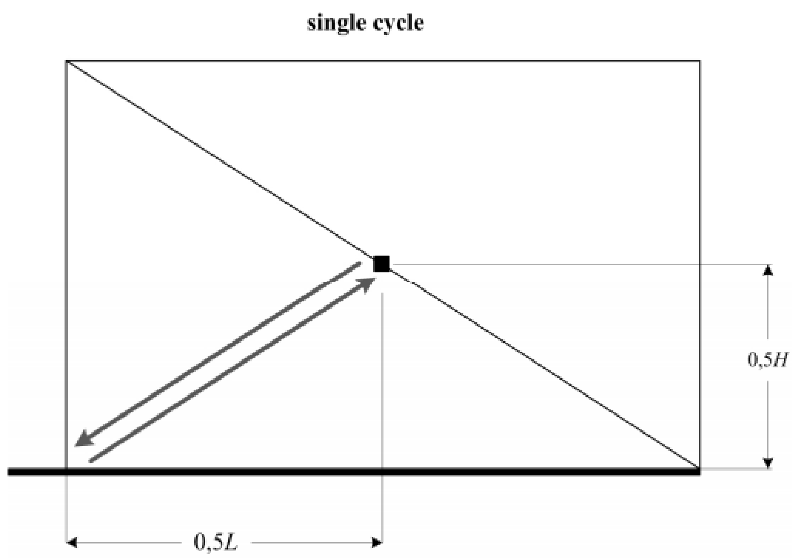


Figure 3.2: Stacker crane travel trajectories for a single cycle

The duration of a single cycle [in minutes per cycle] can be expressed as follows:

$$Tcs = \max\left\{\frac{Lr}{vy}, \frac{Hr}{vz}\right\} + 2\,Tpd \qquad (3.5)$$

Where:

T_{cs} is the duration of a single (simple) cycle [in minutes per cycle],

L_r is the length of a rack [in mm],

H_r is the height of a rack [in mm],

v_y is the horizontal velocity of a stacker crane [in m/s],

v_z is the vertical velocity of a stacker crane [in m/s],

T_{pd} is the load acceptance or collection time [in seconds].

3.5 Torque Equations

It has been assumed that the whole assembly of the machine was rigid enough to hold the load with stability of control. Initially starting with assumption a total mass of the shelf and load (m) of 1kg:

$$\mathrm{W} = m * g \tag{3.6}$$

=1*9.8= 9.8N

- The force acting on the pelt (F) has been calculated as followed:

$$F = U * W \tag{3.7}$$

=1*9.8= 9.8N

Where,

U is the friction of sliding surface.

- The torque around the movable axis has been calculated from the equation below:

$$T = (UL + W) * \pi \ D / (2\pi) \tag{3.8}$$

T = (9.8 +9.8)* 0.06 /2= 0.588 N.m

Where,

D = Final pulley diameter

3.6 Step/mm Value Calculation

It has been assumed that the belt has a Pitch of 2 mm, Pulley Number of Teeth is 8 teeth and the stepper motor controller is set to 20X micro stepping for all axis.

- For step angle of 1.8 degree, the motor steps per revolution has been calculated as followed;

$$\text{Motor steps per revolution} = 360/1.8 = 200\ \text{step/revolution}$$

- The Step/mm value has been calculated as;

$$\text{Steps per mm} = (\text{Steps/Revolution} * \text{Ustep}) / (\text{Belt Pitch} * \text{Pulley Number of Teeth}) \tag{3.9}$$

Steps per mm= (200*20)/ (2*8) = 250 steps/mm

3.7 Electrical Circuit Design

PROTEUS 8 has been used to simulate the electrical circuit. PROTEUS 8 is software tool mainly used for electronic design automation. The software consists of a library tool option in which the designer can select the electronic components for the circuit and modify the values. Figure 3.3 shows Schematic Capture window of PROTUES 8.

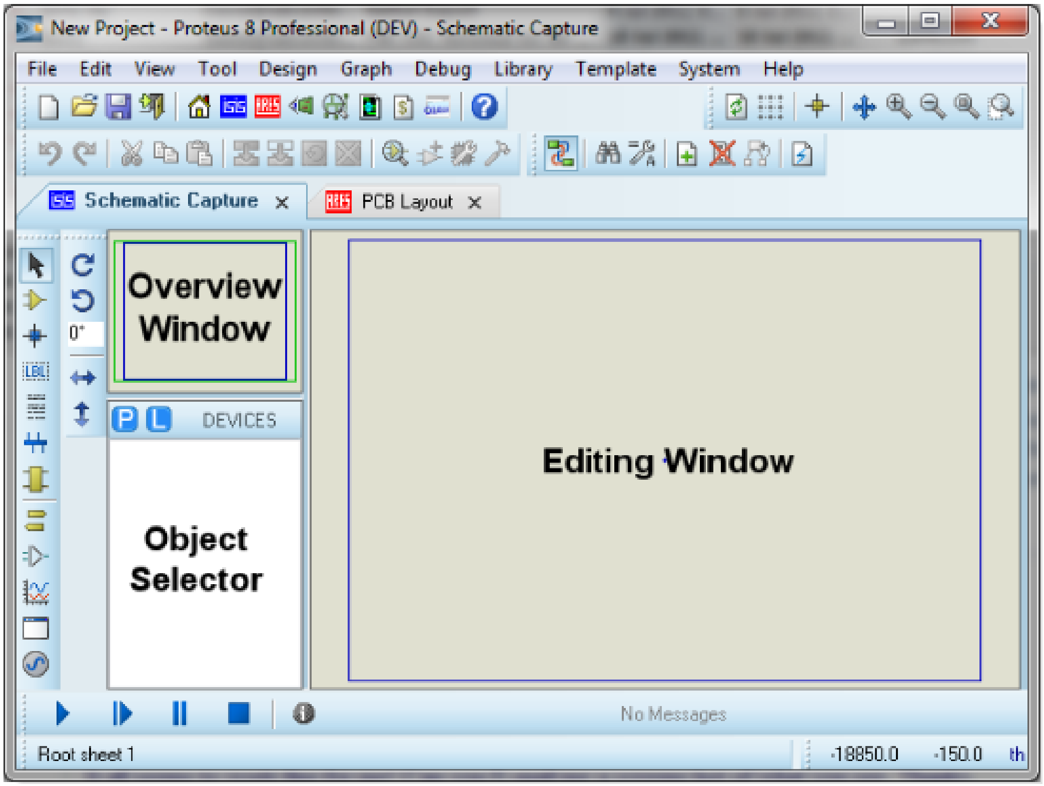


Figure 3.3: Schematic Capture window of PROTUES 8.

CHAPTER FOUR
CONTROL SYSTEM AND SIMULATION

4.1 Introduction

This chapter discusses the control system description, simulation, software and results.

4.2 Control System Description

The idea of the control system is like the way of hyper CNC machines. The control begging from the computer by sending g-code of desired product to the microcontroller inside the ASRS. Microcontroller works by translating the inputs -in this case it is the g-code- to the low current as outputs that motor's drivers can read, then drivers convert it to high currant from the power source to move the stepper motors in steps according to that g-code. The work can be minor by using computer user interface. Figure 4.1 shows the system Block Diagram and figure 4.2 shows the system flowchart.

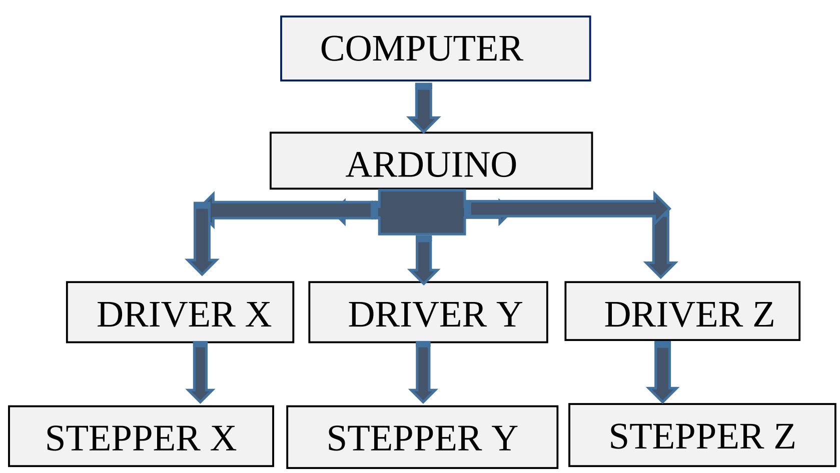


Figure 4.1: Block diagram of the system

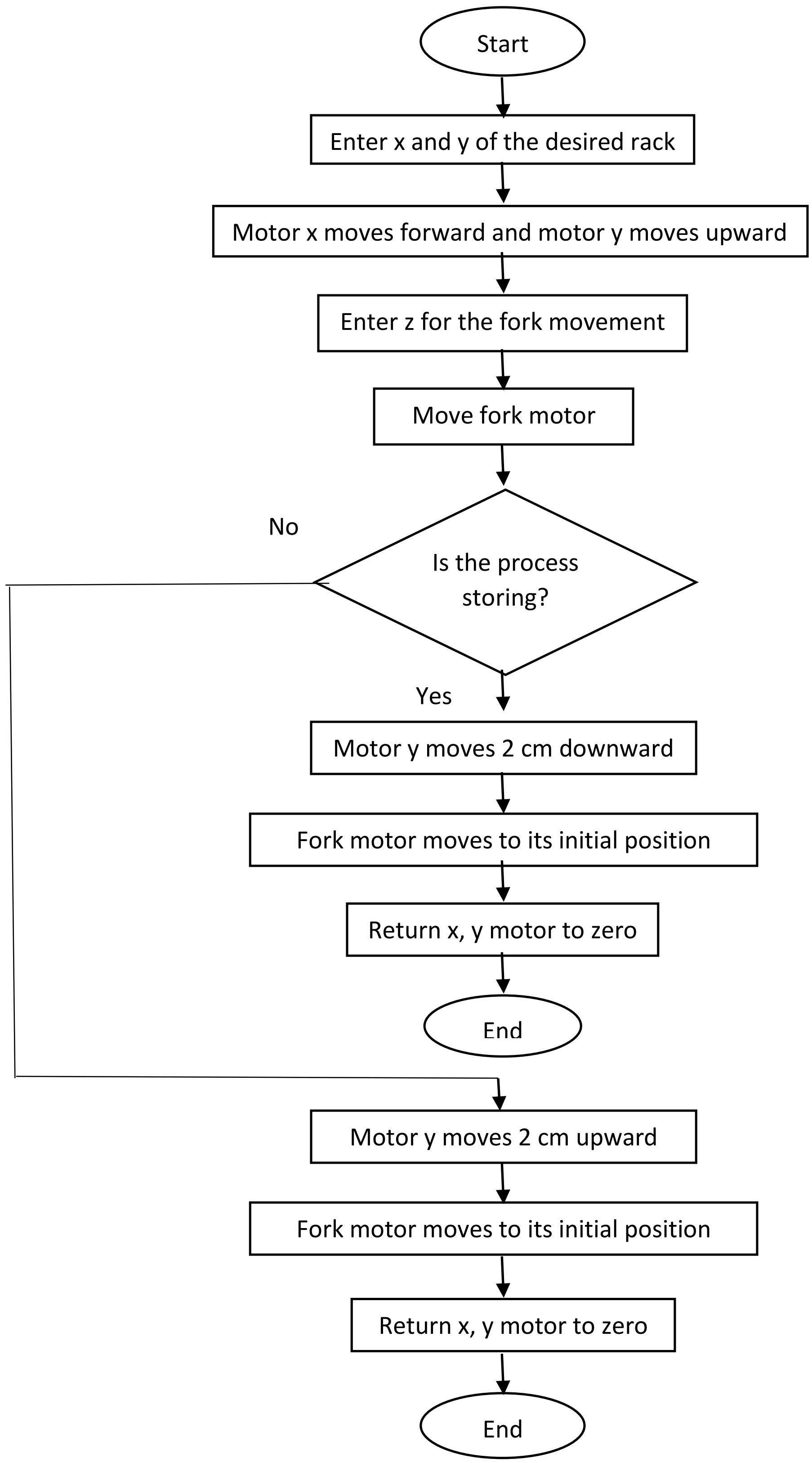


Figure 4.2: System flowchart.

4.3 Simulation

The simulation has been done by using PROTEUS 8. As shown in figure 4.3, three stepper motors were controlled by ARDUINO UNO using L297 controller and L298 driver. PROTEUS has been connected with universal g-code sender software through visual serial port emulator by connecting COMPIM port with ARDUINO UNO.

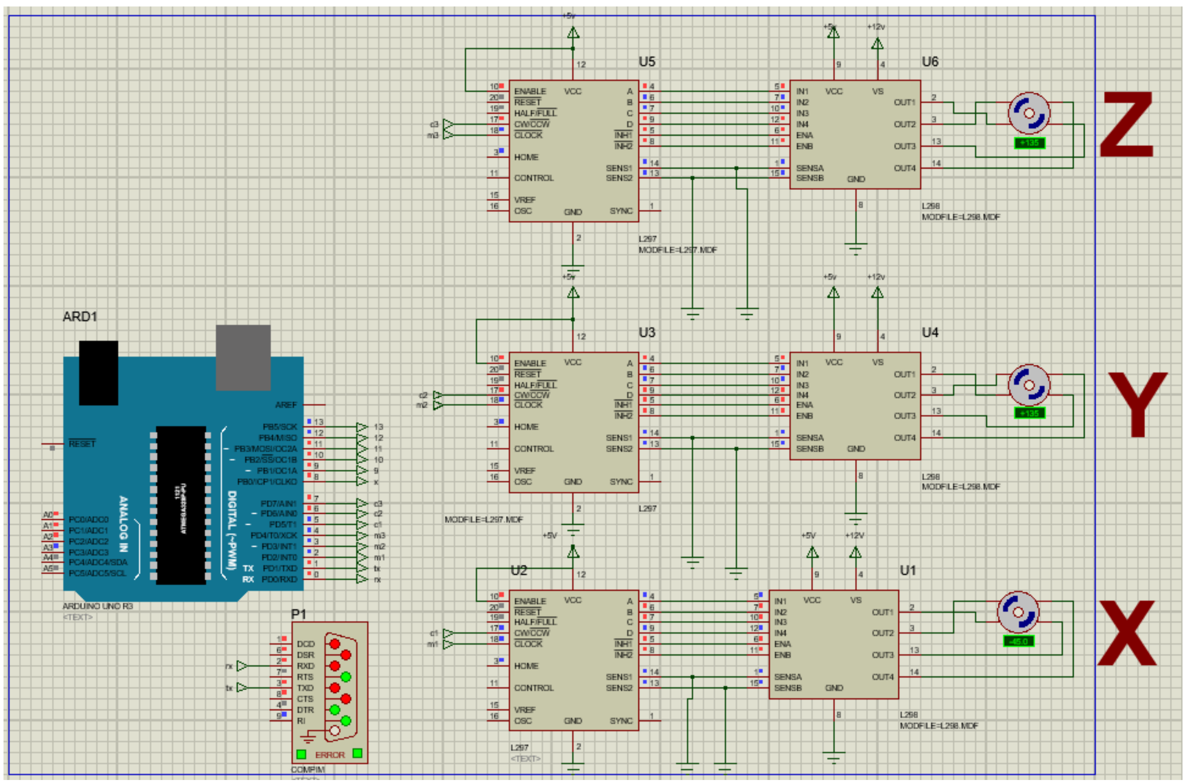


Figure 4.3: System circuit in PROTEUS

4.3.1 ARDUINO UNO

ARDUINO is the brain of the system, which supports UGS software for controlling the machines and making it moves. Microcontroller receives g-code form inputs devices like computer and switches. According to the g-code, microcontroller makes the outputs signals to control the actuators. ARDUINO was meet this requirement, Figure 4.4 shows ARDUINO UNO.

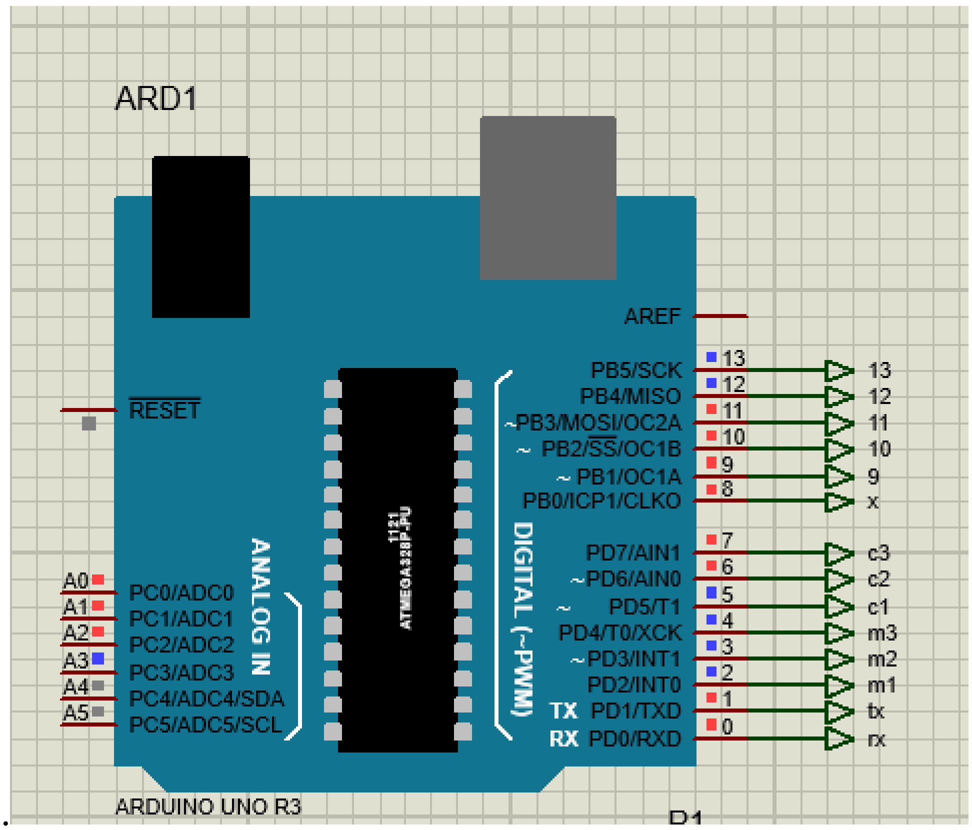


Figure 4.4: ARDUINO UNO

4.3.2 Stepper drivers

The stepper motor driver should be able to solve two major tasks: develop the required time sequence of signals and provide the require current for windings. As shown in figure 4.5, a pair of two drivers were used in the circuit, L297 and L298 driver. The L297 chip contain the logic for developing time sequences, while L298 serves as a powerful coupled half-bridge. These devices fully complement each other and together fulfill the function of a stepper motor driver. The positive aspects of using this pair include the availability of a detailed connection diagram within the documentation, which means that you do not have to waste time on designing a circuit by yourself. Also it helps avoid the failure of the circuit's power component due to the presence of a feedback loop, which is designed to prevent the current from exceeding the maximum allowable value for the L298 chip.

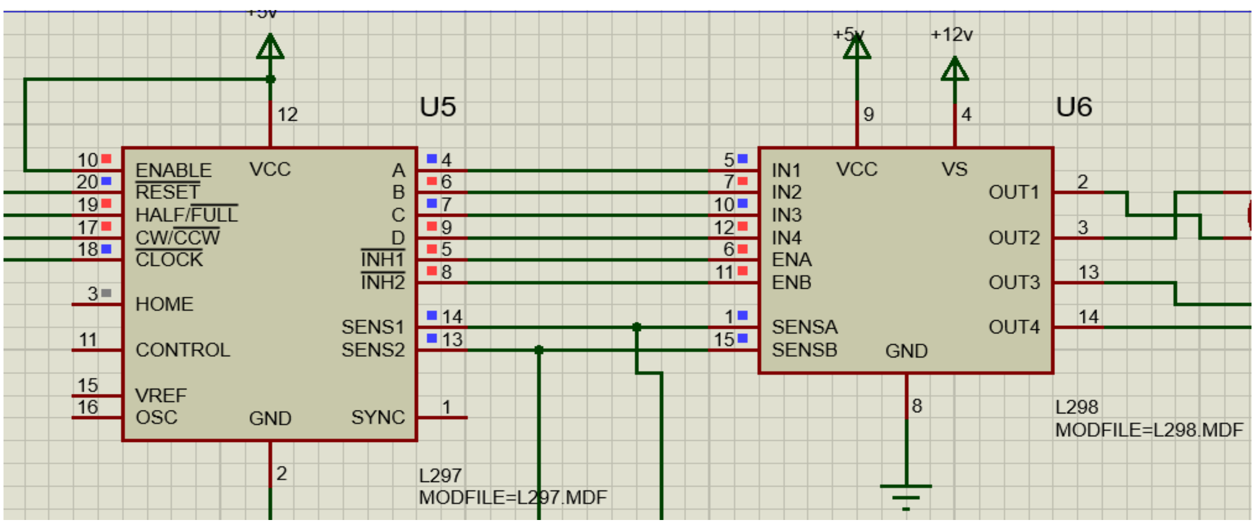


Figure 4.5: Stepper motor driver

4.3.3 Stepper motor

Stepper motor is DC motor which moves full rotation into number of equal steps, the motor position can command by move to one of these steps, according to the group of phases which make the discrete angular steps. Stepper motors receiving signal command from the ARDUINO by the drivers to make the action. Figure 4.6 shows typical motors interfacing with stepper driver.

4.3.4 Power supply

Two levels of voltage have been used, **+5** V and **+12**V to power the L297 motor controller.

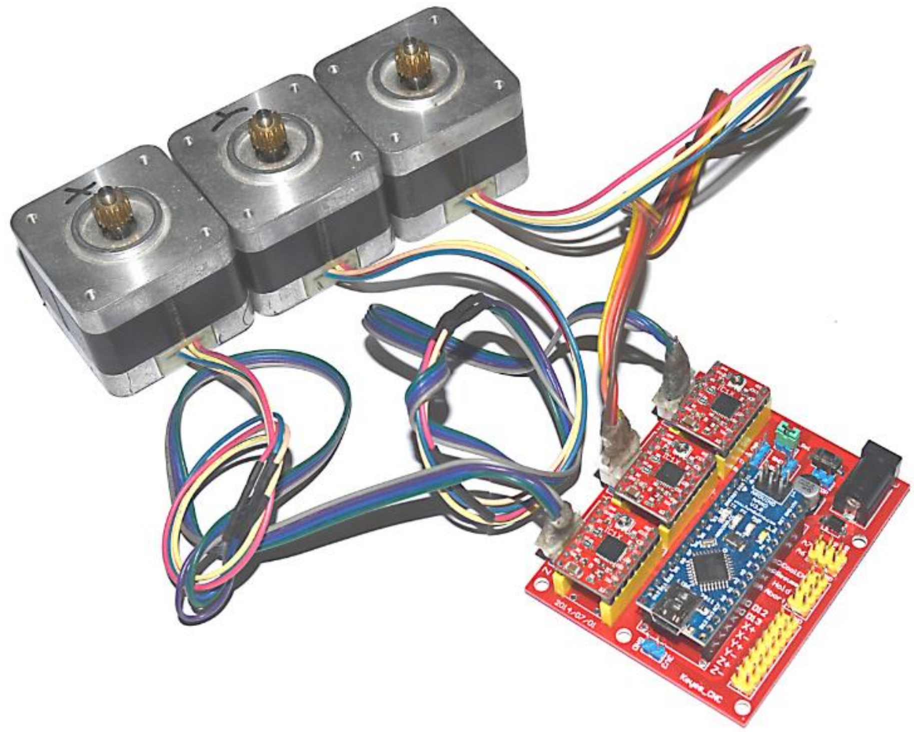


Figure 4.6**:** Typical motor interfacing with stepper driver.

4.4 Control software description

The ASRS was controlled in order to facilitate storing and retrieving processes especially in warehouses, without needing strong programming background. Using a Universal G-code Sender (UGS)-as shown in Figure 4.7- which is used for controlling 3D applications such as 3D printers, laser cutters and CNC machines. UGS is an open source g-code platform which has full featured that used for interfacing with traditional CNC controllers, like GRBL. UGS comes with 3D visualizer, and control bottoms on jog controller to control X, Y and Z axes. UGS was used to control the ASRS to gain properties of those machines with a GRBL firmware which converts the g-code from Cartesian coordinate to ASRS workspace and upload it on the ARDUINO board which will make it able to read the G-code from UGS. Table 4.5 shows important motor parameter settings which has been set in the Universal G-code platform (UGS).

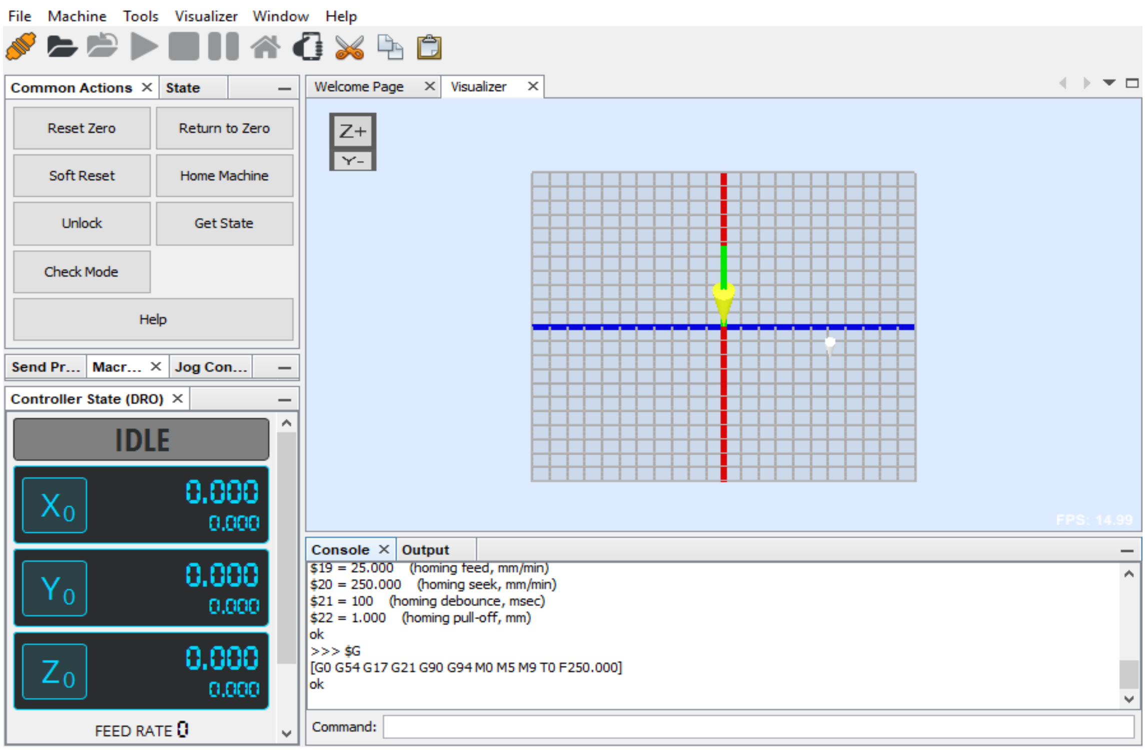


Figure 4.7: UGS user interface

Table 4.1: Motor settings

Settings and values	description
$0=250.000	X steps/mm
$1=250.000	Y steps/mm
$3 = 10	step pulse, Usec
$7 = 255	step idle delay, msec
$8=5.000	Acceleration, mm/sec^2

4.5 Results and Discussions

The system storing and retrieval time has been tested for specific time intervals in comparison with the manual retrieval time by the workers under two conditions. The results had been plotted with respect to specific time limits for storing, as shown in figure 4.8, and retrieving the objects from rack in below graphs as shown in figure 4.9. From the results the system is 20% efficient while storing and 10.1% efficient while retrieving. On an average it reduces nearly 16.55% of the time taken to store and retrieve the objects from rack when compared to manual methods.

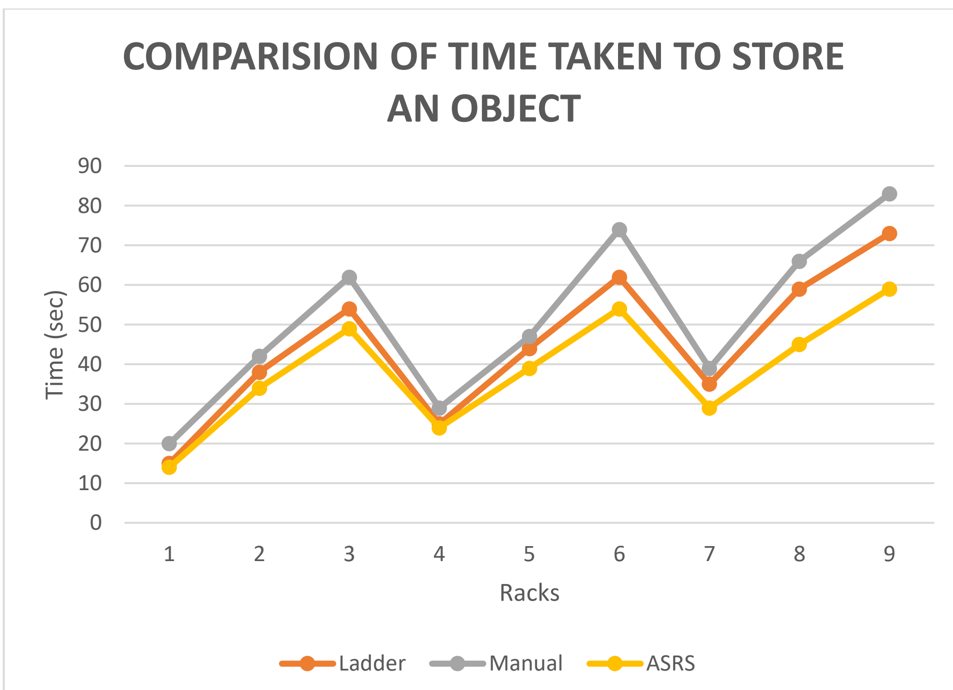


Figure 4.8: Graph showing time taken to store objects in the rack

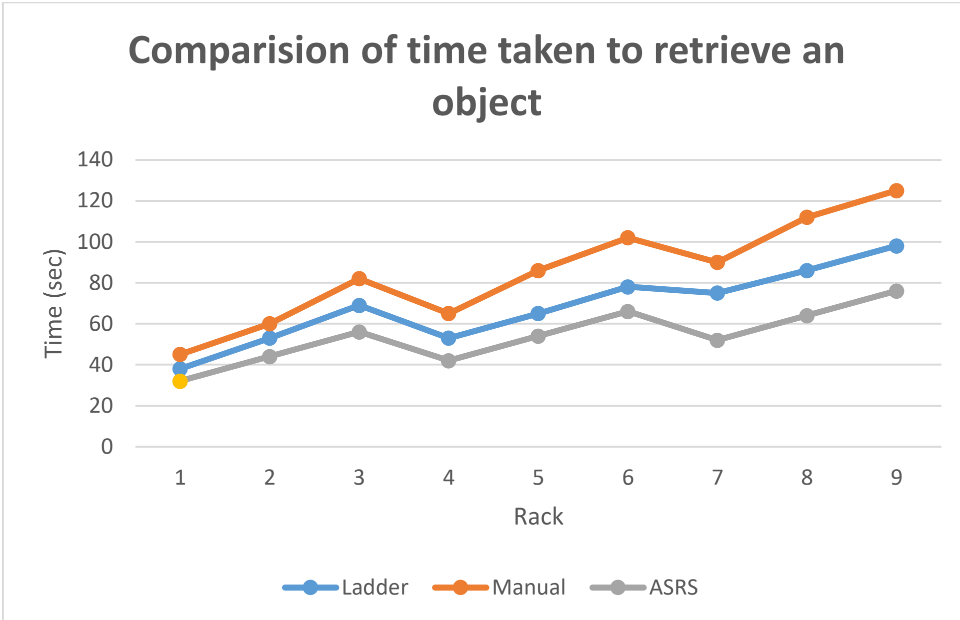


Figure 4.9: Graph showing retrieval times for objects from rack

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study automated storage/ retrieval system (AS/RS) with 9 racks has been presented and simulated. The system has been successfully designed and developed. The control strategy for the system had been designed using ARDUINO. This kind of system can be successfully implemented in various warehouses, where storage racks are accessed by both automated system and users. The main advantages are cost reduction, handling product damages and eliminate time and effort. Overall, the objectives of the project have been successfully achieved.

5.2 Recommendations

The following points can be considered as suggested future works:

- Improvement of position control by using PID controller.
- Improvement of goods tracking by implementing barcode technology.
- Increment of storage assignment policies for working in multiple aisles and/or multiple I/O Points.

REFERENCES

[1] A. Nilsson and D. Elmar Merkle, “Technical solutions for automation of warehouse operations and their implementation challenges,” p. 141, 2018.

[2] H. Y. Sun, “The application of barcode technology in logistics and warehouse management,” Proc. 1st Int. Work. Educ. Technol. Comput. Sci. ETCS 2009, vol. 3, pp. 732–735, 2009.

[3] M. Aslam, Farrukh, A. R. Gardezi, and N. Hayat, “Design, development and analysis of automated storage and retrieval system with single and dual command dispatching using MATLAB,” World Acad. Sci. Eng. Technol., vol. 36, no. 12, pp. 91–95, 2009.

[4] B. Rouwenhorst, B. Reuter, V. Stockrahm, G. J. Van Houtum, R. J. Mantel, and W. H. M. Zijm, “Warehouse design and control: Framework and literature review,” Eur. J. Oper. Res., vol. 122, no. 3, pp. 515–533, 2000.

[5] I. Pihir, V. Pihir, and S. Vidačić, “Improvement of warehouse operations through implementation of mobile barcode systems aimed at advancing sales process,” Proc. Int. Conf. Inf. Technol. Interfaces, ITI, pp. 433–438, 2011.

[6] T. Vamos, “Automation production systems and computer integrated manufacturing. Mikell P. Groover,” Automatica, vol. 24, no. 4, p. 587, 1988.

[7] M. Karkula, “Analysis of the Operation of a Stacker Crane with Simulation Methods,” vol. 1, no. 12, pp. 55–62, 2011.

APPENDIX

Results of Company Interviews

- **Research Area:**

1. Company:

Green Zone for Trading & Investment co. ltd 12th Floor, Sahil & Sahra Tower, Khartoum, Sudan.

2. Warehouse location:

Alsoug Almahali, Khartoum.

3. Warehouse attributes:

Size: 1000m^2 **Height:** 5m slopped to 7m.

Length: 40m **Width:** 25m

Material: metal rods, brick walls, zinc ceiling with thermal coating and turbid floor.

- **Manual Cost:**

Picking & Storing = 0.4$ per 50KG

Estimated annual cost with an average of 4 operations per month = 0.4*4*12= 19.2$ per 50Kg

Estimated annual cost for quantity of 120,000 kg

Total Annual Cost= 46,080$

- **Equipment's Cost:**

Table a shows the proposed system equipment cost.

Table of Equipment's cost

Item no.	**Description**	**Quantity**	**Item cost ($)**	**Total cost ($)**
1	NEMA 23 stepper motor (0.5N.m)	3	15	45
2	Keypad	1	2	2
3	Motor driver	3	4	12
4	ARDUINO Mega	1	6.8	6.8
5	Power supply	1	22.45	22.45

- The data related to the simulation results:

Racks	**Storing**			**Retrieval**		
	manual	**ladder**	**ASRS**	**manual**	**ladder**	**ASRS**
1	15	20	14	38	45	32
2	38	42	34	53	60	44
3	54	62	49	69	82	56
4	25	29	24	53	65	42
5	44	47	39	65	86	54
6	62	74	54	78	102	66
7	35	39	29	75	90	52
8	59	66	45	86	112	64
9	73	83	59	98	125	76