DEVELOPMENT OF AUTOMATED STORAGE AND RETRIEVAL SYSTEM (AS/RS) PROTOTYPE

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DEVELOPMENT OF AUTOMATED STORAGE AND RETRIEVAL SYSTEM (AS/RS) PROTOTYPE

ABDUL HALIM BIN HADZIR

Report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the report entitled “Development of Automated Storage and Retrieval System (ASRS) Prototype” is written by Abdul Halim Bin Hadzir. I have examined the final copy of this report and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Dedicated to my beloved parents (Hj. Hadzir Bin Abd Majid and Hjh Noorlaila Binti Kahar) and my family, truthfully for supports, encouragements and always be there during hard times.

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ABSTRACT

This report deals with the development of automated storage and retrieval system (AS/RS) prototype. The original idea for this project is to help people which working in warehouse such as operator who wants to store and retrieve the drawer (unit loads) into and from cabinet (storage structure). The AS/RS have been widely used in distribution and productions environment. The AS/RS consists of racks and cranes (storage/retrieval machine, lifter and drawer picker) where the racks served by cranes running through aisles between the racks and it's fully automated where it capable of handling drawer without interference of an operator. The development accentuate on mechanical approach. The prototype three-dimensional solid modelling of AS/RS was developed using the computer-aided drawing software. For this project PIC18F452 microcontroller was chosen as a control system. Other than that, stepper motor was used to move the storage/retrieve (S/R) machine during to store and retrieve the drawer. A program in mikroElektronika (MikroC) is written and developed to correspond with the microcontroller to move the stepper motor according to plan sequences. The real time testing was done in order to know the performance of fabricated prototype. The transaction time during depositing and retrieving the drawer into and from cabinet is successfully recorded. The development in phrase can be concluded as an innovation of design and successfully fabricated.

ABSTRAK

Laporan ini membentangkan pembangunan simpanan automatik dan sistem carian (AS/RS) prototaip. Idea asal untuk projek ini adalah untuk membantu orang yang bekerja di gudang seperti operator yang ingin menyimpan dan mengambil laci (beban unit) pada kabinet (struktur simpanan). AS/RS telah banyak digunakan dalam persekitaran pengedaran dan pengeluaran. AS/RS terdiri dari rak dan kren (simpanan/carian mesin, pengangkat dan pengambil laci), di mana rak dilayani oleh kren berjalan melalui lorong antara rak-rak dan ianya sepenuhnya automatik yang mana mampu menangani laci tanpa campur tangan operator. Pembangunan ini meggunakan pendekatan mekanikal. Pemodelan AS/RS prototaip solid tiga dimensi dibangunkan menggunakan perisian melukis dibantu komputer. Untuk projek ini mikrokontroler PIC18F452 dipilih sebagai sistem kawalan. Selain itu, motor pelangkah digunakan untuk memindahkan simpanan/mengambil (S/R) mesin semasa untuk menyimpan dan mengambil laci. Sebuah program di mikroElektronika (MikroC) ditulis dan dibangunkan untuk berinteraksi dengan mikrokontroler untuk menggerakkan motor pelangkah sesuai dengan urutan yang diatur. Pengujian masa sebenar dilakukan untuk mengetahui prestasi prototaip yang dibuat. Waktu transaksi semasa menyimpan dan mengambil laci ke dan dari kabinet telah berjaya dirakam. Pembangunan ini dalam frasa mudah disimpulkan sebagai inovasi terhadap rekabentuk dan telah berjaya dibuat.

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n_y	Number of load compartments along the length of the aisle
n_z	Number of load compartments that make up the height of the aisle
W	Width of the one aisle of the AS/RS rack structure
L	Length of the one aisle of the AS/RS rack structure
H	Height of the one aisle of the AS/RS rack structure
x	Depth of dimensions of a unit load
y	Width of dimensions of a unit load
z	Height of dimensions of a unit load
a, b, and c	Allowances designed into each storage compartment to provide clearance for the unit load and to account for the size of the supporting beams in the rack structure.
Tcs	The cycle time of a single command cycle
Vy	The velocity of the S/R machine along the length of the AS/RS
Vz	The velocity of the S/R machine in the vertical direction of the AS/RS
Tpd	Pickup and deposit time
Tcd	The cycle time for dual command cycle
Rcs	Number of single command cycles performed per hour
Rcd	Number of dual command cycles per hour
U	System utilization during the hour
Rc	Total S/R cycle rate
Rt	Total number of transaction performed per hour
T	Torque
F	Weight

LIST OF SYMBOLS

r	Radius of gear
P	Power
ω	Angular velocity
N	Number of gear's teeth

LIST OF ABBREVIATIONS

AS/RS	Automated Storage And Retrieval System
AGV	Automated Guided Vehicle
S/R	Storage/Retrieval
I/O	Input/output
P/D	Pick/Deposit
FCFS	First Come First Serve
NN	Nearest Neighbour
3D	Three dimensional
RAM	Random access memory
ROM	Read only memory
PROM	Programmable read-only memory
EPROM	Erasable programmable read-only memory
ICs	Integrated circuits
PIC	Programmable interface controller
PSP	Parallel slave port
A/D	Analog-to-digital
C	Computer
3D	Three dimension

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

An automated storage and retrieval system (AS/RS) can be defined as a storage system that performs storage and retrieval operations with speed and accuracy under a defined degree of automation (Aslam,Gardezi, and Hayat, 2009). The performance of any manufacturing industry depends mostly on its material handling and storage system.

Generally, AS/RS refers to a variety of computer-controlled methods for automatically depositing and retrieving loads to and from defined storage locations. Within an automated storage system environment, there are having several layouts such as horizontal carousels, vertical carousels, vertical lift modules, and fixed aisle storage and retrieval systems. The latter utilizing special storage retrieval (S/R) machines to do the work needed to insert, extract and deliver loads to designated input/output locations. AS/RS have many benefits including savings in labour cost, improved material flow and inventory control, high floor space utilization, increased safety and stock rotation. AS/RS, carousels/rotary racks, automated guided vehicles (AGV) systems, and robotic systems are some of the most commonly used material handling systems in manufacturing industries.

The right application of AS/RS provides a long list of user benefits. It has been demonstrated time and time again that automated storage and retrieval systems are proven technologies capable of effectively and consistently handling and buffering raw materials, work-in-process inventories and finished goods of all kinds, and making it possible to totally integrate material handling storage. This system works by enable user to store their packages in the safe place and retrieve the packages correctly without the limit of human working hours. The system can be extended from medium to large storage capacity without difficulty to redesign the storage management. In this project, the design and development of AS/RS prototype was concentrated for small unit loads (small drawer). The capacity of the designated AS/RS to store various parts is ten of drawer. The developed storage structure (cabinet) of AS/RS consists of two rows and five columns to store parts in vertical and horizontal direction.

1.2 PROBLEM STATEMENT

This AS/RS is designed to reduce the error rates and increased reliability while savings labour costs and floor space. Material storage can be performed manually but the automated methods for storing and retrieving materials are more efficient. With the conventional system, need a lot of labour touching the material which can lead to errors and contribute the longer time since automated system is more accurate with higher stock reliability, for these reasons, safety stock figures can be lower, which means storage costs will be reduced. Other than that, the possibilities of error occur during storing and retrieving of the items at original location and find the items in shelving can sometimes be difficult.

1.3 OBJECTIVES OF THE PROJECT

The objectives of this project are:

i. To design a prototype of automated storage and retrieval system (AS/RS) for small loads.
ii. To integrate microcontroller on the storage/retrieval (S/R) machine.
iii. To fabricate, assemble, and test the prototype as following a design.

1.4 PROJECT SCOPE

This project focuses on design and fabrication of the AS/RS prototype. The design was developed using Solidworks software. Other than that, programmable autonomously storage/retrieve (S/R) machine is used in conjunction to store and retrieve the small drawer. Furthermore, design of electronic circuit to suit the software programming. Generally, every technology has its limitations, and for this project it is no exception. The movement of this system is limited to store and retrieve the small unit loads (drawer) into and from storage structure (cabinet).

This equipment is not durable. It cannot expose too much to any work pressure since it is available in portable small component. This system requires higher initial investment for start-up process. The design of this system needs precise decision making to get the best mechanism.

1.5 CONCLUSION

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project on development of automated storage and retrieval system to achieve the objective mentioned. This chapter is as a fundamental for the project and act as a guidelines for project research completion.

CHAPTER 2

LITERATURE REVIEW

2.1 INRODUCTION

This chapter summarizes the general of AS/RS development highlighting the most recent research in this area. Automated storage and retrieval systems (AS/RS) have been widely used worldwide in distribution and production environments since their introduction in the 1950s. For both in production and distribution environments, AS/RS are used for putting products in store and for retrieving those products from storage to P/D station in other word to fulfil an order.

Between 1994 and 2004, there has been a continuously increase in the number of AS/RS used in distribution environments in the United State (Roodbergen and Vis, 2008). The AS/RS consists of four scheduling policies. A scheduling policy is a combination of a storage rule and retrieval rule. The storage rule in all cases was first-come-first-serve (FCFS), closest open location to the dock. The retrieval rules examined were FCFS, nearest neighbour (NN) which minimize the expected travel time from the current location to the target location and from location to the dock and two variations of NN that set limits on maximum waiting time for items. The results showed that the throughput for all systems was maximized when using those schedules (Randhawa and Shroff, 1994).

There are many factors was depends on AS/RS which is the dimensions of the storage rack, the horizontal and vertical speed of the crane, whether the crane perform single or dual cycles, initial loading of the system, and sequencing of storage and retrieval operations.

2.2 AUTOMATED STORAGE SYSTEMS

The primary examples of automated storage systems are automated storage and retrieval system (AS/RS) and carousel storage systems. The general objective of storage system is to store materials for a certain period. Normally the basic AS/RS consists of rack structure for storing load and the motions of a storage/retrieval mechanism are linear (x-y-z direction) compare to a basic carousel system uses bins or baskets hanging from an overhead conveyors that revolve around an oval track loop to transport the bins or baskets to a load/unload station (Groover, 2008). The differences between an AS/RS and a carousel storage system are presented in Table 2.1. The types of materials that are stored by most manufacturing companies are shown in Table 2.2. Actually, most production plants use conventional or manual method for storing and retrieving items into and from storage. Automated methods are appropriate for those companies to treat the problem storage especially for worldwide company.

Table 2.1: The differences between AS/RS and carousel storage system

Feature	**Basic AS/RS**	**Basic carousel storage system**
Storage structure	Rack system to support pallets	Baskets or bins suspended from overhead conveyor trolleys
Motions	Linear motion of storage/retrieval (S/R) machine	Revolution of overhead conveyor trolleys around oval track
Storage/ retrieval operation	S/R machine travels to compartments in rack structure	Conveyor revolve to bring baskets to load/unload station
Replication of storage capacity	Multiple aisles each consist of rack structure and S/R machine.	Multiple carousels each consist of oval track and suspended bins

Source: Groover, 2008

Generally, each company has different reasons for installing an automated storage system for storing materials. A list of possible objectives for installing an automated storage system in a warehouse is shown below.

i. Increase storage capacity.
ii. Increase storage density.
iii. Recover space for manufacturing facilities.
iv. Improve security and reduce pilferage.
v. Reduce labour cost in storage operations.
vi. Increase labour productivity in storage operations.
vii. Improve safety in storage function.
viii. Improve control over inventories.
ix. Increase stock rotation.
x. Improve customer service.

Table 2.2: Type of materials generally stored in a warehouse

Type	Description
Raw materials	• Raw stock to be processed or assembled by factor (e.g., sheet metal, bar stock).
Purchased parts	• Parts from vendors to be processed or assembled by factory (e.g., castings, purchased components).
Work in process	• Partially completed parts between processing and assembly operations.
Finished product	• Completed product ready to be shipped to customer.
Rework and scrap	• Parts that are out of specification, either to be reworked or scrapped; chips, other materials that must be discarded by the factory.
Tooling	• Cutting tools, jigs and fixtures, welding rod, other supplies, and tools used in the manufacturing and assembly operations; supplies used in factory (e.g., rags, gloves, helmets) are usually included in this category.
Spare part	• Spare parts used to repair machines and equipment in the factory.
Office supplies	• Supplies, paper, paper forms, and other items used in support of plant and company office staff.
Plant records	• Record on product, maintenance records.

Source: Groover, 2008

The AS/RS contains of four important categories that can be distinguished.

i. **Unit load AS/RS:** Normally, this is a large automated system designed to handle unit loads stored on pallet. This system is computer controlled where the storage/retrieval (S/R) machines are automated to control the unit loads.

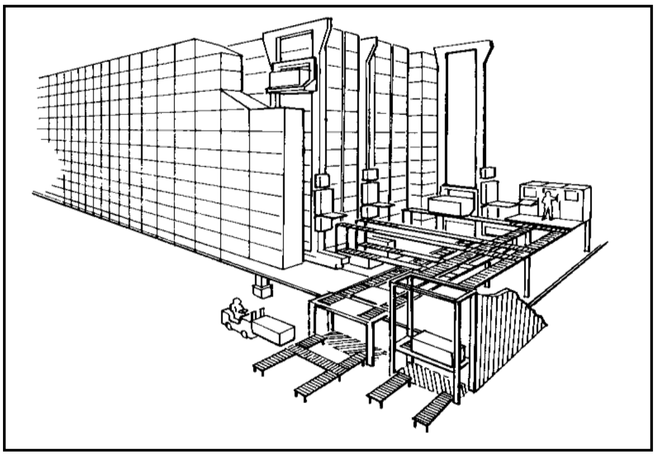

Figure 2.1: Unit load AS/RS

Source: www.ise.ncsu.edu

ii. **Mini load AS/RS:** This automated system is used to handle small loads are usually contained in drawers or bins within the storage system. For this system, S/R machine is designed to store and retrieve the drawer to an input/output point at the end of the aisle so that the items can be removing from the drawers. After that the drawer will be return to its location in the system.

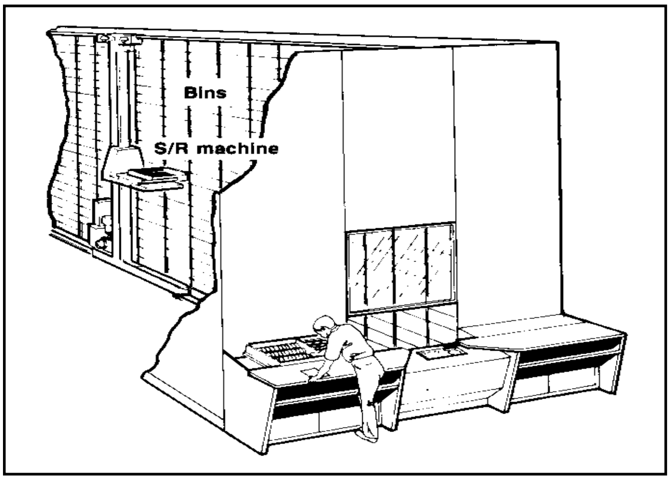

Figure 2.2: Mini load AS/RS

Source: www.ise.ncsu.edu

iii. **Man-on-board AS/RS:** This system is an alternative approach to the problem of storing and retrieving items. The man-on-board system allows the items to be picked directly at their storage locations which can contribute to reduce the transaction time.

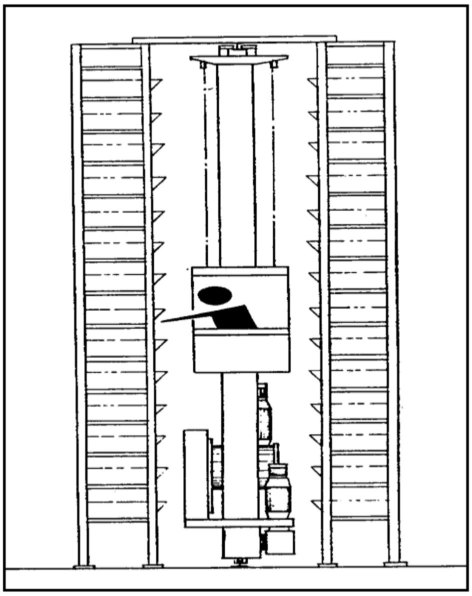

Figure 2.3: Man-on-board AS/RS

Source: www.ise.ncsu.edu

iv. **Deep-lane AS/RS:** This system is a high density unit load and suitable for those company want to store a large quantities but the number of separate types of material is quite small.

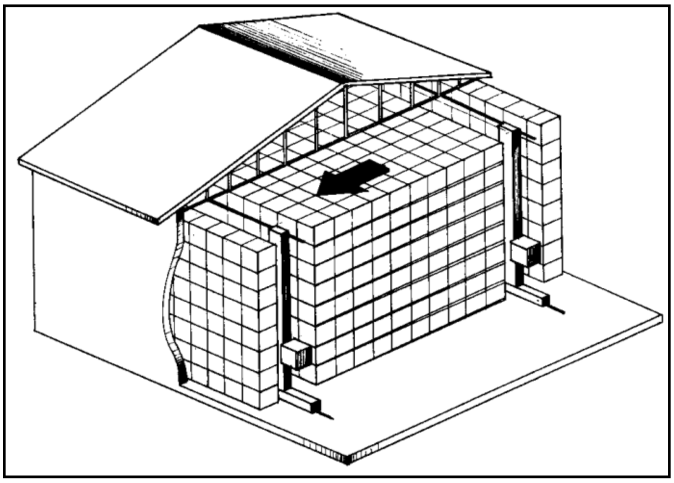

Figure 2.4: Deep-lane AS/RS

Source: www.ise.ncsu.edu

There are seven terms defined about AS/RS below are taken from Aslam, Gardezi, and Hayat, (2009).

Storage density: It is the volumetric space available for actual storage relative to the total volumetric space in the storage facility.

Storage capacity: It can be measured as the total number of storage compartments available in the system for items or loads.

Randomized storage: In this storage system the items are storage are at any available location.

Dedicated storage: In this storage system the items are assigned to specific locations.

Unit load: It is simply the mass that is to be handled at one time.

Single command cycle: In this cycle, storage or retrieval transactions are performed alone.

Dual command cycle: In this cycle, storage and retrieval transactions are performed one cycle.

2.2.1 Carousel Storage Systems

A carousel storage system is a series of bins or baskets fastened to carries that are connected together and revolve around long, oval track system. The typical of this system is mechanized rather than automated. The worker controls the load/unload station and activates the powered carousel to deliver a desired bin or basket to the station. There are several types of carousel storage system can be distinguishing such:

i. **Horizontal Carousels:** As a storage device, a horizontal carousel consists of a fixed number of adjacent storage columns or bays that are mechanically linked to either an overhead or floor mounted drive mechanism to form a complete loop. Each column is divided into a fixed number of storage location or bins which in most applications are constructed of a welded wire frame. Loads consisting of containers or totes may be inserted and retrieved either manually or by an automatic inserter/extractor mechanism. However, rotation of the carousel, whereby a specific storage location is brought to the picking location, is almost always controlled automatically.

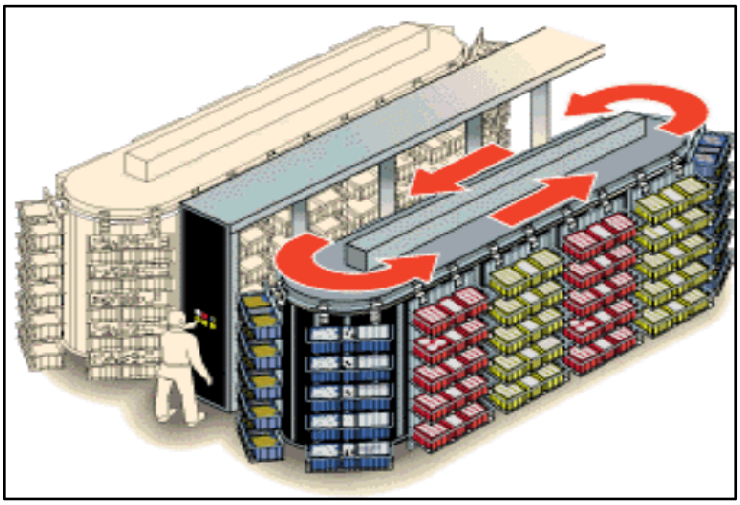

Figure 2.5: Horizontal carousels

Source: www.swautomation.com

ii. **Vertical Carousels:** As a storage device, a vertical carousel provides for closed loop automatically controlled rotation of the basic storage unit, which in this case may be a shelf that can be subdivided into multiple bin locations. However, a shelf or a given vertical position need not be divided in order to handle large items such as a bolt of fabric or a roll of carpet. Because storage is vertical, such systems are popular when conserving floor space. Although automatic insertion and extraction of individual items or loads is possible, it is not as common as it is with horizontal carousel applications.

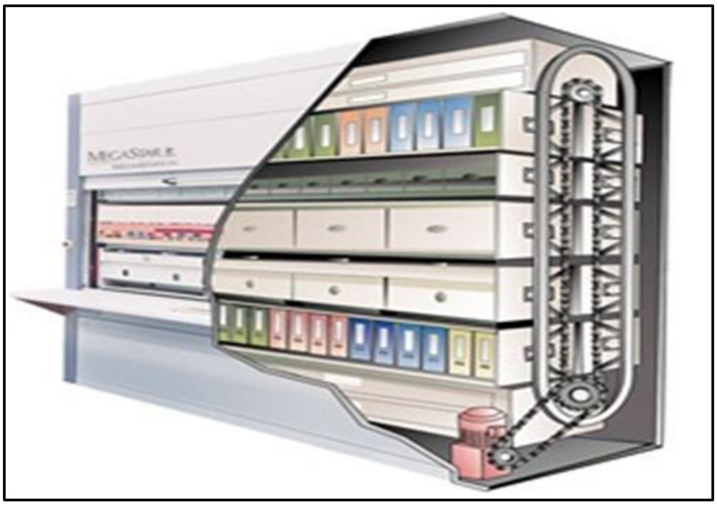

Figure 2.6: Vertical carousels

Source: www.southwestsolutions.com

2.3 AS/RS TYPES

There are four main components of AS/RS such as racks, cranes, aisles, and Input/output points (I/O-point) or pick/deposit station. Racks are usually metal structures that can accommodate loads that need to be stored. Cranes are the automated storage and retrieval machines that can automatically move, pick up and drop off racks or loads. Aisles are defined empty space between the racks, where the cranes can easily move. An input/output point (I/O-point) is a location where the incoming loads are pick up for storage and retrieve loads are drop off.

Pick positions are places where the labours are working to remove individual items from retrieved load before the load sent back for storage (Roodbergen and Vis, 2008).

The single unit-load aisle-captive AS/RS is the basic version which has in each aisle one crane, which cannot leave its aisle design (aisle-captive), and only one unit load can transport at a time (single shuttle). Product handling in this case is by unit load only; no need labours are involved to handle individual products. The racks are single deep, which means every load is directly accessible by the crane. Figure 2.7 is presented about an overview of AS/RS options.

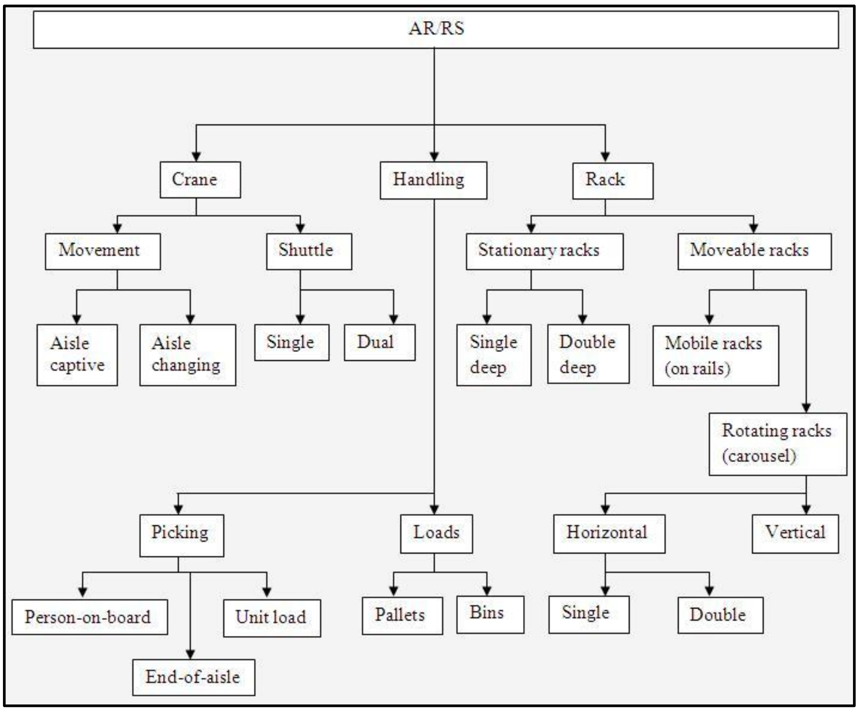

Figure 2.7: Classification of various AS/RS options

Source: Roodbergen and Vis, 2008

The basic AS/RS is when cranes are capable of changing aisles which means it is possible to have fewer cranes than aisles in the system. This may be useful if the amount of requests does not justify the purchase of a crane for each aisle. The multi shuttle cranes which a crane can transport two or more loads at a time. The dual-shuttle cranes can also transport two loads. Cranes capable of transporting more than two loads are still rarely seen.

Frequently, AS/RS is installed for handling units-loads only. Unit loads arrive at the I/O point of the AS/RS from other part of the warehouse such as automated guided vehicles, conveyors, or forklift truck. In the AS/RS the unit loads are stored and retrieved again after a period of time, for example to be shipped to a customer. Usually in many cases, only part of the unit load may be needed to fulfil a customer's order. This can be resolve by having a separate picking area in the warehouse where the AS/RS serves to replenish the picking area. Other option is to design the crane such the person can ride along (person-on-board). As a replacement for retrieving a full pallet automatically from the location, the person can pick the items from the location. The AS/RS drops off the retrieved unit loads at a workplace are ordinary option to integrate item picking. A person at this workplace takes the required amount of product from the unit load after which the AS/RS moves the remainder of the load back into storage rack. This system usually referred to as an end-of-aisle system. The system is generally called a mini-load AS/RS when the unit-loads are bins.

Single or double deep may occur when storage in the racks. For double deep rack, each rack location has space for two unit-loads where one load is stored in front of other load. A load can only be put into second position if there is no load in the first position. Double deep storage might be advantageous if the variety of loads is relative low and turnover rate of these loads is high. For storing small and medium sized products at different levels carousel system (horizontal or vertical, single or double) are appropriately. From the rotating carousel a crane is used to store and retrieve rack. For a double carousel, the upper and lower part can independently rotate of each other.

Finally, AS/RS can separate horizontal and vertical travel where vehicles travel horizontally over rails through aisles, while lifts are used to transfer loads vertically.

2.4 SIZING THE AS/RS STORAGE STRUCTURE

The total storage capacity of one storage aisle depends on how many storage compartments are arranged horizontally and vertically in the aisle as shown in Figure 2.8 (Groover, 2008). This can be expressed as follows:

$$capacity/aisle=2n_y n_z \tag{2.1}$$

Where:

n_y = number of load compartments along the length of the aisle.

n_z = number of load compartments that make up the height of the aisle.

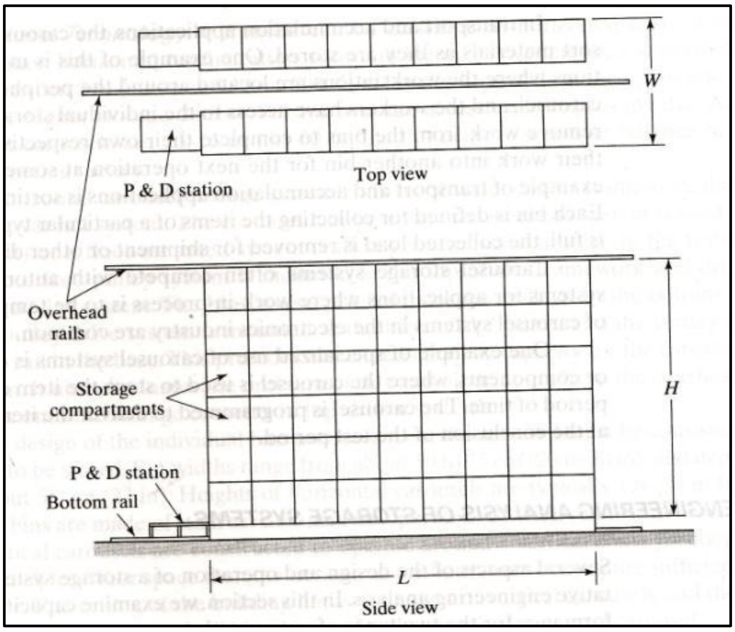

Figure 2.8: Top and side views of a unit load AS/RS, with nine storage compartments horizontally (n_y = 9) and six compartments vertically (n_z = 6)

Source: Groover, 2008

The constant 2, accounts for the fact that loads are contained on both sides of the aisle. If a standard compartments along is assumed (to accept a standard size unit load), then the compartment dimensions facing the aisle must be larger than the unit load dimensions. Let *x* and *y* = the depth and width dimensions of a unit load (example, a standard pallet size), and *z* = the height of the unit load.

The width, length and height of the rack structure of the AS/RS aisle are related to the unit load. The width, length, and height of the rack structure of the AS/RS aisle are related to the unit load dimensions and number of compartments as follows:

$$W = 3(x+a) \tag{2.2}$$

$$L = ny(y+b) \tag{2.3}$$

$$H = nz(z+c) \tag{2.4}$$

Where:

W, *L*, and *H* = width, length and height of the one aisle of the AS/RS rack structure, (m).
x, *y*, and *z* = the dimensions of unit load, (m).
a, *b*, and *c* = allowances designed into each storage compartment to provide clearance for the unit load and to account for the size of the supporting beams in the rack structure, (m).

For the case of unit loads contained on standard pallets, Groover, (2008) recommends values for the allowances as follows: *a* = 150mm, *b* = 200mm, and *c* = 250mm. An AS/RS with multiple aisles, *W* is simply multiplied by the number of aisles to obtain overall width of the storage system. The rack structure is built above floor level by 300 – 600 mm, and the length of the AS/RS extends beyond the rack structure to provide space for the Pick and Deposit (P/D) station.

2.5 AS/RS THROUGHPUT

The hourly rate of storage/retrieve transactions that the automated storage system can perform is called system throughput. A transaction involves depositing a load into storage or retrieving a load from storage. AS/RS throughput is increased by using dual command cycle compare in a single command cycle.

Several methods are available to compute AS/RS cycle times to estimate throughput performance. The method presented here is recommended by the Material Handling Institute as outline by Groover, (2008). It assumes:

i. Randomized storage of loads in the AS/RS (example, any compartment in the storage aisle is equally likely to be selected for a transaction).
ii. Storage compartments of equal size.
iii. The P/D station is located at the base and end of the aisle.
iv. Constant horizontal and vertical speeds of the Storage/Retrieve (R/S) machine.
v. Simultaneous horizontal and vertical travel.

For a single command for a single command cycle, the load to be entered or retrieved is assumed to be located at the centre of the rack structure. Thus the S/R machine must travel half length the length and half the height of the AS/RS and it must return to the same distance. The single command cycle time can be expressed by:

$$Tcs = 2Max\{\frac{0.5L}{Vy}, \frac{0.5H}{Vz}\} + 2T\,pd = Max\{\frac{L}{Vy}, \frac{H}{Vz}\} + 2T\,pd \quad (2.5)$$

Where:

Tcs = cycle time of a single command cycle, (min/cycle).

L = length of the AS/RS rack structure, (m).

H = height of the rack structure, (m).

Vy = velocity of the S/R machine along the length of the AS/RS, (m/min).

Vz = velocity of the S/R machine in the vertical direction of the AS/RS, (m/min).

Tpd = pickup and deposit time, (min).

Two P/D times are required per cycle, representing load transfer to and from the S/R machine. For dual command cycle, the S/R machine is assumed to travel to the centre of the rack structure to deposit a load, and then it travels to ¾ the length and height of the AS/RS to retrieve a load. The total distance travelled by the S/R machine is ¾ the length and ¾ the height of the rack structure, and back. For this case, cycle time can be expressed by:

$$Tcd=2Max\{\frac{0.75L}{Vy}, \frac{0.75H}{Vz}\} + 4T\ pd = Max\{\frac{1.5L}{Vy}, \frac{1.5H}{Vz}\} + 4T\ pd \quad (2.6)$$

Where:

Tcd = cycle time for dual command cycle (min/cycle)

The equation for the amounts of time spent in performing single and dual command cycles each hour is:

$$RcsTcs + RcdTcd = 60U \quad (2.7)$$

The right hand side of the equation gives the total number of minutes of operation per hour. To solve this equation the relative proportions of *Rcs* and *Rcd* must be determined, or assumptions about these proportions must be made. The total hour hourly cycle rate is given by:

$$Rc = Rcs + Rcd \quad (2.8)$$

Note that the total number of storage and retrieval transactions per hour will be greater than this value unless $Rcd = 0$, since there are two transactions accomplished in each dual command cycle.

$$Rt = Rcs + 2Rcd \quad (2.9)$$

Where:

Rcs = number of single command cycles performed per hour.

Rcd = number of dual command cycles per hour at a specified or assumed utilization level.

U = system utilization during the hour.

Rc = total S/R cycle rate, (cycles/hr).

Rt = total number of transaction performed per hour.

2.6 MICROCONTROLLER

Microcontroller is gaining popularity among technology user. For this project, the microcontroller was to be chosen to control this system. This because of its size, cost and the performance of the microcontroller is much better. There are containing at least two primary components in microcontroller which random access memory (RAM) and an instruction set. RAM is a type of internal logic that stores information temporarily. When the power is turned off the RAM contents is disappear. Whereas RAM is used to hold any kind of data, some RAM is specialized, referred to as registers. An instruction set is a list of all commands and their corresponding functions. The microcontroller will step through a program setup. To one differentiate one microcontroller from another, each valid instruction set and the matching internal hardware will be considering (Iovine, 2004).

The read-only memory (ROM), programmable read-only memory (PROM), or erasable programmable read-only memory (EPROM) are contain in most microcontroller. Basically, all of these are permanent they keep what is programmed even during loss of power. They are used to store the program that tells the microcontroller how to function. Regularly these memories cannot reside in the microcontroller instead they are contained in external integrated circuits (ICs), and the instructions are fetched as the microcontroller runs. This allows quick and low cost updates to the program by replacing the ROM.

Basically, a microcontroller contains two or more of the following elements below (Duarte, 1998):

i. RAM.
ii. Instruction set.
iii. ROM, PROM, or EPROM.
iv. Input/output ports.
v. Clock generator.
vi. Reset function.
vii. Watchdog timer.
viii. Serial port.
ix. Interrupts.
x. Timers.
xi. Analog to digital converters.
xii. Digital to analog converters.

2.6.1 Types of Microcontroller

This section contains device specific information for the following device below:

i. PIC18F242.
ii. PIC18F252.
iii. PIC18F442.
iv. PIC18F452.

These types of microcontroller come in 28-pin and 40/44-pin packages. The 28-pin microcontrollers do not have a Parallel Slave Port (PSP) implemented and the number of Analog-to-Digital (A/D) converter input channels is reduce to 5. Figure 2.9 is presented of microcontroller feature.

Features	PIC18F242	PIC18F252	PIC18F442	PIC18F452
Operating Frequency	DC - 40 MHz	DC - 40 MHz	DC - 40 MHz	DC - 40 MHz
Program Memory (Bytes)	16K	32K	16K	32K
Program Memory (Instructions)	8192	16384	8192	16384
Data Memory (Bytes)	768	1536	768	1536
Data EEPROM Memory (Bytes)	256	256	256	256
Interrupt Sources	17	17	18	18
I/O Ports	Ports A, B, C	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C, D, E
Timers	4	4	4	4
Capture/Compare/PWM Modules	2	2	2	2
Serial Communications	MSSP, Addressable USART	MSSP, Addressable USART	MSSP, Addressable USART	MSSP, Addressable USART
Parallel Communications	—	—	PSP	PSP
10-bit Analog-to-Digital Module	5 input channels	5 input channels	8 input channels	8 input channels
RESETS (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST)
Programmable Low Voltage Detect	Yes	Yes	Yes	Yes
Programmable Brown-out Reset	Yes	Yes	Yes	Yes
Instruction Set	75 Instructions	75 Instructions	75 Instructions	75 Instructions
Packages	28-pin DIP 28-pin SOIC	28-pin DIP 28-pin SOIC	40-pin DIP 44-pin PLCC 44-pin TQFP	40-pin DIP 44-pin PLCC 44-pin TQFP

Figure 2.9: Microcontroller feature

Source: www.microchip.com

In this project, the PIC 18F452 microcontroller is chosen to be used to control the movement of this system, so that the AS/RS can perform accordingly after processing the input signals received. This microcontroller is chosen because it small, provides enough input and output ports, availability of low cost, serial programming capability, and support more functions. In addition, a comprehensive set of development tools, application notes and datasheets are also available for download. Figure 2.10 shows the pin outs for the microcontroller.

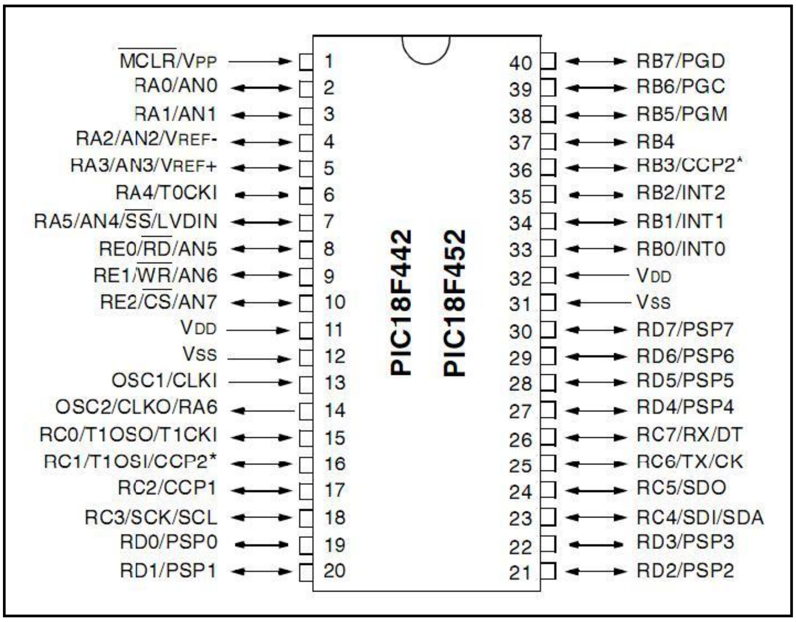

Figure 2.10: PIC 18F452 microcontroller

Source: www.microchip.com

2.7 CONCLUSION

As conclusion, the mini load AS/RS is chosen for the type of AS/RS because it’s compatible with the first objective of this project where to design a prototype of automated storage and retrieval system (AS/RS) for small loads. As mentioned before, PIC18F452 microcontroller is chosen in this project in order to control the movement of S/R machine.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This project is divided into two parts. First is the mechanical design such design and fabricate a prototype of the AS/RS. The other part is the electrical design. This project must be done step by step. It begins with searching and collecting the information related to this project from other related scientific perspective. The review is about the mechanical structure design of the AS/RS, electronic circuit design and also software programming implementation.

This project began by finding the concept and idea related to this title from the literature reviews. The AS/RS depending on how it will be design and programmed should follow the entire characteristic like to retrieve and store the individual item. A survey regarding prices, availability, and choices had be done on the component that will be used. Then, research on mechanical design how to create and other mechanical part look alike. The process designs were begun with sketching the several drawing were depending the best mechanism of the AS/RS. After that, the best drawing will be selected and create in three dimensional (3D) drawing by using Solidworks software. Furthermore, electrical circuit design also was considered as well as refers the mechanical design mechanism. Just after completing the design of mechanical and electrical part, it proceeds to fabricate and assemble the mechanical design. The next process is to build and construct the breadboard for the electrical circuit followed by developing the software in C programming. Trouble shoot will always be done as long as there is an error in final testing to get final product.

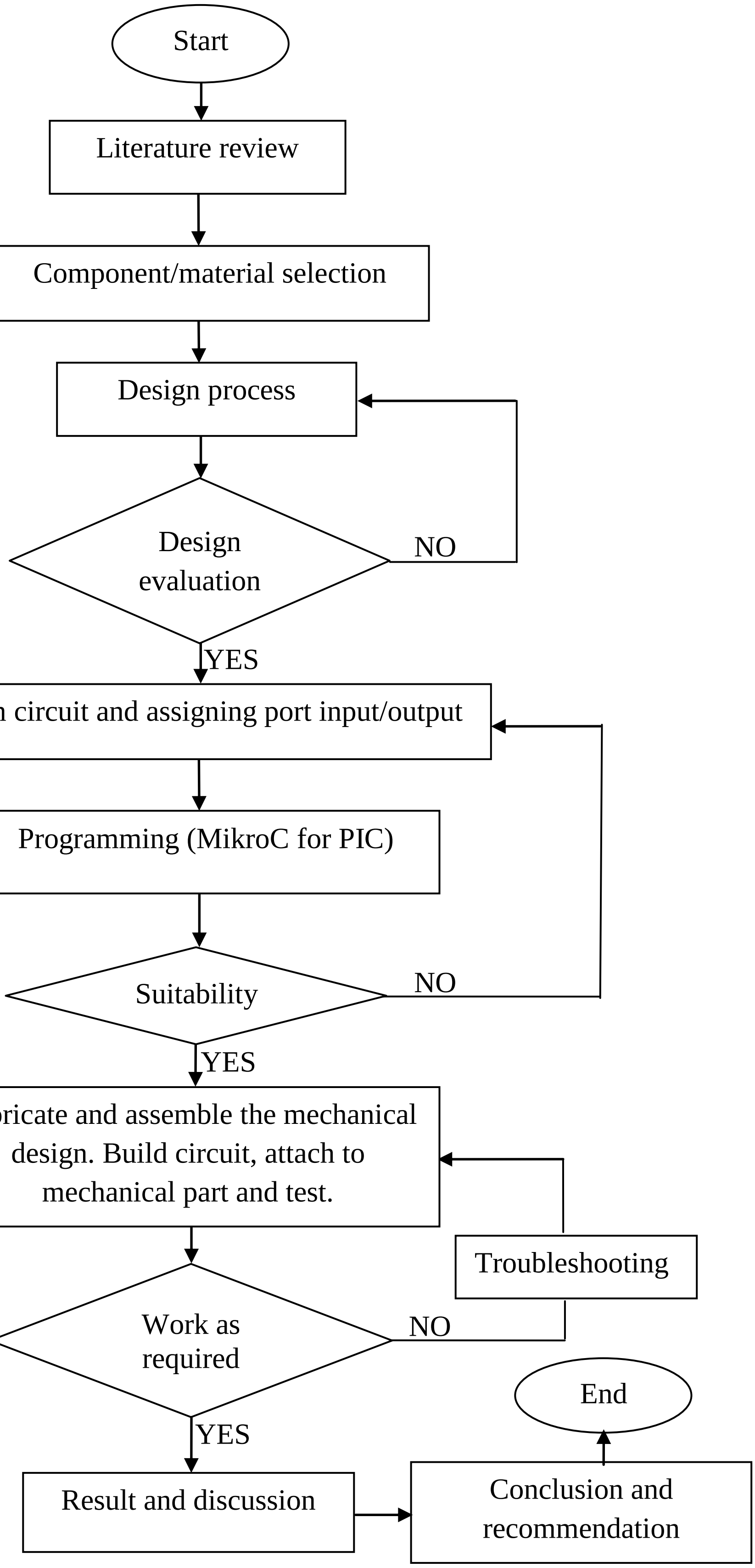

Figure 3.1: Flow Chart for Project Methodology

3.2 COMPONENT AND MATERIAL SELECTION

There are two parts of component to be selected in order to design and fabricate a prototype of the AS/RS. The first part is mechanical component and the second part is electrical component. The built AS/RS consist of mechanical main structure such storage/retrieval (S/R) machine, pulley, spur gear, and rack and pinion gear. Most of these parts were built from raw material and some are modified to congruent with this project. Most of the material used is carbon steel, iron, and sheet metal aluminium. Aluminium is used in this project to built most of the part in order to obtain a light of AS/RS. It is important to achieve the target so that the stepper motor can drive the S/R machine and able to store and retrieve the drawer. For electrical component, PIC18F452 microcontroller and stepper motor are chosen to be used to control and move the S/R machine. In order to get the excellent movement and return to the same location accurately, that why stepper motor is preferred.

3.3 MECHANICAL STRUCTURE DESIGN PROCESS

The engineering process is the decision making process which integrates the basic science, mathematics and engineering principles required in a project. The design process begins with an identified need, in this project it is need detail consideration of many factor to make sure the design can be fabricated and the parts are all functioning. For this project, the AS/RS under study is single aisle, small unit loads and one sided rack system served by a single storage/retrieval (S/R) machine. The pick and deposit (P/D) station or input/output point is located at the bottom left of the cabinet from front view and accessed by the S/R machine. The design of AS/RS is considered with the several assumptions below:

i. The system is being considered as mini load AS/RS.
ii. The first come first serve (FCFS) rule is used according to the items are selected for storage.
iii. According to randomized storage strategy the items are allocated to storage location.
iv. The single unit loads is specified for each storage location.

v. There are two rows and five columns of equally sized storage location in cabinet. Each location has length of 50 mm, width of 50 mm and height of 35 mm.

After the consideration with several assumptions above, AS/RS was designed with the following specifications:

Sizes of AS/RS:

i. Capacity= 5 x 2 = 10 storage compartments.
ii. Cabinet, length = 299 mm, width = 120 mm, height = 217 mm.
iii. Length = 692 mm.
iv. Width = 358 mm.
v. Height = 550 mm.

Unit load dimensions (drawer):

i. Length = 50 mm.
ii. Width = 50 mm.
iii. Height = 35 mm.

3.3.1 Sketching

From the assumption in Section 3.3, this project will start with brainstorming several designs of AS/RS. There are two sketches of design are shown in Figure 3.2 and Figure 3.3.

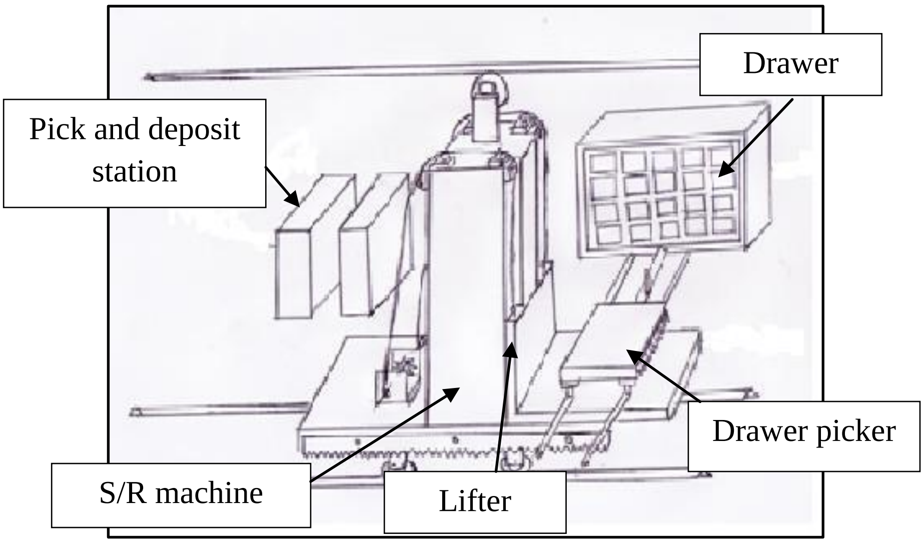

Figure 3.2: Single mast of S/R machine

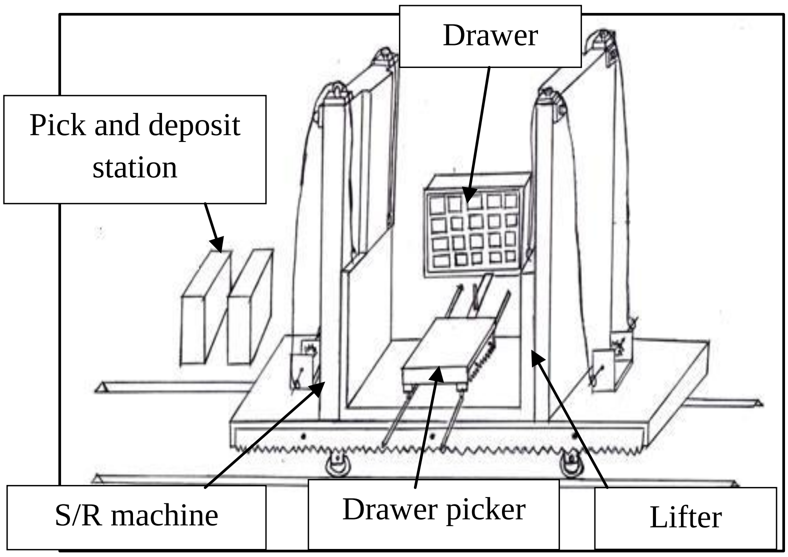

Figure 3.3: Double mast of S/R machine

From the design review, actually the mechanism for both design are same but the different is the type of S/R machine where Figure 3.2 is single mast and Figure 3.3 is double mast. Criteria or characteristic for the design to be fabricated are the important thing to be considered. The important criteria are durability, ease to use, ease to handling, ease of manufacture, product manufacturing cost, material requirement and safety to use. After considered the important criteria above, Figure 3.2 was selected as the best design for this project.

3.3.2 Computer Aided Design Drawing

After the selected design was chosen, the sketched design was transferred to solid modelling and engineering drawing using Solidworks software. The design was separated into part by part and the dimensioning process was firstly sketched on paper. Finally, the engineering drawing of the design was drawn using Solidworks software application. Part by part solid modelling created according to the dimension done before, after all part created, the 3D model was assembled with each other based on the design. Figure 3.4 until Figure 3.8 shows the 3D drawing model.

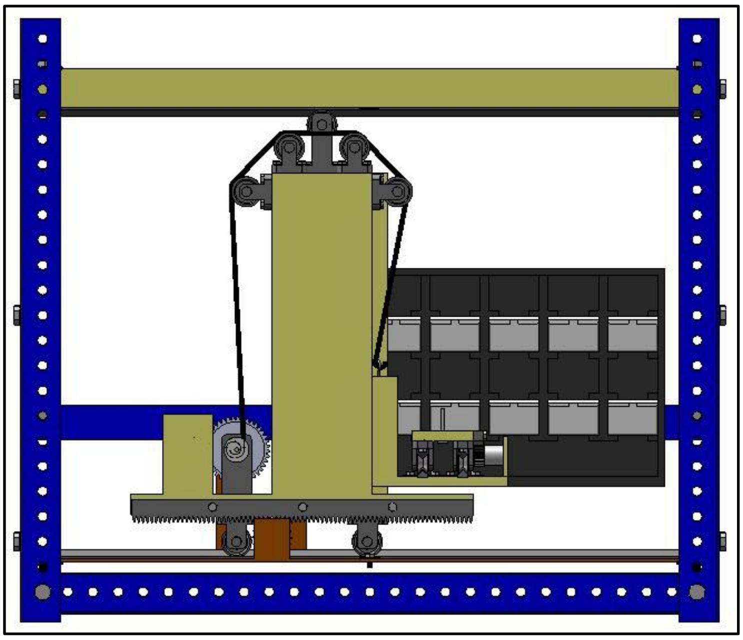

Figure 3.4: Front view of AS/RS

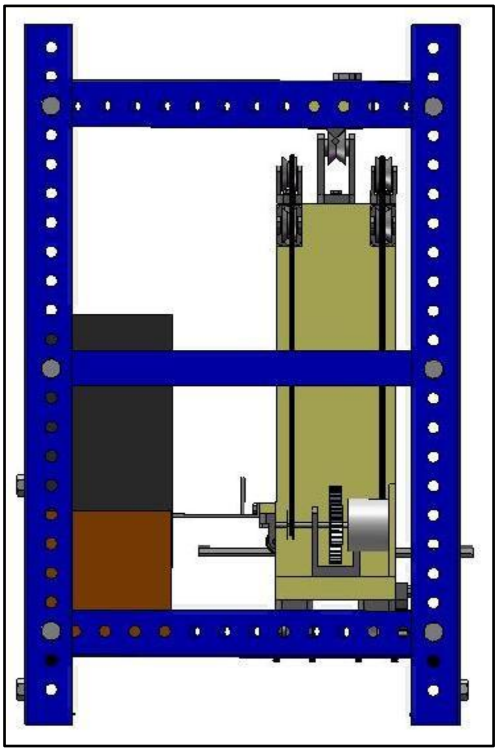

Figure 3.5: Left side view of AS/RS

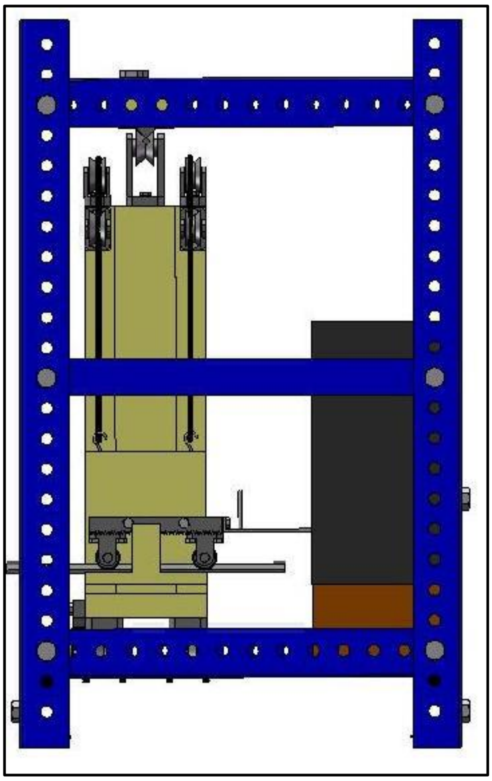

Figure 3.6: Right side view of AS/RS

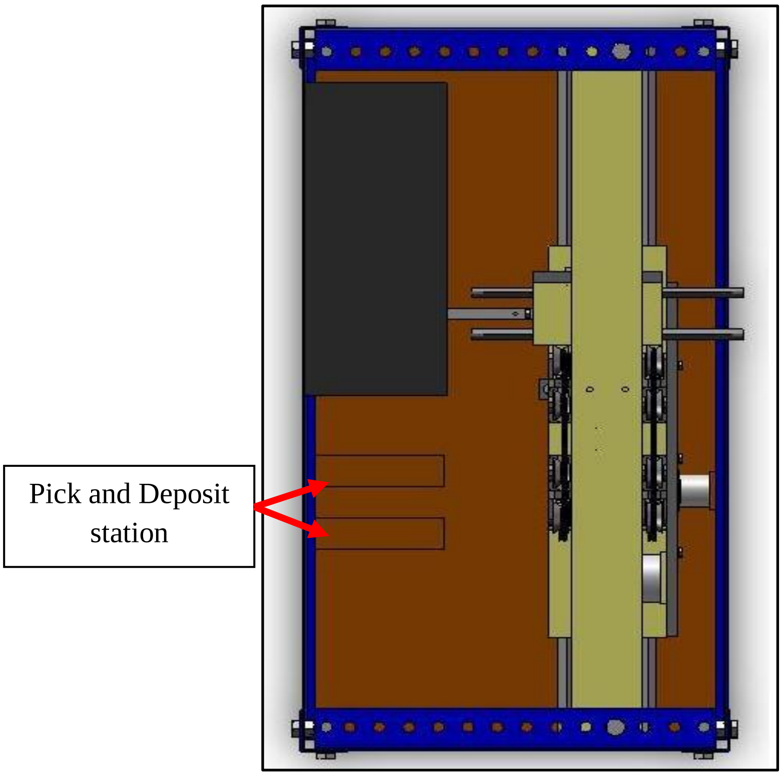

Figure 3.7: Top view of AS/RS

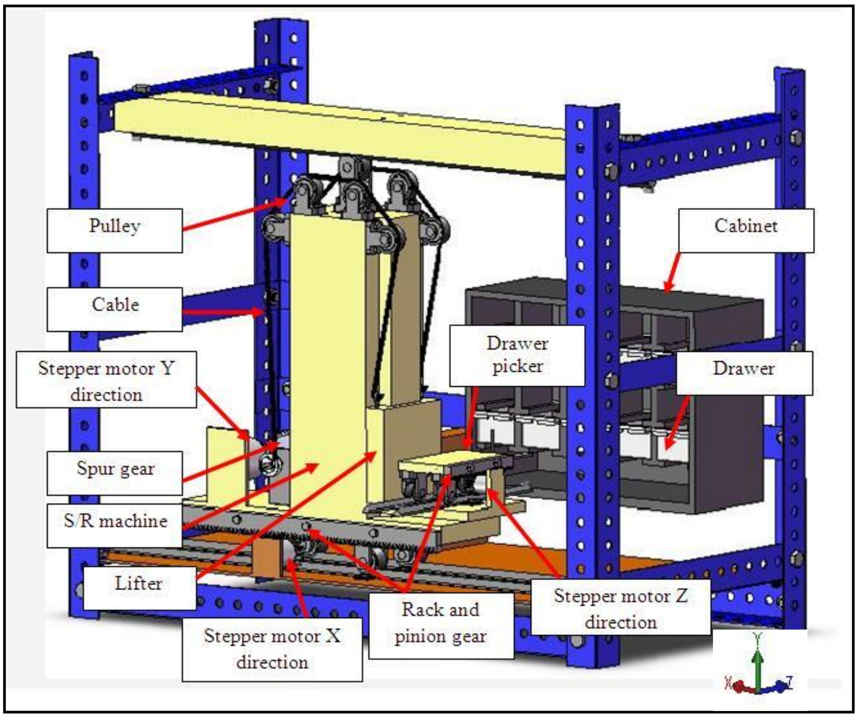

Figure 3.8: Isometric view of AS/RS

The design of AS/RS is mainly inspired from the Figure 3.8. There are lot innovations and ideas have been done from the sketching. The main objective in this chapter to construct the mechanical structure as followed the selected design. AS/RS structure was built for the target of following the store and storage the small drawer. In order to do that, a few design of this kind of AS/RS has been studied.

The AS/RS was built consists of rack and pinion gear, spur gear, pulley, cable, P/D position and mechanical main body (S/R machine, lifter and drawer picker). The movement of this AS/RS consists of three direction which X direction, Y direction and Z direction. This AS/RS are powered by a three of battery 9 Volts. Three stepper motor are needed where stepper motor X direction in order to move S/R machine forward and reverse direction, stepper motor Y direction is used to lift the drawer picker, and stepper motor Z direction is used to move drawer picker also forward and reverse direction.

3.3.3 Stepper Motor

In this project there are three stepper motor needed for the movement x, y, and z direction. Stepper motor in Figure 3.9 is used for x direction in order to move S/R machine forward or reverse and for y direction due to going up or going down the lifter. Stepper motor in Figure 3.10 is used for z direction in order to move the drawer picker also forward or reverse. All the stepper motor is the same in term of functionality. These motors can be programmed to move it shaft to a specific angle where the shaft can turn from 0º to 360º or vice versa if given the right signal.

Figure 3.9: 103-807-S unipolar stepper motor

Figure 3.10: PM42S-048 unipolar stepper motor

103-807-S unipolar stepper motor specifications

Volume: 0.0003436 m^3
Number of steps per rotation: 1.8º/step
Drive method: 2-phase
Drive voltage: 5 V

PM42S-048 unipolar stepper motor specifications

Volume: 0.00001271 m^3
Number of steps per rotation: 7.5º/step
Drive method: 2- 2phase
Drive voltage: 9 V

3.4 FINALIZED DESIGN

After the design was finalized, the overall objective for the first stage of the development of AS/RS was accomplished. The finalization was done after consider overall of aspect during literature review, sketching, material selection and cost. Then, the upcoming process will be writing and preparation for fabrication.

3.5 MATERIAL AND EQUIPMENT PREPARATION

The next process in this project executed is preparation for fabrication. The purpose of this process is to give the specific idea on how to fabricate the AS/RS, where to get the material, component and equipment for fabrication and what type of real time testing should be implementing in order to estimate the AS/RS performance. The type of material and component used to fabricate the AS/RS as mentioned in Section 3.2. The equipment for fabrication will involve heavy machine such as hydraulic shear machine, truma bend v series machine, drilling machine and rivet pop gun.

3.6 THE FABRICATION

The fabrication began after all the selected materials were completely obtained. The purpose here to fabricate the prototype as exactly equal to initial specification during design except there is circumstances that excuse the modification. Fabrication process was used at the whole system production. This was include part by part fabrication until assembly to others component. The fabrication was started with S/R machine, lifter and drawer picker where the specification as followed the Appendix A1, Appendix A2, and Appendix A3 respectively. The other part such as spur gear, rack and pinion gear, and pulley were ordered at T.S.M Gear Company to manufacture because of the component is special size.

3.6.1 Process of Fabrication

In order the make the design come to the reality, fabrication processes need to be done appropriately. The processes involved are:

i. **Measuring:** Sheet metal aluminium was measured to desired dimension by using measuring tape.
ii. **Marking:** All measured materials need to marked to give precise dimension.
iii. **Cutting:** Sheet metal aluminium was then cut into dimension needed by using hydraulic shearing machine as shown in Figure 3.11.
iv. **Bending:** By using truma bend v series machine as shown in Figure 3.12, the materials were bended into 90º as following the dimension requirement.
v. **Drilling:** Marked the holes are then drilled to make holes for assembled the part by using drilling machine as shown in Figure 3.13.
vi. **Joining:** Sheet metal aluminium was joined by the method of rivet pop by using rivet pop gun as shown Figure 3.14.

Figure 3.11: Hydraulic shear machine

Figure 3.12: Truma bend V series machine

Figure 3.13: Drilling machine

Figure 3.14: Rivet pop gun

3.7 BASIC CIRCUIT FOR PIC 18F452

Figure 3.15 shows the minimum circuit required by the PIC 18F452 in order to function. S1 is the push button to reset the PIC microcontroller. The input/output port (RA, RB, RC and RD) can be connected to application circuit.

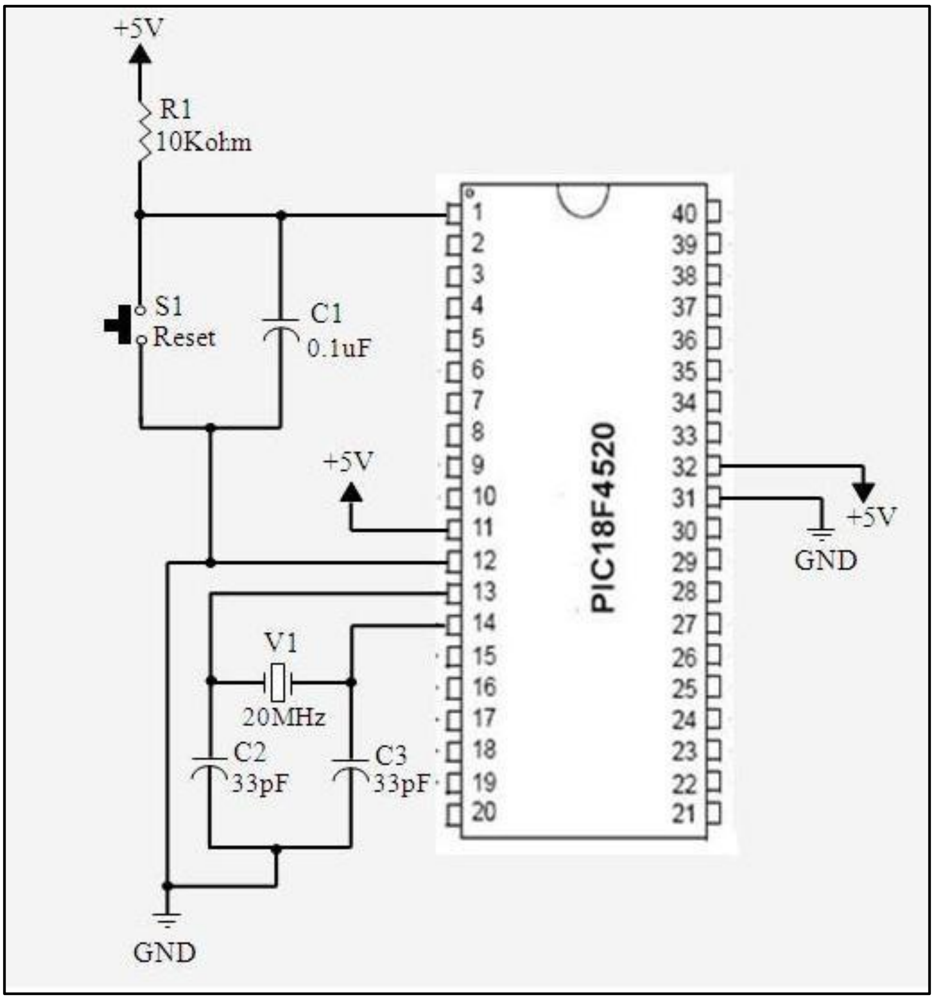

Figure 3.15: Schematic diagram for PIC 18F452 circuit

In this project, there are 3 inputs of PIC 18F452 is used. The inputs are stepper motor 1, stepper motor 2, and stepper motor 3 that are connected to port (RA0, RA1, RA2, and RA3), (RB0, RB1, RB2, AND RB3) AND (RC0, RC1, RC2, and RC3) respectively.

3.7.1 Stepper Motor Circuit

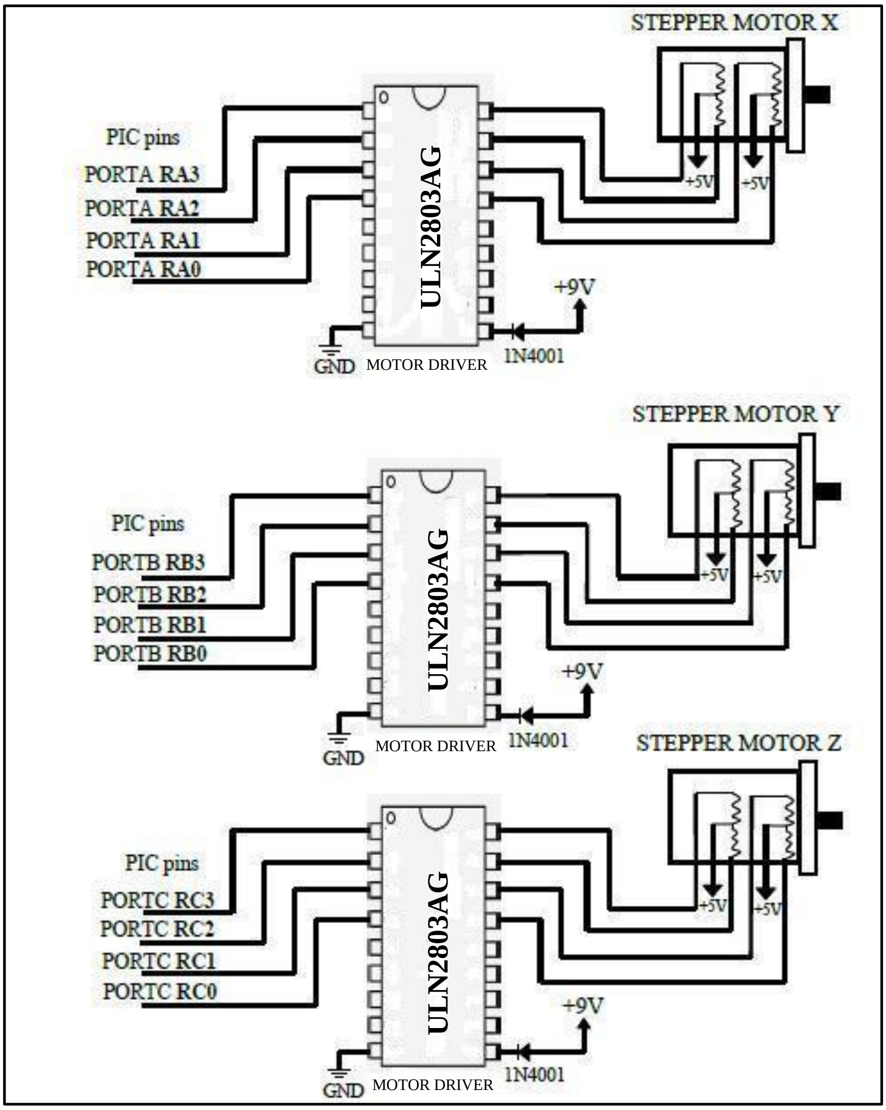

Figure 3.16: Schematic diagram for stepper motor circuit

The stepper motor circuit consists of three motor drivers (ULN2803AG) were used in order to prevent motor from burnt due to its capability that easily burnt when the current flow through it exceed current allowed and to control movement of stepper motor. The motor driver requires 9 Volts for control connection and stepper motor requires around 5 to 9 Volts in order to operate.

3.8 SOFTWARE PROGRAMMING DESIGN

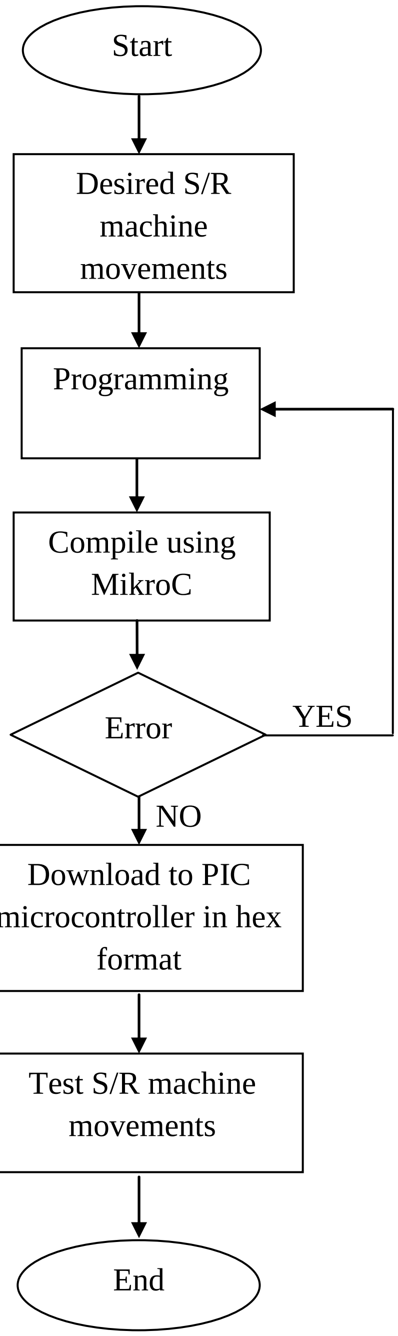

Figure 3.17: Process flow chart for PIC programming

For the programming part, there are consists of two software and a hardware was used. The mikroElektronika (MikroC) compiler used to compile the C code to the hex code. WinPic800 is used to load the hex file into microcontroller by using USB PIC programmer. In this project, C language was used in programming microcontroller. So the mikroC software is needed to compile the C language before programmed into microcontroller. WinPic800 is software is used to load the hex file into microcontroller by using USB PIC programmer.

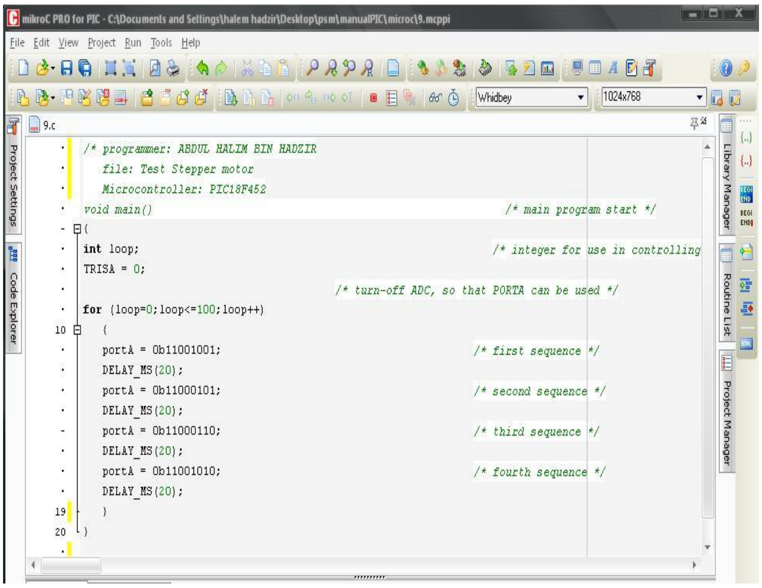

Figure 3.18: MikroC compiler

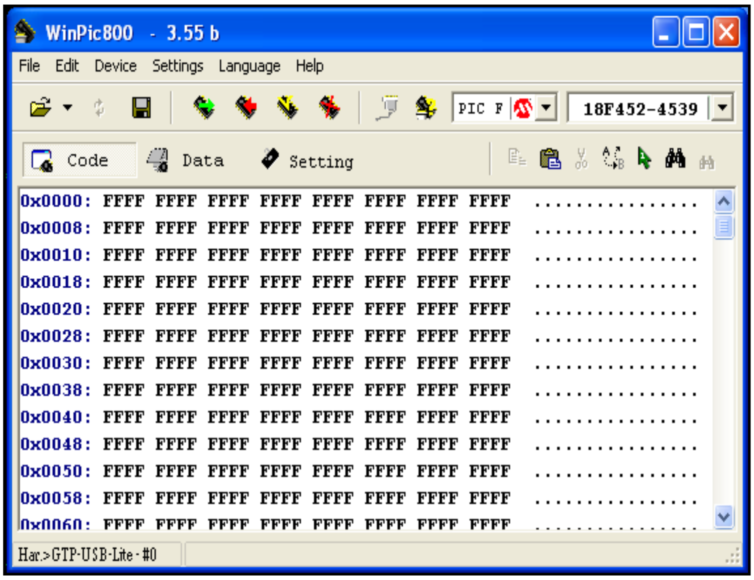

Figure 3.19: WinPIC800 interface

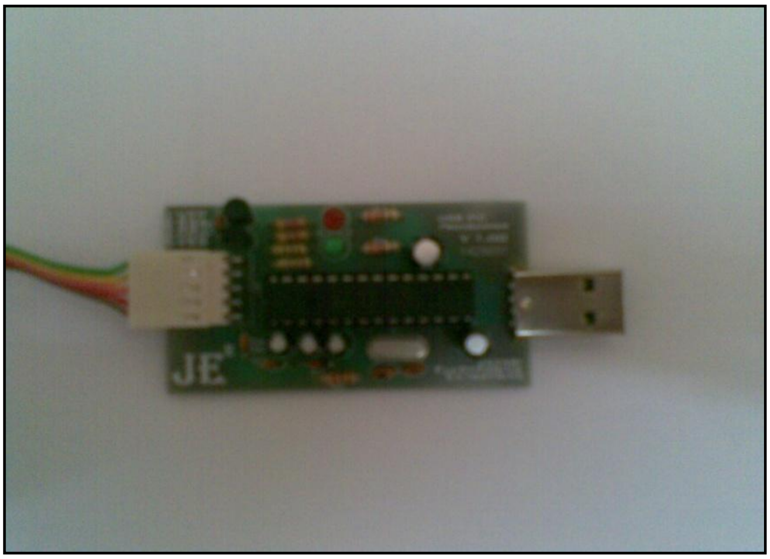

Figure 3.20: JAZARI USB PIC programmer

3.8.1 Stepper Motor Programming

```
Void main ( )                                   /* main program start */
{
int loop;                                   /* integer for use in controlling the loop */
TRISA = 0;
                                        /* turn-off ADC, so that PORTA can be used */
for (loop=0;loop<=100;loop++)
  {
  portA = 0b11001001;                           /* first sequence */
  DELAY_MS(20);
  portA = 0b11000101;                           /* second sequence */
  DELAY_MS(20);
  portA = 0b11000110;                           /* third sequence */
  DELAY_MS(20);
  portA = 0b11001010;                           /* fourth sequence */
  DELAY_MS(20);
  }
```

The program for an AS/RS must be able to move forward and reverse into three directions (x, y, and z direction). The programming was tested on the stepper motor how it rotation regarding the generated pulse by microcontroller. The programming above primarily show for stepper motor movement only with various speed and direction. The C languages used in the programming of microcontroller are referred from Tan and D’orazio, (1999). The overall programming is showed in Appendix D1 until Appendix D10.

3.9 CONCLUSION

This chapter describe research methodology consist of mechanical structure design, electronic system design, and software programming design. For mechanical structure design it shows AS/RS's structure. The main part of AS/RS's structure consists of S/R machine, lifter, drawer picker, small cabinet, and stepper motor. This part discussed on how to fabricate AS/RS and material selection. For the electronic system design, two circuits had been built such as main circuit of microcontroller and stepper motor circuit. Finally, focus on software development of AS/RS programming whereby it starts on writing the program using C language programming. The mikroC compiler and its development tools include WinPIC800 and USB PIC programmer was used.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The objective of this chapter is to provide a review of result fabrication of real prototype and followed by discussion related to the results presented. This chapter consists of two stage where for the first stage will focus about the fabrication result of the real prototype. As the prototype finished, the real time test was done in order to observe the performance of manufactured prototype. For real time testing, only few numerical values were documented as the test only done by recorded observation. At the same time, the discussion about the different of AS/RS specification was target and AS/RS specification when completed. The second stage will discuss about power and torque transmitted to this system. In conjunction with the progress of the project, several calculations were made so that AS/RS will achieve desired task. However, the design only focuses on the operating principles and design simplicity. Finally, all results were documented properly in order to offer sequential flow of result obtained as the development progress from time to time.

4.2 RESULT OF FABRICATION

The fabrications mark the progress of the development as the crucial stage for real time testing. The fabrication initiated strictly according to initial specification unless the predicament prevent it to be so. Whereas certain areas need to be troubleshooting, the fabrication differs from initial arrange. The complete fabrication of AS/RS is shown in Figure 4.1, Figure 4.2, Appendix C1, and Appendix C2.

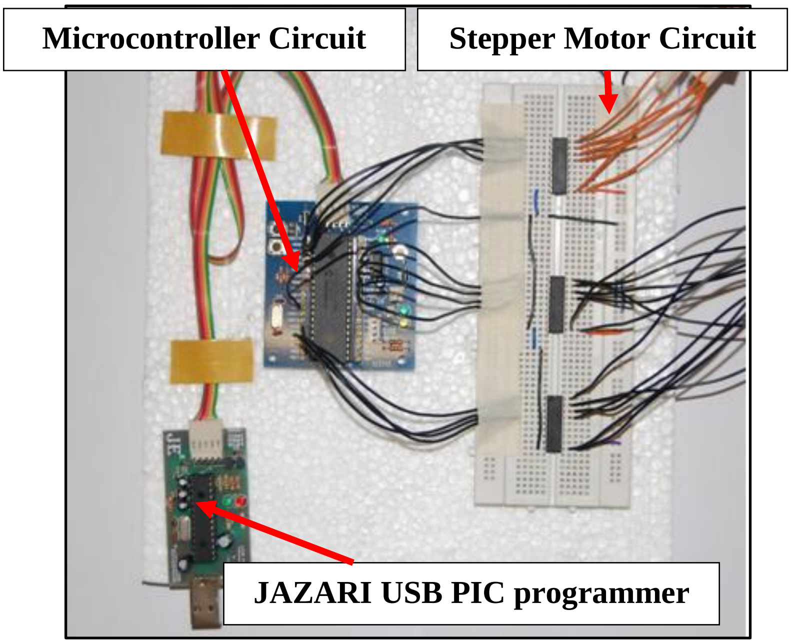

Figure 4.1: Control system circuit

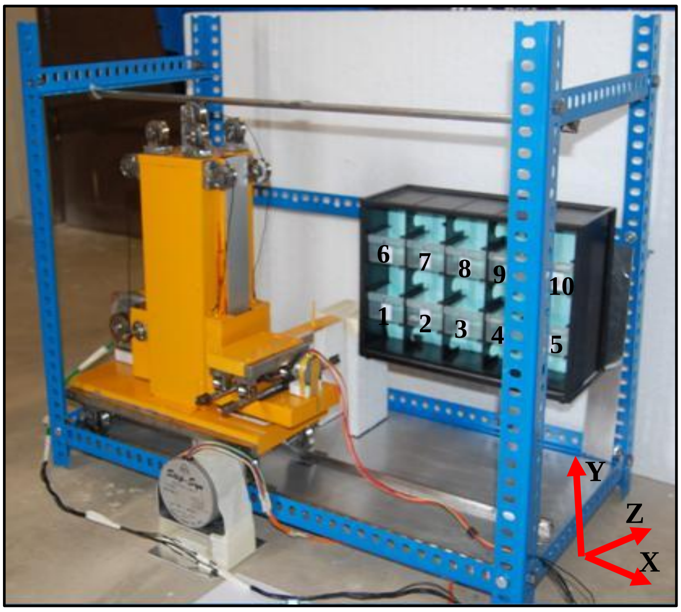

Figure 4.2: Isometric view of AS/RS prototype

4.2.1 Properties of Components/Part

The AS/RS itself made of different components. These components properties affect the overall performance of design. Any missing information will cause the incapability of the stepper motor to perform the desired task. Table 4.1 numerically records the component's properties. These properties were meant to be the volume sum up and the total weight of AS/RS. In significance, the density and weight of the AS/RS could be easily resolute.

Table 4.1: Properties of components

Component	Area, m^2	Volume, m^3	Weight, N
S/R machine	0.01564	0.004691	36.80712
Lifter	0.022	0.00055	4.4204
Drawer picker	0.00902	0.0001012	4.5734
Stepper motor x and y direction	0.005542	0.0003436	12.6843
Stepper motor z direction	0.000908	0.00001271	0.9045
Overall	0.05311	0.005698	59.3897

4.3 THE MODIFICATION

The prototype was modified due to several problem occur during fabrication but the mechanism of the system still same. The problem is lack of space to locate the stepper motor for y direction into S/R machine. This problem lead to modification of prototype where increasing the width of S/R machine from 100mm to 150mm. Figure 4.3 represents the additional width of S/R machine during its fabrication process. The complete prototype after finishing touch up can be seen in Figure 4.4.

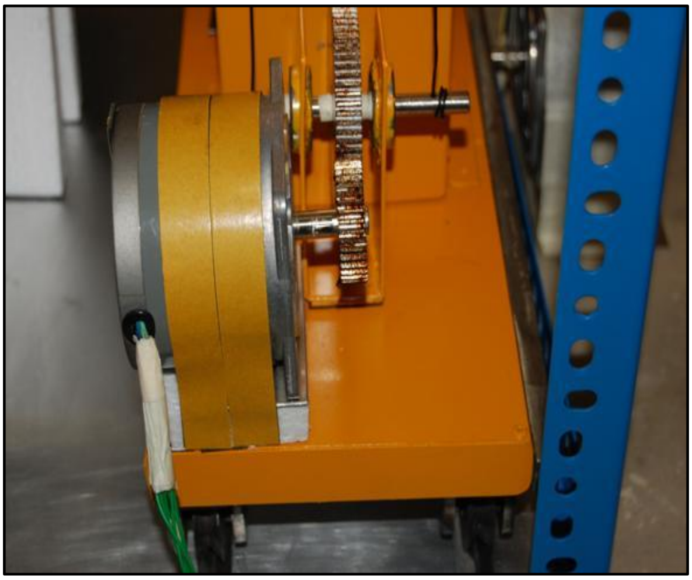

Figure 4.3: Modification of AS/RS prototype

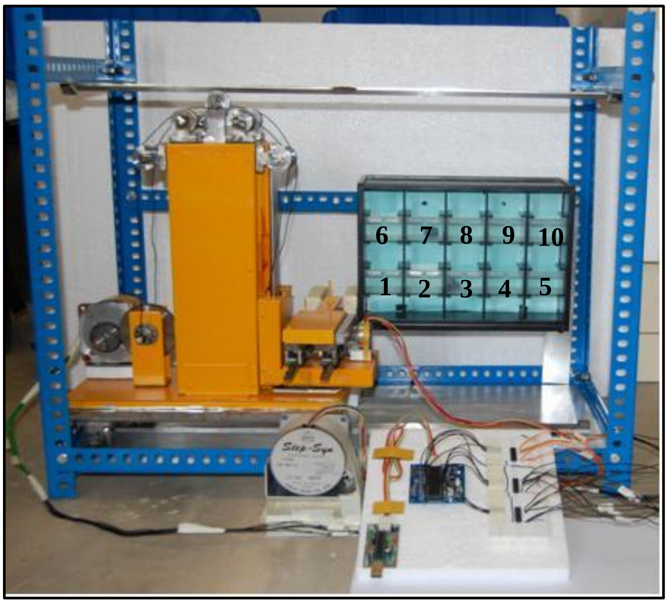

Figure 4.4: The complete prototype

4.4 THE REAL TIME TESTING

The real time testing was major step take in the development of the project. In this part AS/RS was tested in order to know how the performance of AS/RS during store and retrieve the drawer. Figure 4.4 shows initial position of S/R machine before it was moved. A transaction involves storing a drawer into storage (cabinet) or retrieving a drawer from cabinet. Either one of these transactions alone is accomplished in a single command while a dual command cycle represents both transaction types in one cycle.

Figure 4.5 shows the movement of S/R machine in order to retrieve the drawer from cabinet. The sequential figures were shown in alphabetical order.

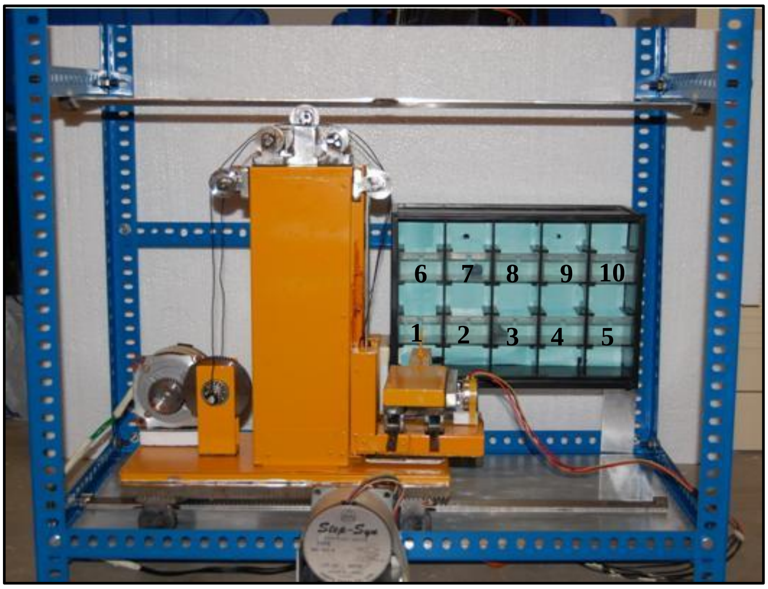

Figure 4.5a: S/R machine move to right

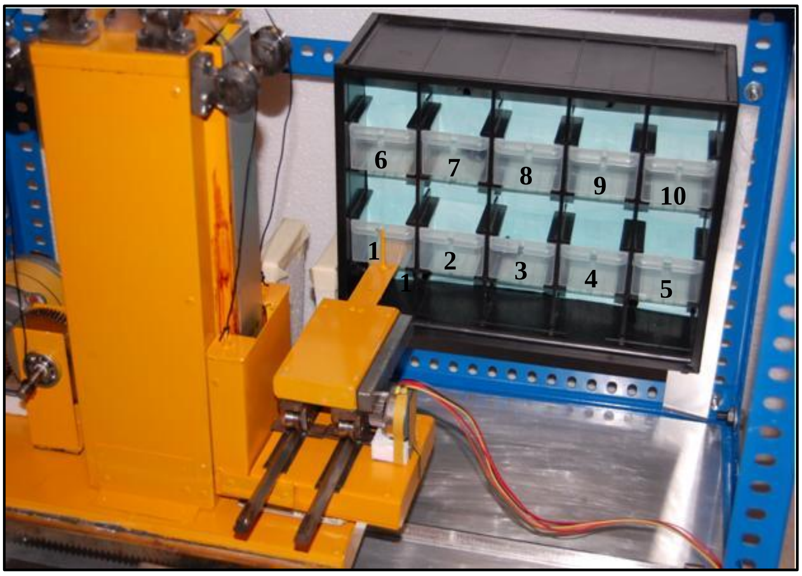

Figure 4.5b: Drawer picker move forward

Figure 4.5c: Drawer picker move reversely with the drawer

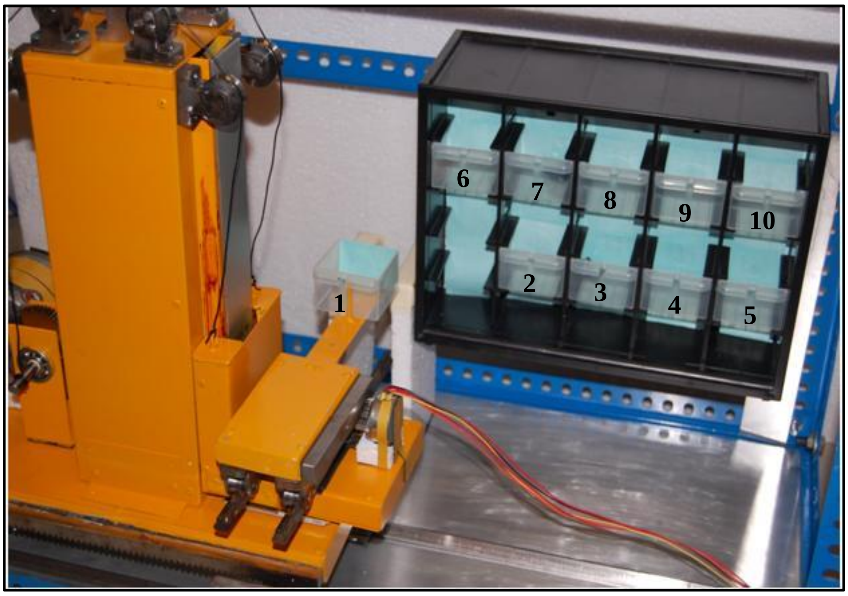

Figure 4.5d: S/R machine move to left until initial position

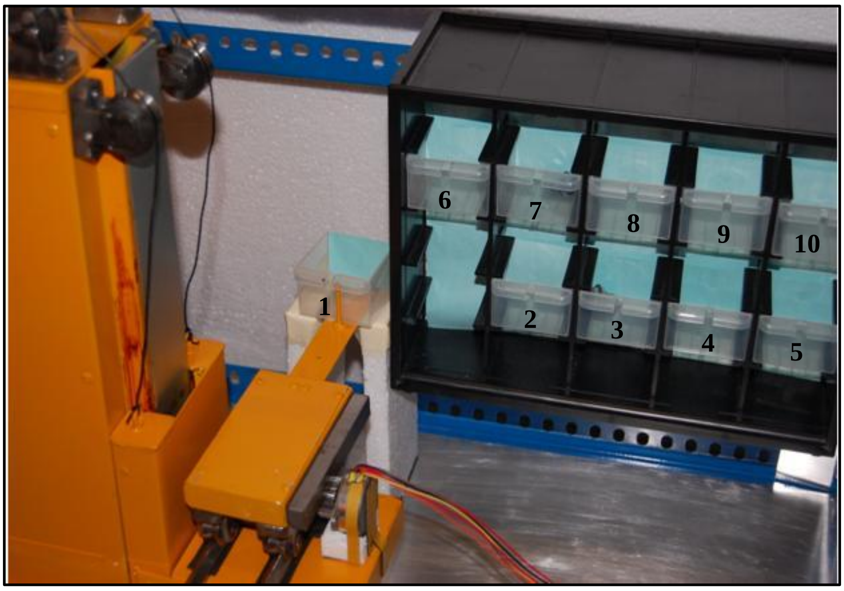

Figure 4.5e: Drawer picker move forward until arrive P/D station

Figure 4.5: Transaction involves retrieving the drawer from cabinet

In order to conduct analysis for selected component, there are few parameters which need to be predetermined before analysis could be conducted individually. From previous studies (Aslam,Gardezi, and Hayat, 2009), it could be seen that average velocity of S/R machine is approximately 0.1m/s, and 0.05 m/s for horizontal and vertical direction respectively. Therefore, from the real time testing, the velocity for S/R machine(x direction), lifter (y direction) and drawer picker (z direction) is represents in Table 4.2 until Table 4.7.

Table 4.2: Velocity and acceleration of S/R machine for drawer coordinate x=1 and y=2

Drawer coordinate x=1 and y=2		
No.	**Time, s**	**Distance, m**
1	5.64	0.0825
2	5.47	0.0825
3	5.57	0.0825
Average	5.56	0.0825
Velocity, m/s	0.01484	
Acceleration, m/s²	0.001335	

Table 4.3: Velocity and acceleration of S/R machine for drawer coordinate x=5 and y=2

Drawer coordinate x=5 and y=2		
No.	**Time, s**	**Distance, m**
1	21.14	0.31
2	21.04	0.31
3	21.08	0.31
Average	21.09	0.31
Velocity, m/s	0.01470	
Acceleration, m/s²	0.0003485	

Table 4.4: Velocity and acceleration of lifter for drawer coordinate x=1 and y=2

Drawer coordinate x=1 and y=2		
No.	**Time, s**	**Distance, m**
1	44.86	0.084
2	45.01	0.084
3	44.95	0.084
Average	44.94	0.084
Velocity, m/s	0.001870	
Acceleration, m/s²	0.00002081	

Table 4.5: Velocity and acceleration of lifter for drawer coordinate x=5 and y=2

Drawer coordinate x=5 and y=2		
No.	**Time, s**	**Distance, m**
1	44.67	0.084
2	45.10	0.084
3	44.87	0.084
Average	44.90	0.084
Velocity, m/s	0.001871	
Acceleration, m/s^2	0.00002084	

Table 4.6: Velocity and acceleration of drawer picker for drawer coordinate x=1 and y=2

Drawer coordinate x=1 and y=2		
No.	**Time, s**	**Distance, m**
1	2.28	0.075
2	2.02	0.075
3	2.14	0.075
Average	2.15	0.075
Velocity, m/s	0.03488	
Acceleration, m/s^2	0.008111	

Table 4.7: Velocity and acceleration of drawer picker for drawer coordinate x=5 and y=2

Drawer coordinate x=5 and y=2		
No.	**Time, s**	**Distance, m**
1	2.20	0.075
2	2.10	0.075
3	2.06	0.075
Average	2.12	0.075
Velocity, m/s	0.03538	
Acceleration, m/s^2	0.008345	

Based on Table 4.2 until Table 4.7, the average velocity for S/R machine, lifter and drawer picker is 0.01477 m/s, 0.001871 m/s, and 0.03513 m/s respectively. The difference velocity occurred because the different weight of component, type of stepper motor used, surface friction, and human error during taken the time.

The transaction time involves depositing a drawer into cabinet and retrieving a drawer from cabinet are presented in Table 4.8. The variation time shows in Table 4.8 during the transaction because the different coordinates of drawer at the cabinet.

Table 4.8: Transaction time

Drawer	Time for store, s	Time for retrieve, s
Coordinate x=1 and y=1	66	49
Coordinate x=2 and y=1	73	55
Coordinate x=3 and y=1	79	60
Coordinate x=4 and y=1	86	66
Coordinate x=5 and y=1	93	76
Coordinate x=1 and y=2	140	123
Coordinate x=2 and y=2	149	131
Coordinate x=3 and y=2	157	140
Coordinate x=4 and y=2	167	149
Coordinate x=5 and y=2	175	158

From the observation during real time testing, there are several problem occurred during drawer picker want to store the drawer at the cabinet because of under certain circumstances. This problem will be improve for the future work and were explained in recommendation in the next chapter.

4.5 AS/RS WORKING

The positions of the different storage/drawer location in AS/RS are shown in Figure 4.4. The initial position of S/R machine also as shown in Figure 4.4, takes the position variables x = 0 and y = 0. The working of AS/RS is for example, drawer coordinate x = 2 and y = 2 want to retrieve from cabinet, S/R machine will move right according to matched condition and lifter will move up until certain distance as programmed, then drawer picker will move forward until shaft of drawer picker was attached the drawer. S/R machine will move right again slightly, shaft of drawer picker also move right, after that drawer picker will move reverse and retrieve the drawer from cabinet. The reverse procedure will be adopted to store the drawer from the P/D Station.

4.6 POWER AND TORQUE TRANSMITTED ANALYSIS

In order to calculate power and torque transmitted in the system of AS/RS, the parameter such as weight of component, perimeter of gear, angular velocity, and radius of gear must be known. All of the equation below was referred from Budynas and Nisbett, (2008).

$$T = F \times r \tag{4.1}$$

Where:
T = Torque, Nm
F = Weight, N
r = Radius of gear

$$P = T \times \omega \tag{4.2}$$

Where:
P = Power, watts
ω = Angular velocity, rad/s

For stepper motor x direction (S/R machine):

Total mass of S/R machine = 6.054 kg
Radius of gear = 0.02 m
Perimeter of gear = $2\pi r$ = 2(3.1416) (0.02) = 0.1257 m/rev
Velocity, v = 0.01477 m/s,
Angular velocity, ω = v / $2\pi r$ x 60= (0.01477 / 0.1257) x 60 = 7.0501 rpm

$$T = F \times r$$
$$T = (6.054 \times 9.81) \times 0.02$$
$$\mathbf{T = 1.1878Nm}$$

$$P = T \times \omega$$

$$P = 1.1878 \times 7.0501 \left(\frac{2\pi}{60}\right)$$

P = 0.8770 watts

For stepper motor y direction (lifter):

Total mass of lifter = 1.009 kg,

Radius of pinion = 0.02 m,

Radius of gear = 0.0375 m,

Perimeter of pinion = 2πr = 2(3.1416) (0.02) = 0.1257 m/rev,

Perimeter of gear = 2πr = 2(3.1416) (0.0375) = 0.2356m/rev,

Velocity, v = 0.001871 m/s,

Angular velocity of pinion, ω = v / 2πr x 60= (0.001871/ 0.1257) x 60 = 0.8931 rpm,

Angular velocity of gear, ω = v / 2πr x 60= (0.001871/ 0.2356) x 60 = 0.4762 rpm,

Number of teeth (pinion), N = 38,

Number of teeth (gear), N = 73,

For pinion:

$$T = F \times r$$

$$T = 1.009(9.81) \times 0.02$$

T = 0.1980 Nm

$$P = T \times \omega$$

$$P = 0.1980 \times 0.8931 \left(\frac{2\pi}{60}\right)$$

P = 0.01852watts

For gear:

$$T = 1.009(9.81) \times 0.0375$$

T = 0.3712 Nm

$$P = 0.3712 \times 0.4762 \left(\frac{2\pi}{60}\right)$$

P = 0.01852 watts

For stepper motor z direction (drawer picker):

Total mass of drawer picker = 0.4662kg

Radius of gear = 0.012 m

Perimeter of gear = 2пr = 2(3.1416) (0.012) = 0.07539 m/rev

Velocity, v = 0.03513 m/s,

Angular velocity, ω = v / 2пr x 60= (0.03513 / 0.07539) x 60 = 27.9585 rpm

$$T = F \times r$$

$$T = 0.4662(9.81) \times 0.012$$

T = 0.05488 Nm

$$P = T \times \omega$$

$$P = 0.05488 \times 27.9585 \left(\frac{2\pi}{60}\right)$$

P = 0.1607 watts

Table 4.9: Torque and power transmitted

Stepper motor	**Torque, Nm**	**Power, W**
X direction	1.1878	0.8770
Y direction, pinion	0.1980	0.01852
Y direction, gear	0.3712	0.01852
Z direction	0.05488	0.1607

Table 4.9 shows the different torque and power transmitted for stepper motor x, y, and z direction. This is because of the different radius of gear used, the different weight of component, surface friction and surrounding effect. The value of torque and power for stepper motor x direction is the higher because the weight of component(S/R machine) is greater than other component. Roughly, the overall value of the torque and power is slightly small due to the small unit loads of AS/RS.

4.7 THE PREDICAMENTS

4.7.1 Problem of Fabrication Process

Fabrication process encountered several problems especially in the early stage of development. The problems were explained in tabulated form of Table 4.10. Listed problems consist of deficiency to find company/supplier, defective adhesive, ordered components is not delivered in time, and error in writing programming. In addition, the encountered problem is due to the current situation and unfortunate circumstances, although all the preventive ways was taken.

Table 4.10: Problems encountered during the progress of fabrication

Problem	Description
Deficiency to find company/supplier	• The all component of AS/RS are not totally fabricated but the some component such as rack and pinion gear, pulley and spur gear was order from company/supplier because of the component is special size and lack of skill. • Several companies have been contacted for inquiries and quotation of the components but no positive response up to this date.
Defective adhesive	• The adhesive used failed to perfectly attach the component. The affected components are rack gear, pulley, and stepper motor holder.
The ordered components is not delivered in time	• The supplier wants to extend the due date for delivery.
Error in writing programming	• During writing the program, the problems occur during decided C language. C language must be corrected before programmed into microcontroller.

4.7.2 The Defects of Prototype

Real time testing of fabricated model discovered several defects that decrease the performance of the AS/RS. The imperfections were arranged and explained in tabulated form in Table 4.11. Listed defects consist of locomotion of AS/RS, only light of drawer can store and retrieve, emergency stop button, sensor, and graphical user interface.

Table 4.11: Defects of the fabricated AS/RS

Defect	Description
Locomotion of AS/RS	• Especially during store and retrieve the drawer. Drawer picker cannot store and retrieve the drawer properly because of the tendency of drawer to sway whether to the left or the right due to the imperfection design of drawer picker. • Late in terms of time during transaction from cabinet to P/D station or vice versa compare to other AS/RS.
Only light of drawer can store and retrieve	• Drawer picker is not stable if it store and retrieve the exceed range of its weight.
Emergency stop button	• This AS/RS did not have an emergency stop button.
Sensor	• The sensor is used to detect the storage location whether it's empty or not and will attach to the S/R machine and storage compartment. Unfortunately, this AS/RS did not use the sensor.
Graphical user interface	• Graphical user interface is user friendly to use the system but the AS/RS did not have a graphical user interface because of lack of knowledge about this.

4.8 THE TROUBLESHOOTING

4.8.1 Solution of Fabrication's Problems

The solution were figured and proposed to solve the problems. Implementations of solution were done according to possibilities and opportunities available during this project. Some solutions remain as suggestion which is essential to be carried out in future development of the product. The solutions for problems faced during fabrication were discussed in Table 4.12.

Table 4.12: Solution for problems faced during fabrication

Problem	Description
Deficiency to find company/supplier	• Widen the list of company/supplier that capable to fabricate the component in economic cost.
Defective adhesive	• Replace the adhesive with the strong and effective one.
The ordered components is not delivered in time	• Long term solution is to follow up the company so that will deliver the component as soon as possible.
Error in writing programming	• Study and expose the C language and find the suitable language which to control movement of stepper motor.

4.9 CONCLUSION

By the end of this chapter, the fabricated of AS/RS had performed it task successfully even though there are several imperfection faced. Even the project was completed successfully there are several problems which should be improved in the future. Result of test shows that the AS/RS can move into three directions (x, y, and z direction) but the small problem occur during to store and retrieve the drawer. The improvement needed to make sure the weakness and problems can be overcome. Overall conclusion and recommendations will further explained in the next chapter.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will conclude the development of the project. The result and outcome of the project will be related to the objective and scope of the project. From that, the project will be determined whether its objective was achieved or not. The conclusion and recommendation were also described.

5.2 CONCLUSION

The entire objective was achieved. This project had developed a new layout of AS/RS which can store and retrieve the small unit loads. Thru the development process, the AS/RS has been design and fabricated with innovative idea and slightly follow the conceptual of real AS/RS. Real time testing prove that this conceptual design work and perform basic movement forward, reverse, move up and move down, even though there have several problems occurred. This problem will be troubleshooting for the future work. The testing was done in order to store and retrieve the drawer even small problems occur because of under certain circumstances.

The outcomes of this project are ready to further develop by the society. The knowledge and skill obtained through this project will bring in benefit. These skills can be used next time during work that is related to engineering field.

5.3 RECOMMENDATION

The prototype now is still in the early phase before go through for the commercial benchmarks. Similar with many such projects there is always room for improvement and development. Some modification can be implemented to enhance the AS/RS for the future work. The future prospects were explained in tabulated form of Table 5.1.

Table 5.1: Future prospects for defection of fabricated AS/RS

Defect	Future prospect
Locomotion of AS/RS	• Redesign or improve the AS/RS layout in order to increase and improve the performance in terms of time and precise during to store and retrieve the unit loads.
Only light of drawer can store and retrieve	• Modification the design of drawer picker due to stability and competently.
Emergency stop button	• Quick fix is to add emergency stop button for safety precautions.
Sensor	• In order to get the precise movement of S/R machine during to store and retrieve the drawer, sensor must be used and attach to this system.
Graphical user interface	• Study and research more on visual basic and C programming. Then, implement the knowledge to the AS/RS prototype.

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APPENDIX A1

2D ENGINEERING DRAWING

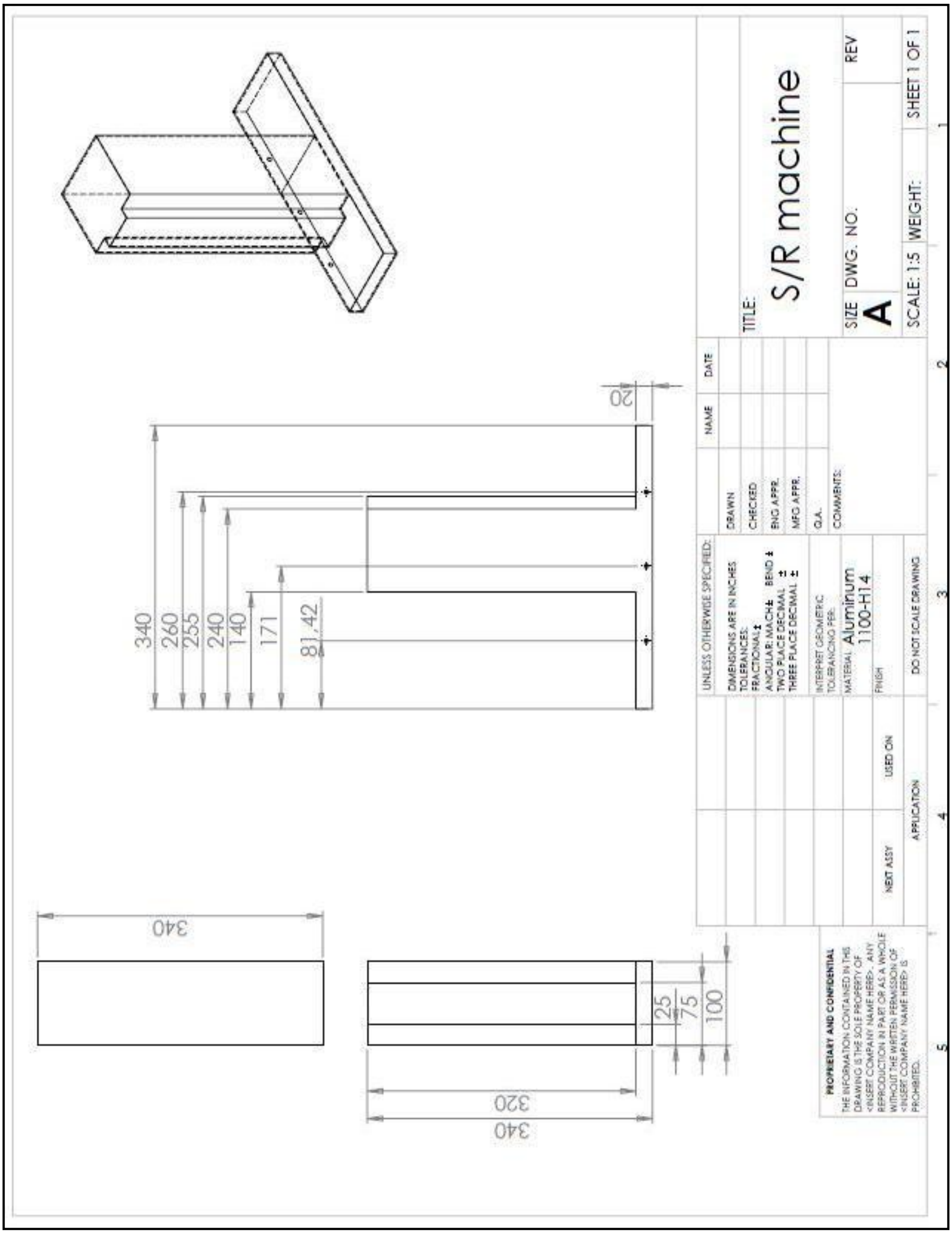

Figure 6.1: Technical drawing for S/R machine

APPENDIX A2

2D ENGINEERING DRAWING

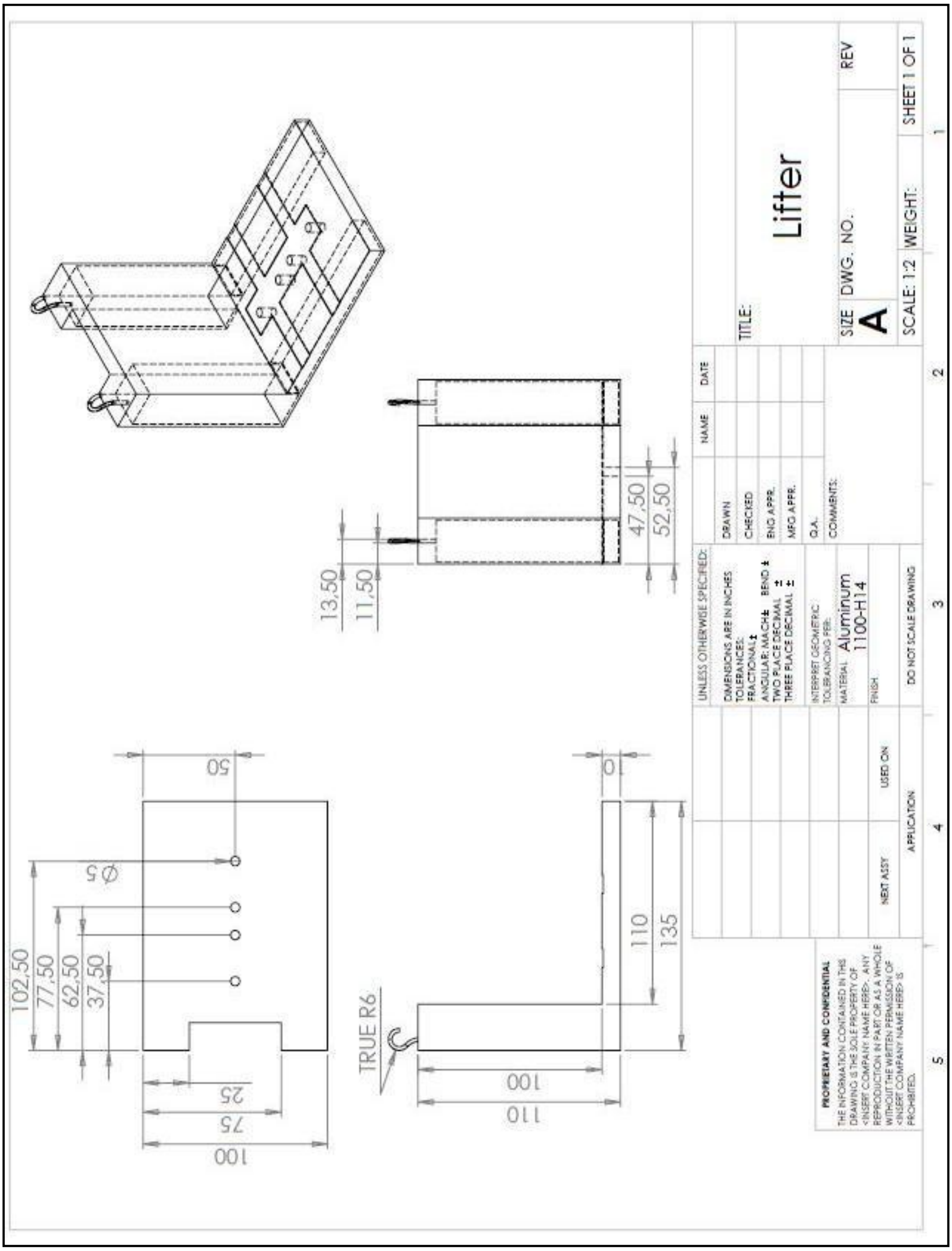

Figure 6.2: Technical drawing for lifter

APPENDIX A3

2D ENGINEERING DRAWING

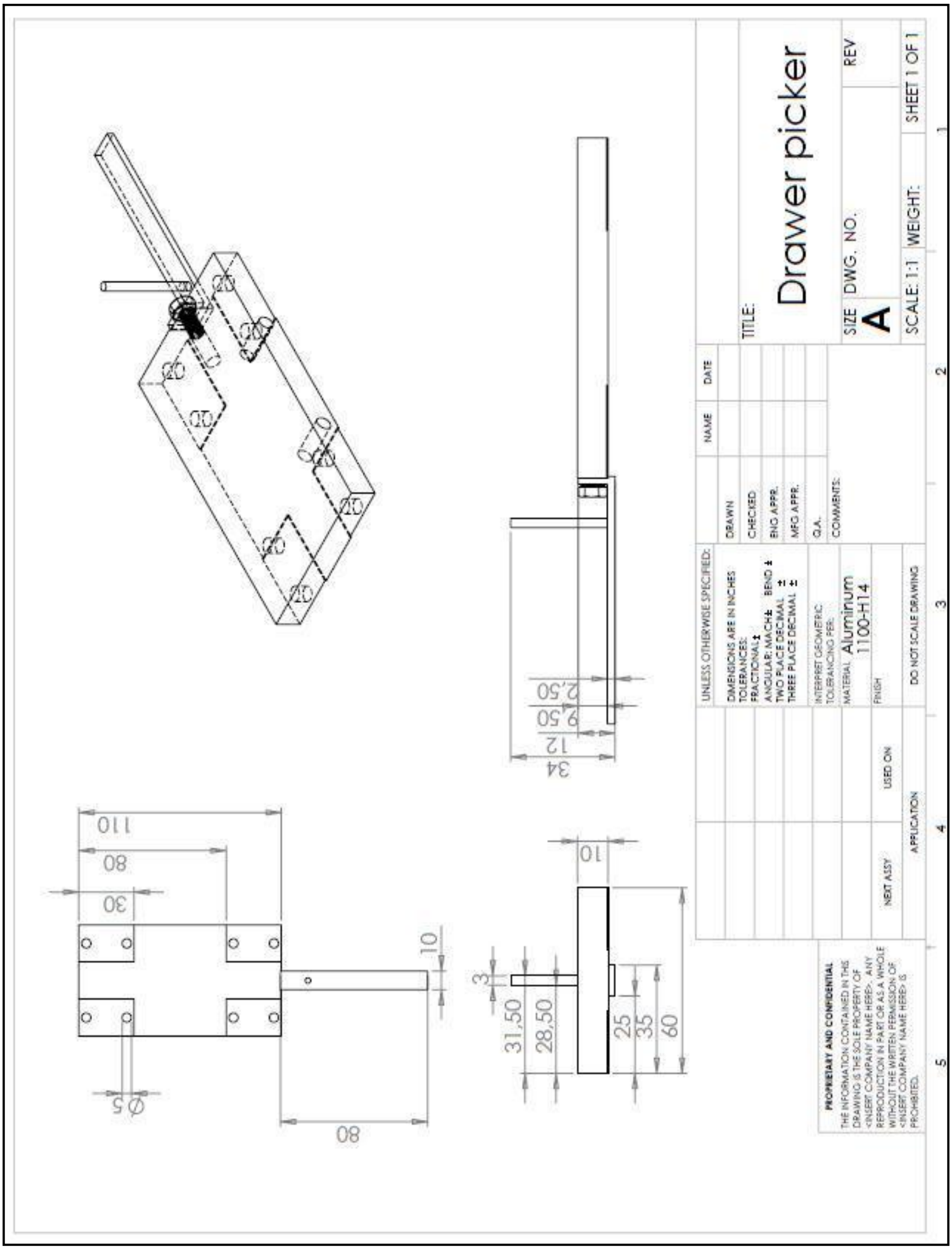

Figure 6.3: Technical drawing for drawer picker

APPENDIX A4

2D ENGINEERING DRAWING

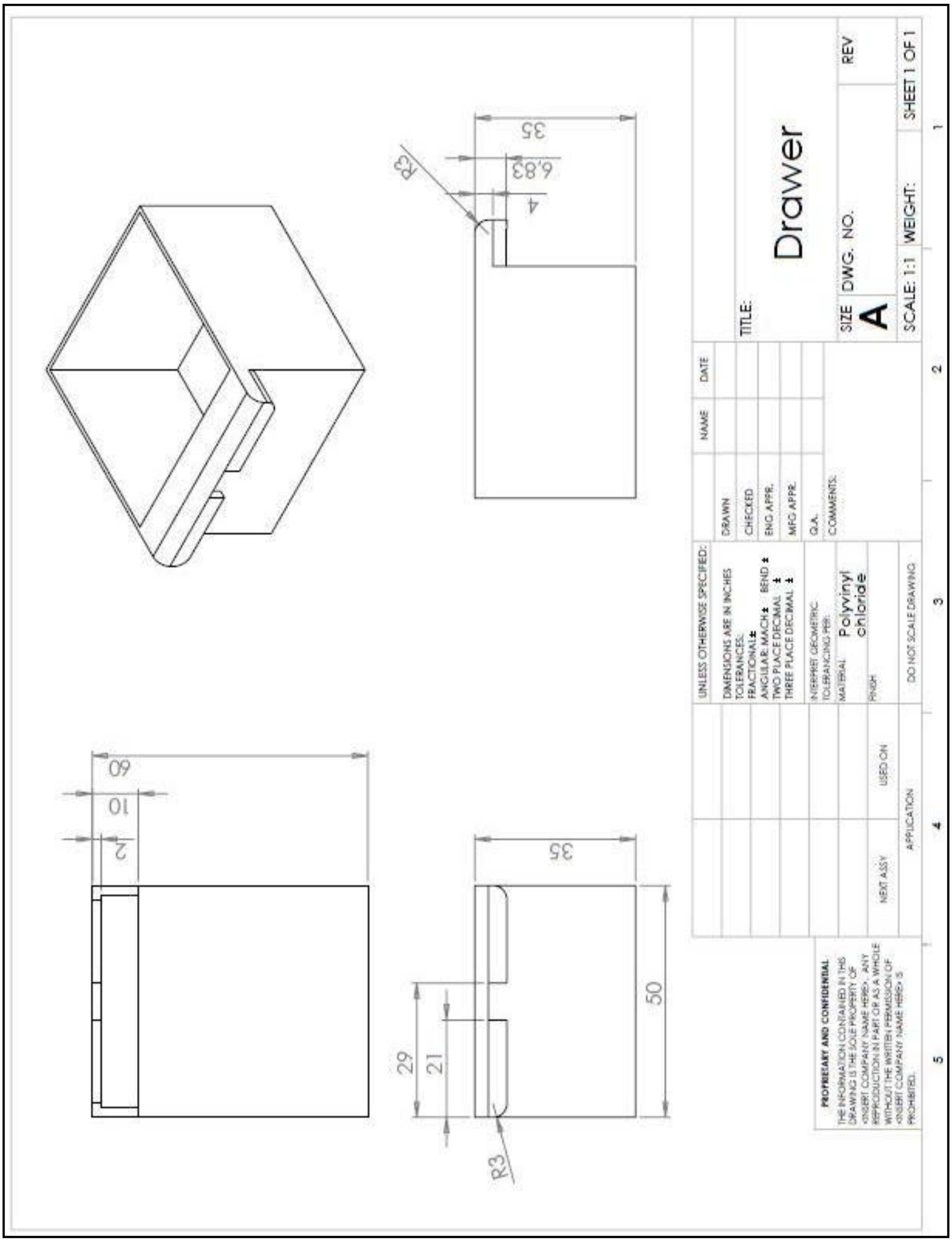

Figure 6.4: Technical drawing for drawer (unit load)

APPENDIX A5

2D ENGINEERING DRAWING

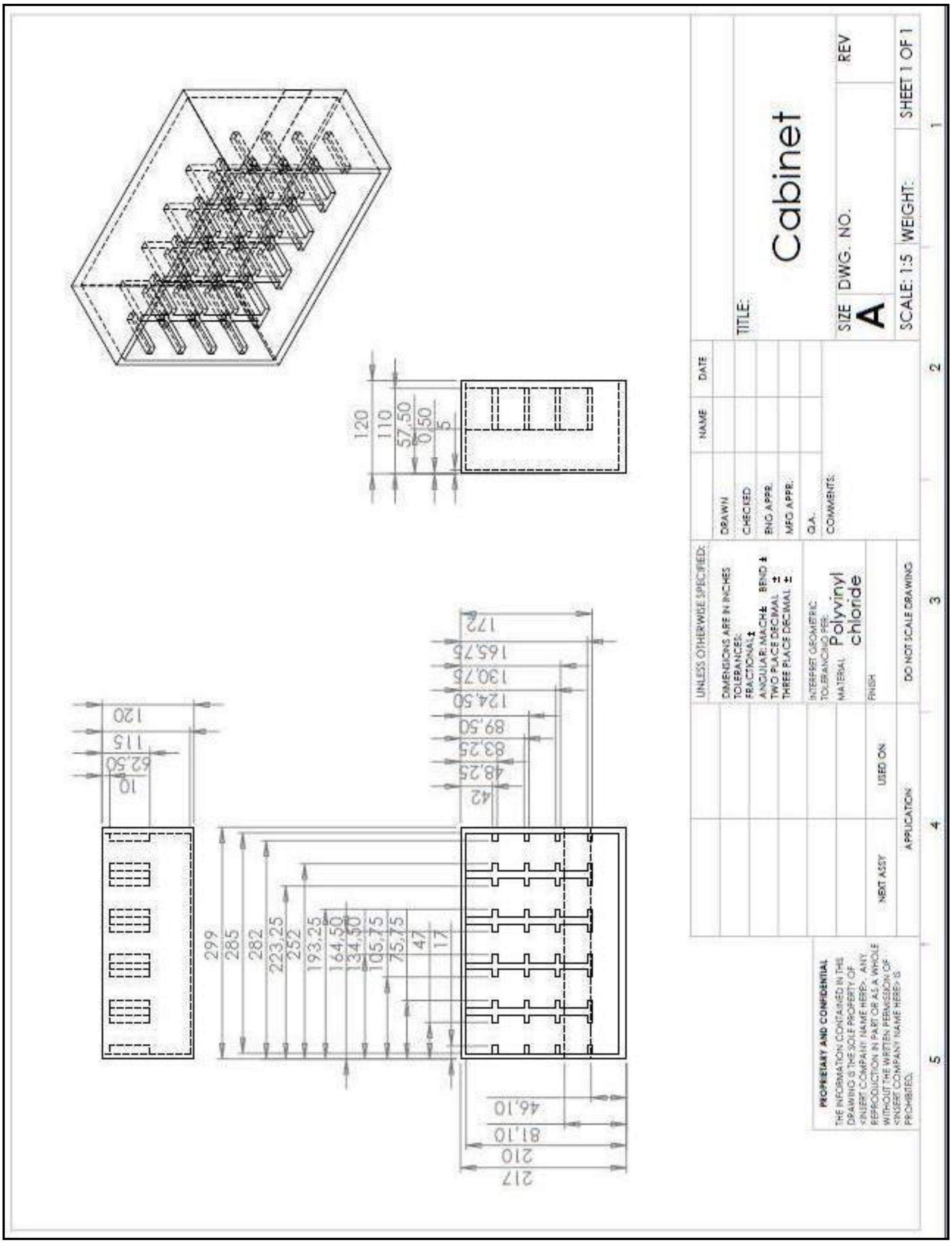

Figure 6.5: Technical drawing for cabinet (storage structure)

APPENDIX A6

2D ENGINEERING DRAWING

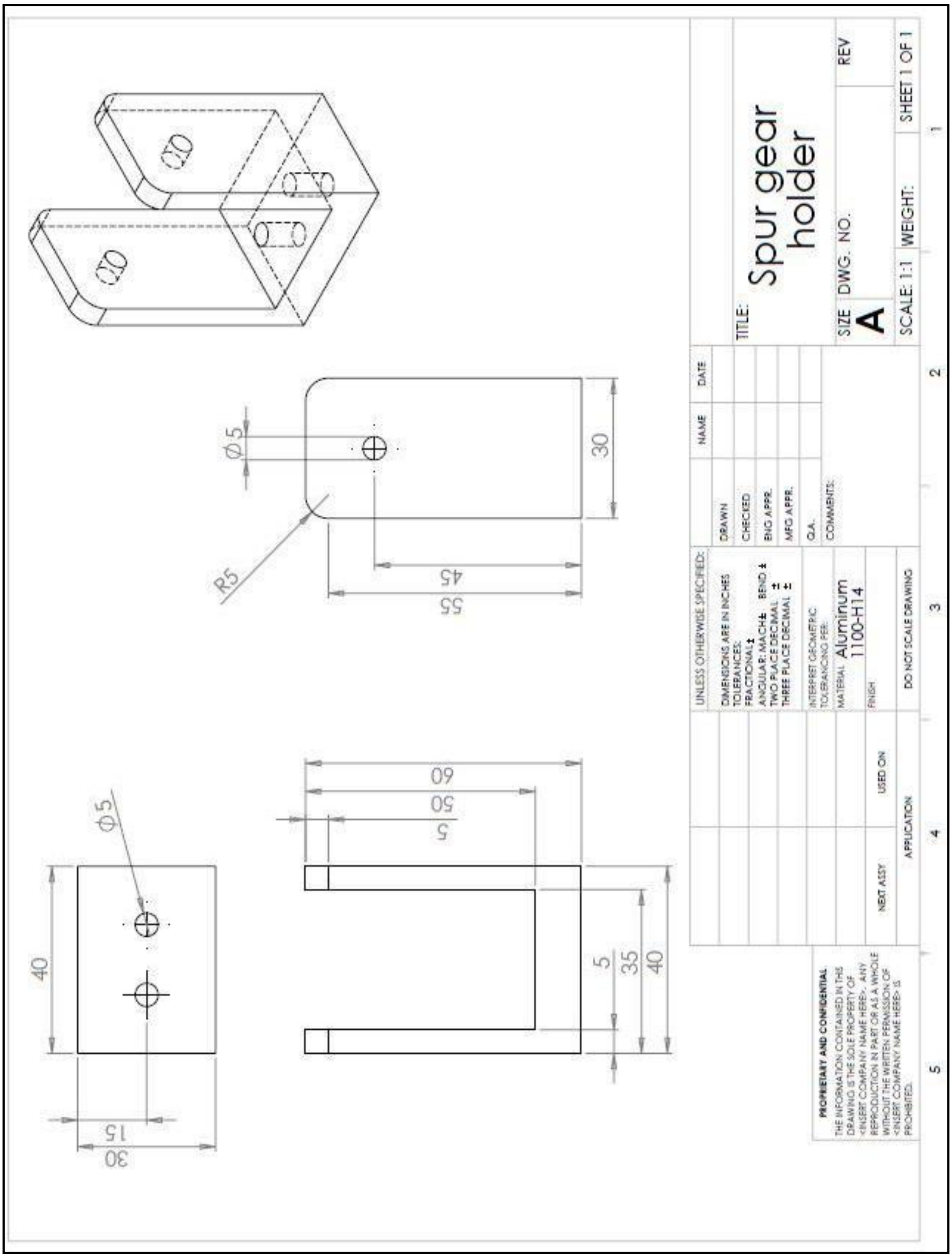

Figure 6.6: Technical drawing for spur gear holder

APPENDIX A7

2D ENGINEERING DRAWING

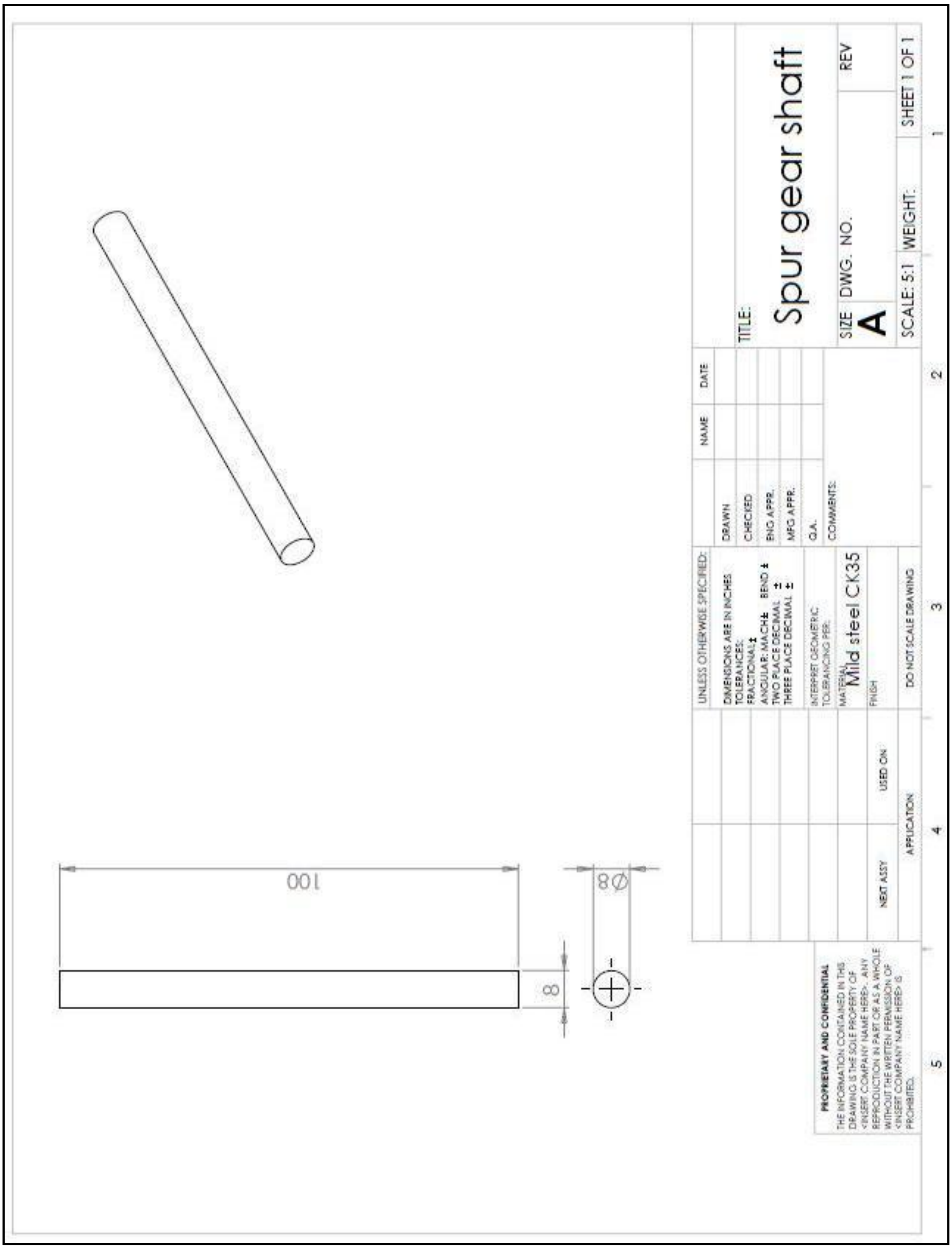

Figure 6.7: Technical drawing for spur gear shaft

APPENDIX A8

2D ENGINEERING DRAWING

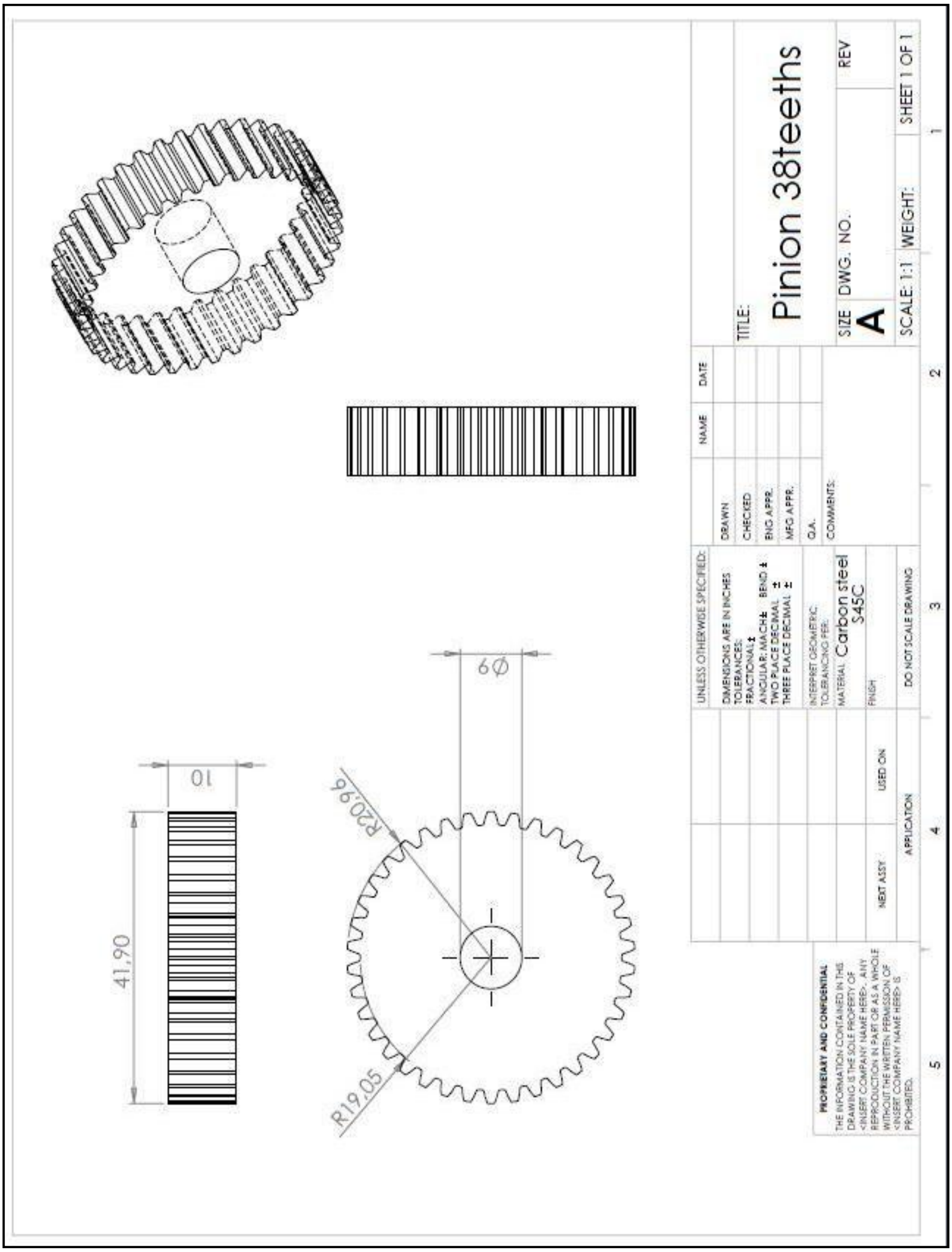

Figure 6.8: Technical drawing for pinion 38 teeth's

APPENDIX A9

2D ENGINEERING DRAWING

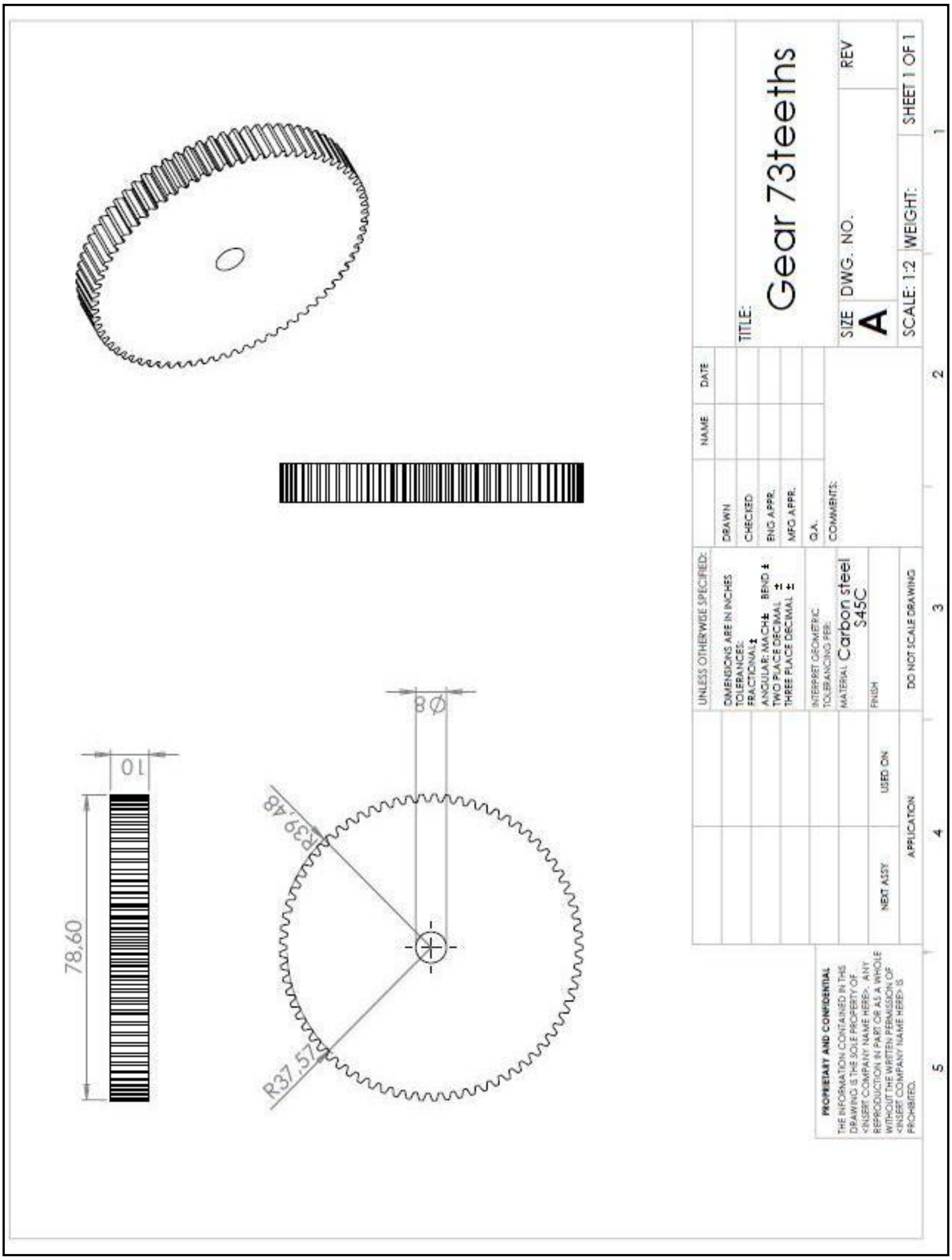

Figure 6.9: Technical drawing for gear 73 teeth’s

APPENDIX A10

2D ENGINEERING DRAWING

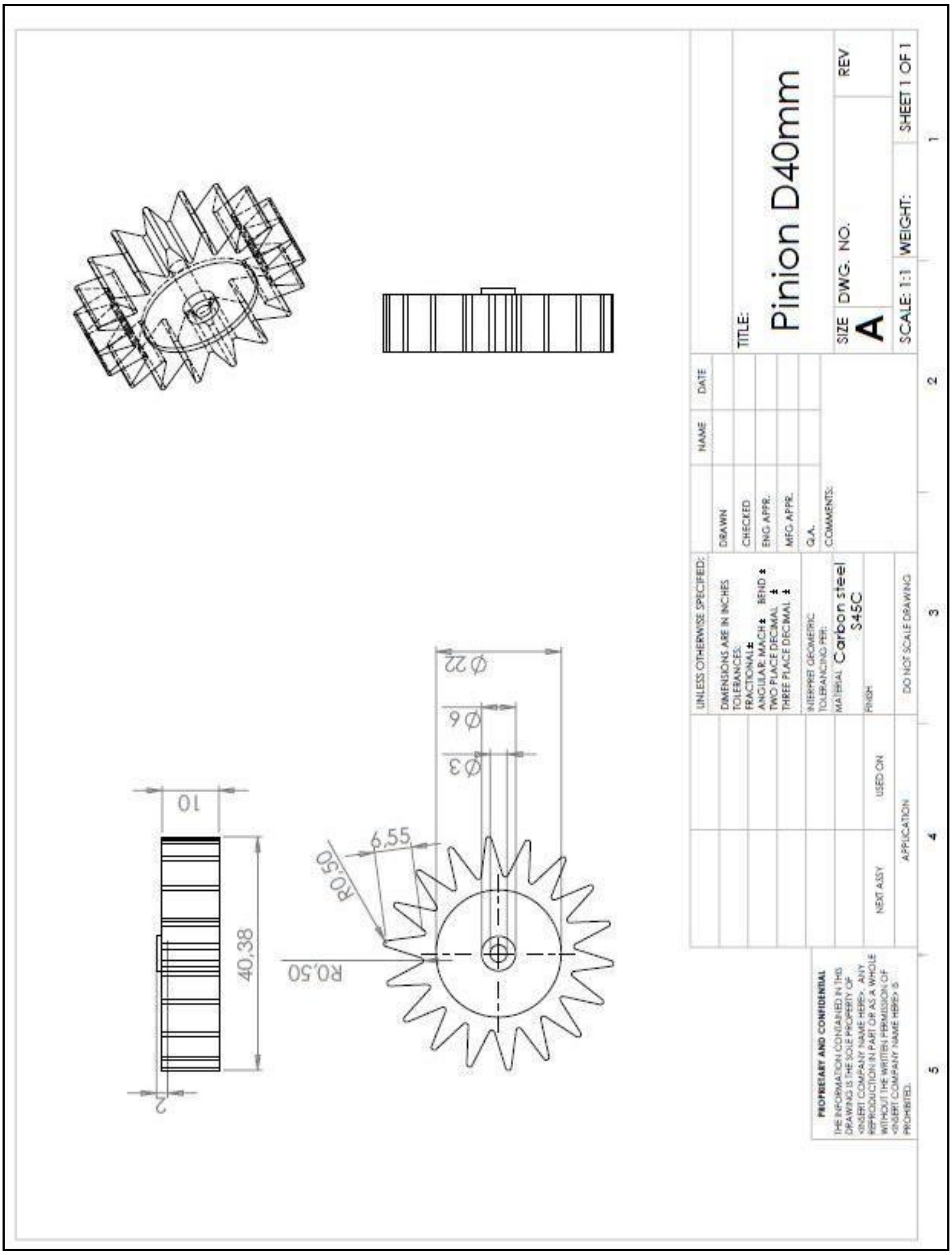

Figure 6.10: Technical drawing for pinion D40 mm

APPENDIX A11

2D ENGINEERING DRAWING

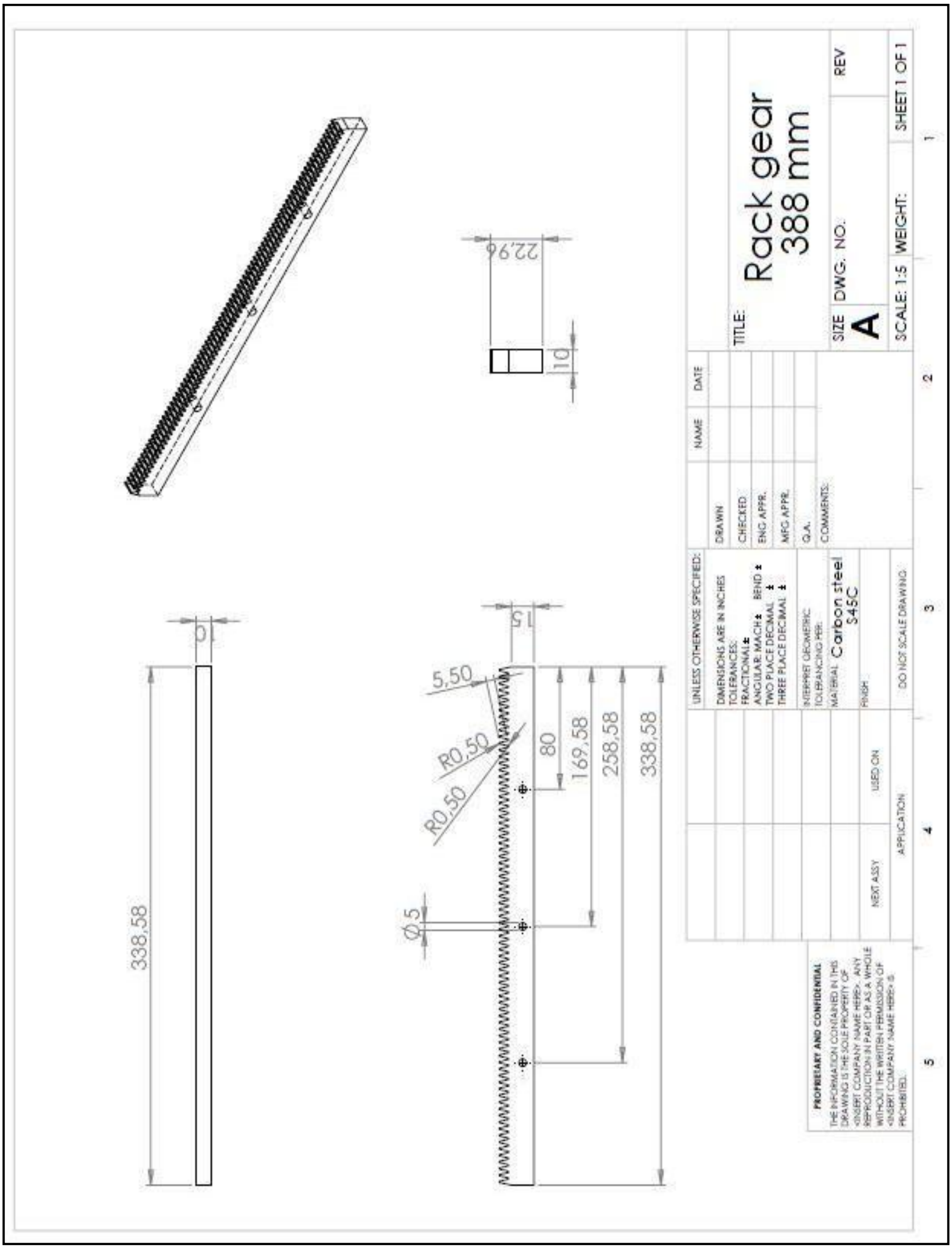

Figure 6.11: Technical drawing for rack gear 388 mm

APPENDIX A12

2D ENGINEERING DRAWING

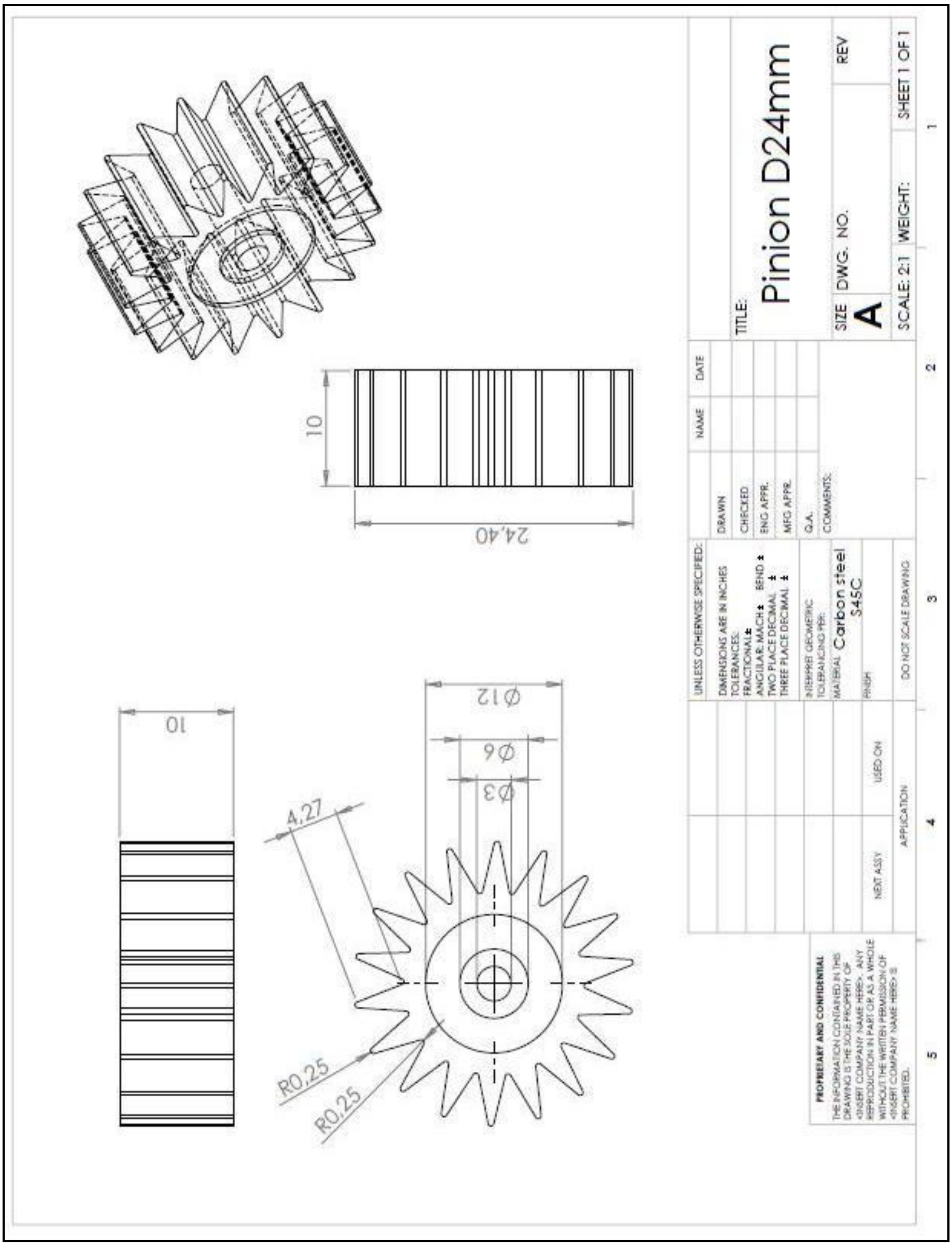

Figure 6.12: Technical drawing for pinion D24 mm

APPENDIX A13

2D ENGINEERING DRAWING

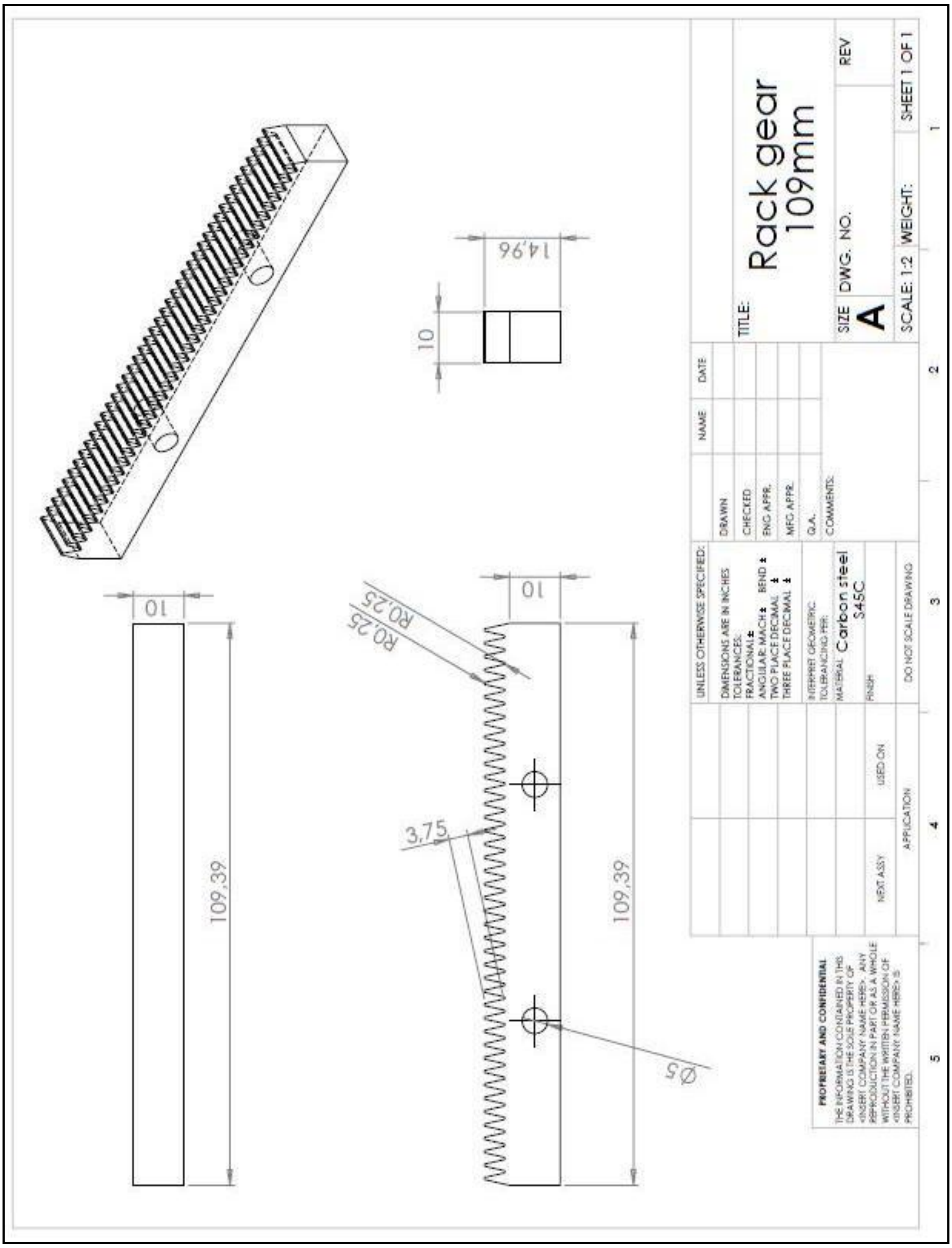

Figure 6.13: Technical drawing for rack gear 109 mm

APPENDIX A14

2D ENGINEERING DRAWING

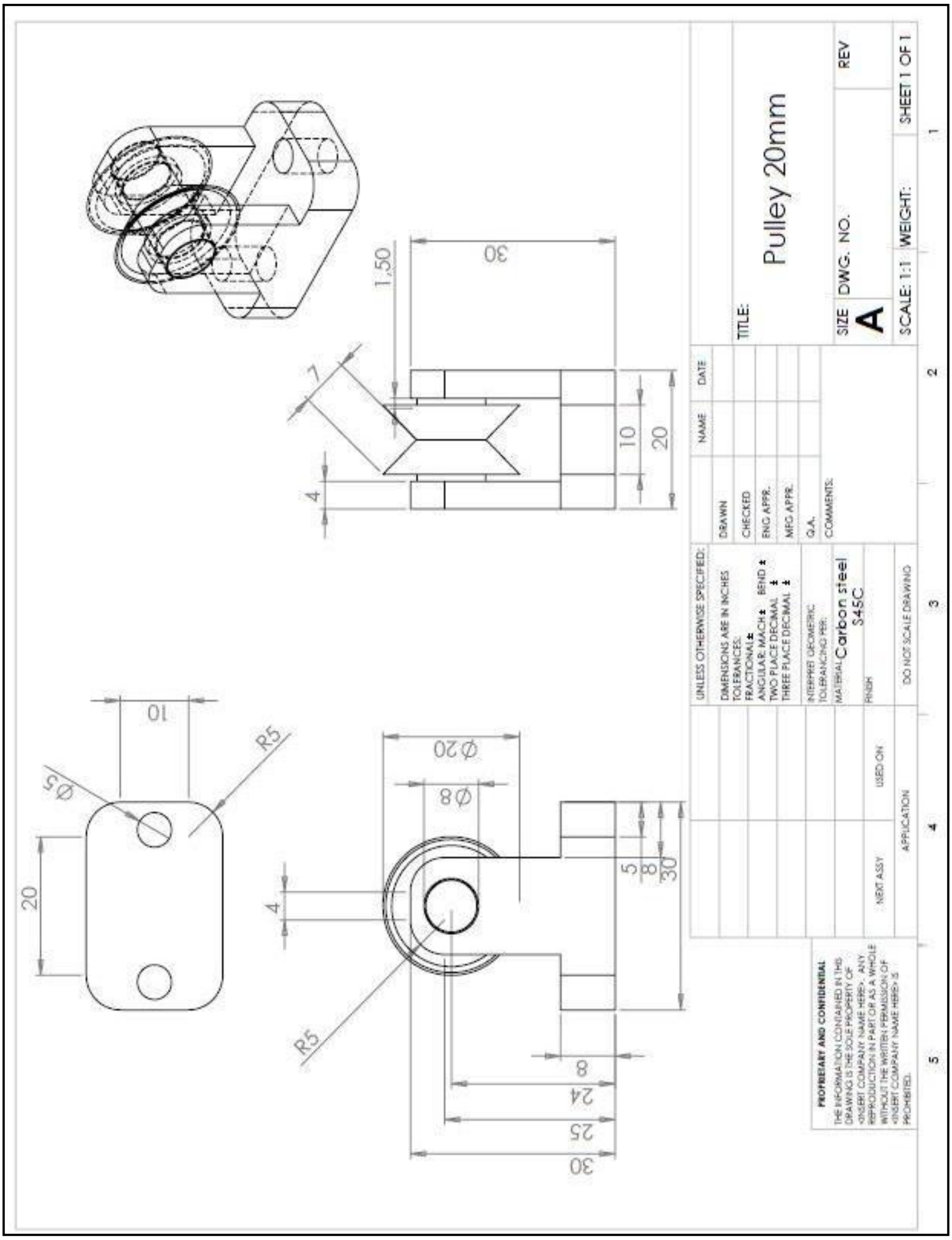

Figure 6.14: Technical drawing for pulley D20 mm

APPENDIX A15

2D ENGINEERING DRAWING

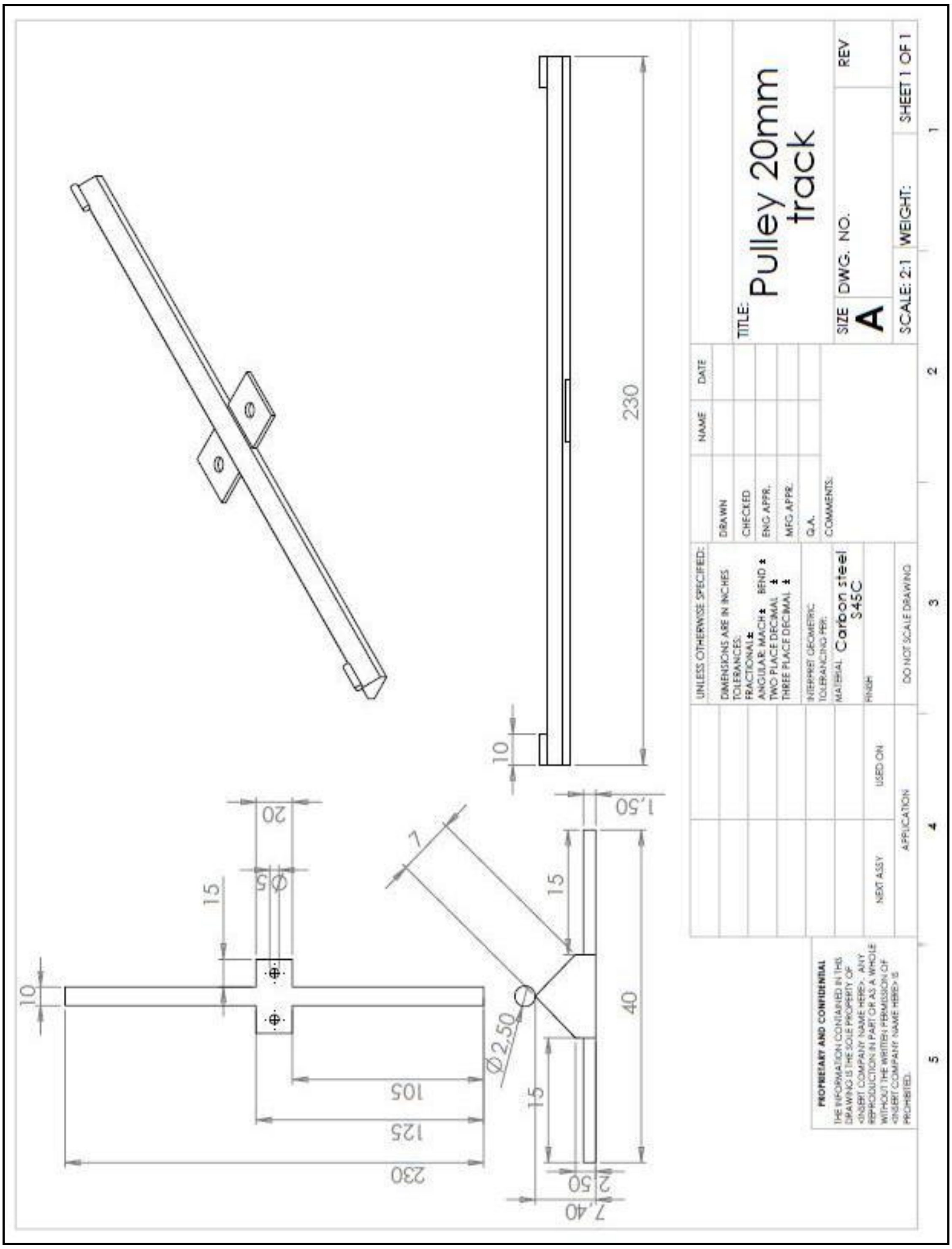

Figure 6.15: Technical drawing for pulley D20 mm track

APPENDIX A16

2D ENGINEERING DRAWING

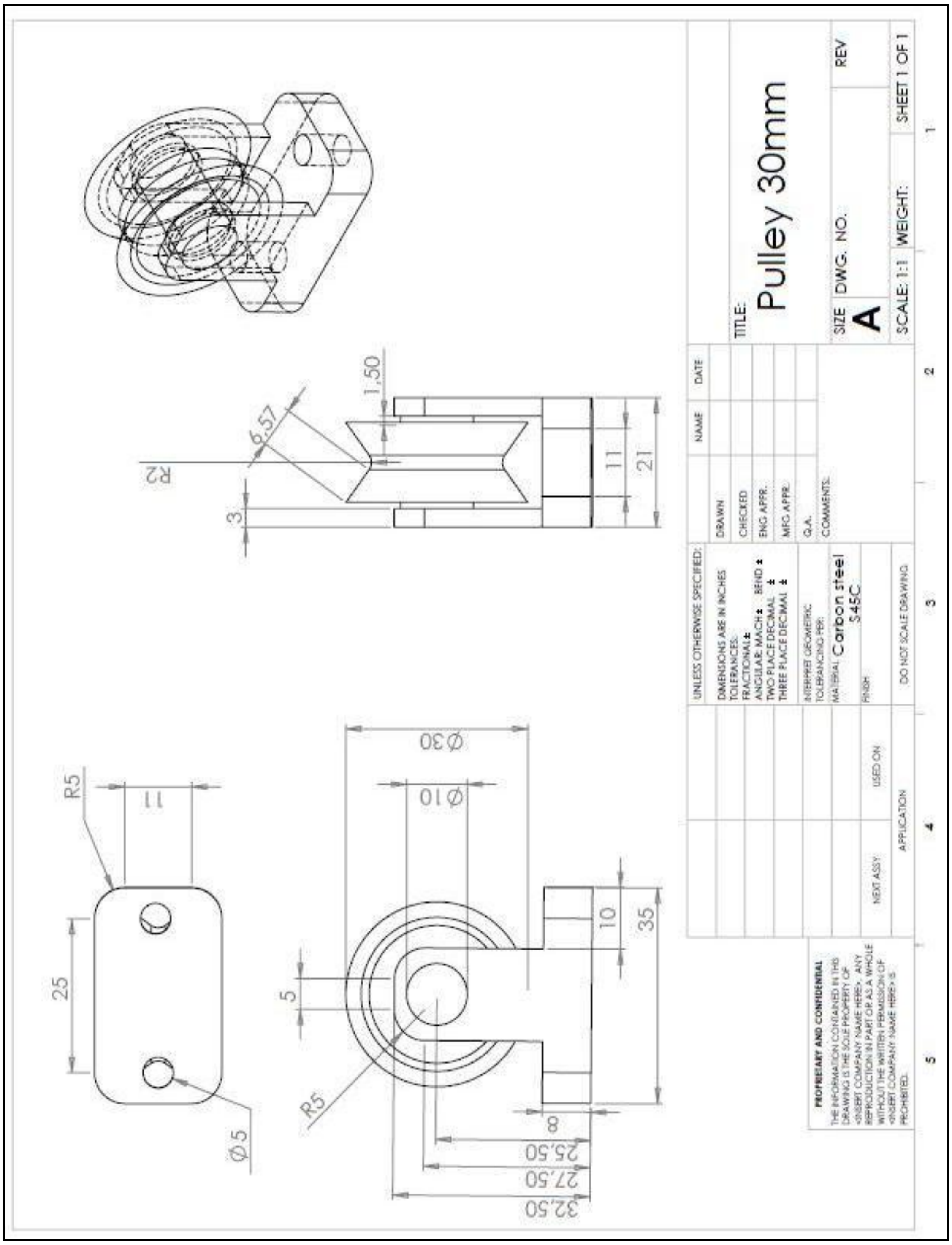

Figure 6.16: Technical drawing for pulley D30 mm

APPENDIX A17

2D ENGINEERING DRAWING

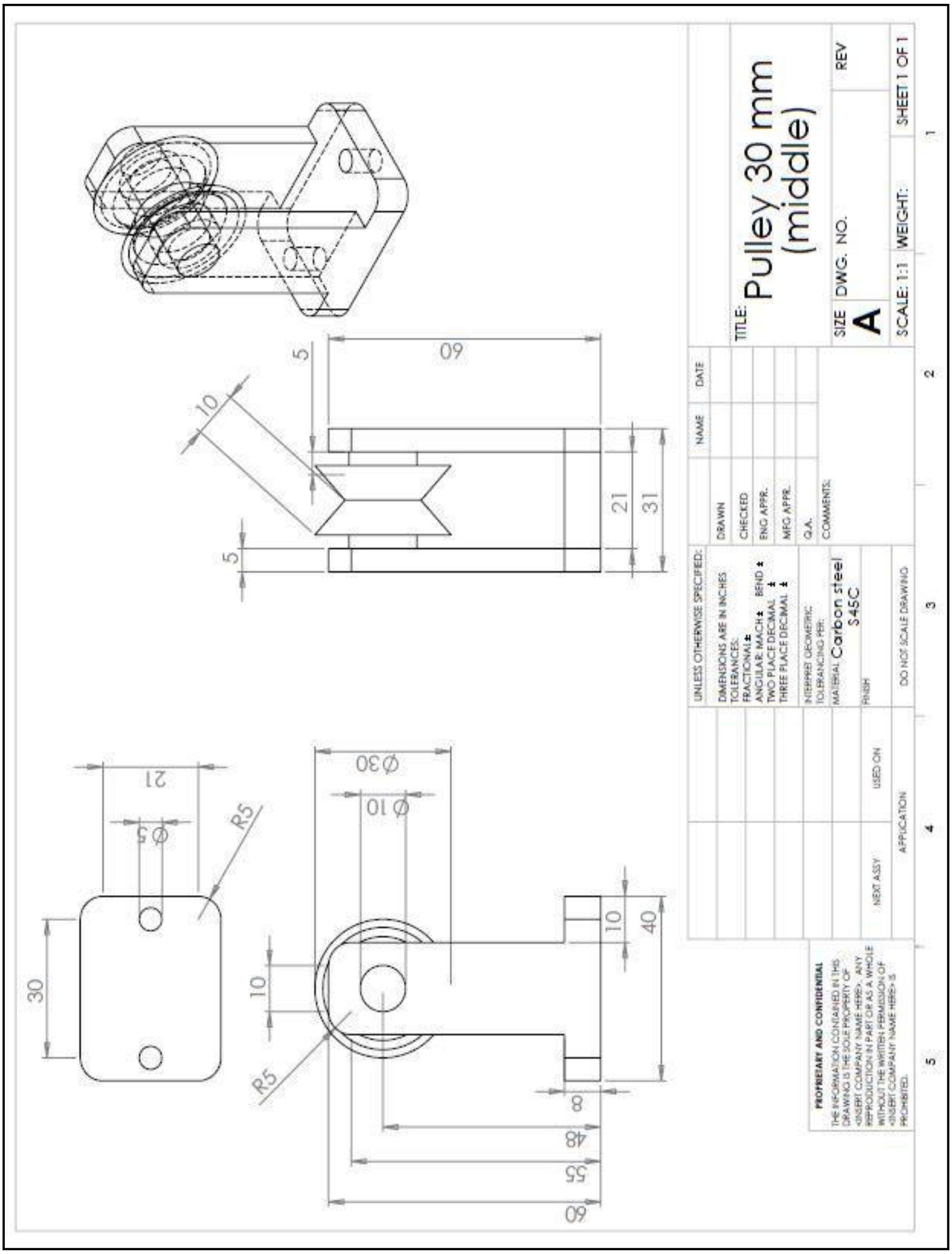

Figure 6.17: Technical drawing for pulley D30 mm middle

APPENDIX A18

2D ENGINEERING DRAWING

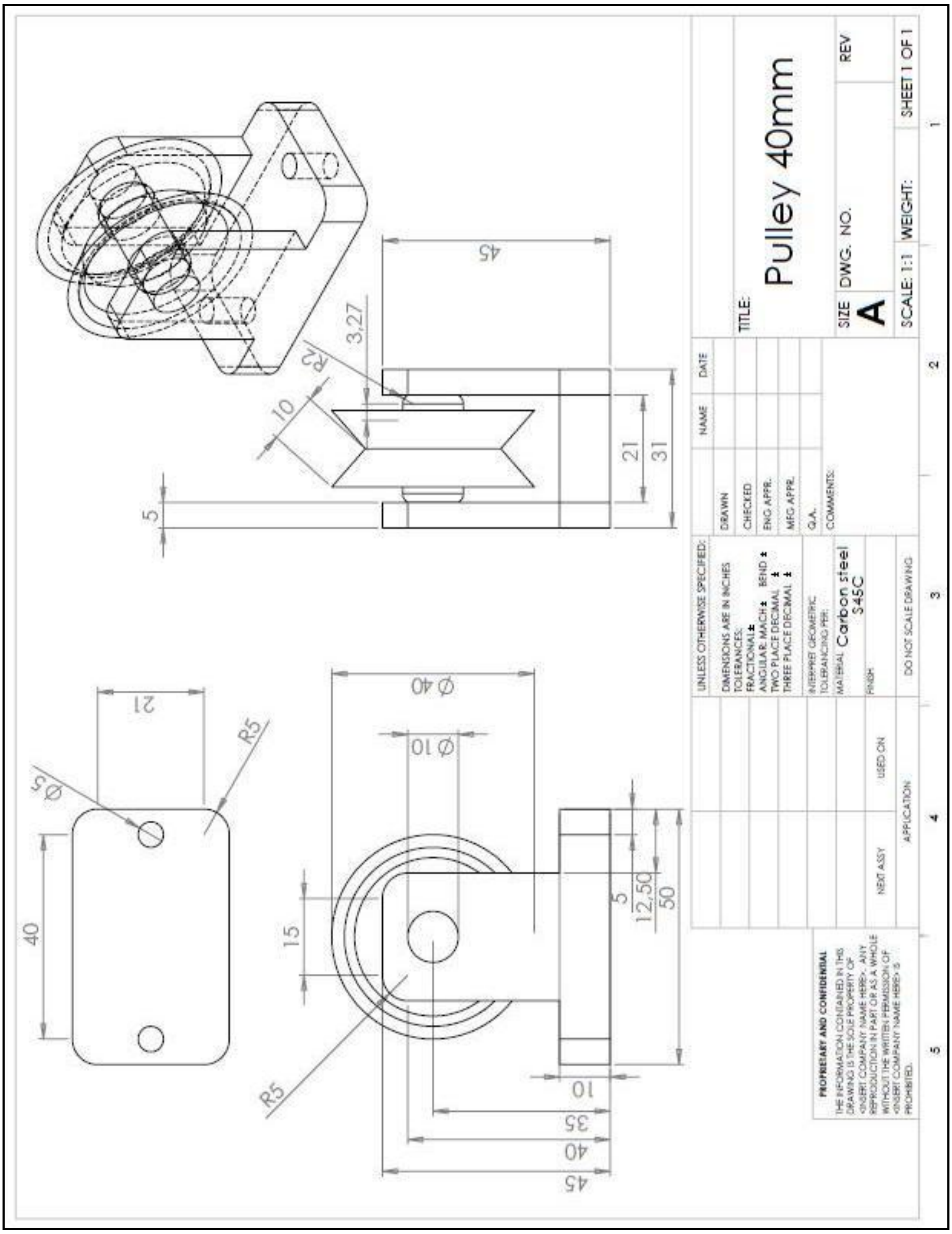

Figure 6.18: Technical drawing for pulley D40 mm

APPENDIX A19

2D ENGINEERING DRAWING

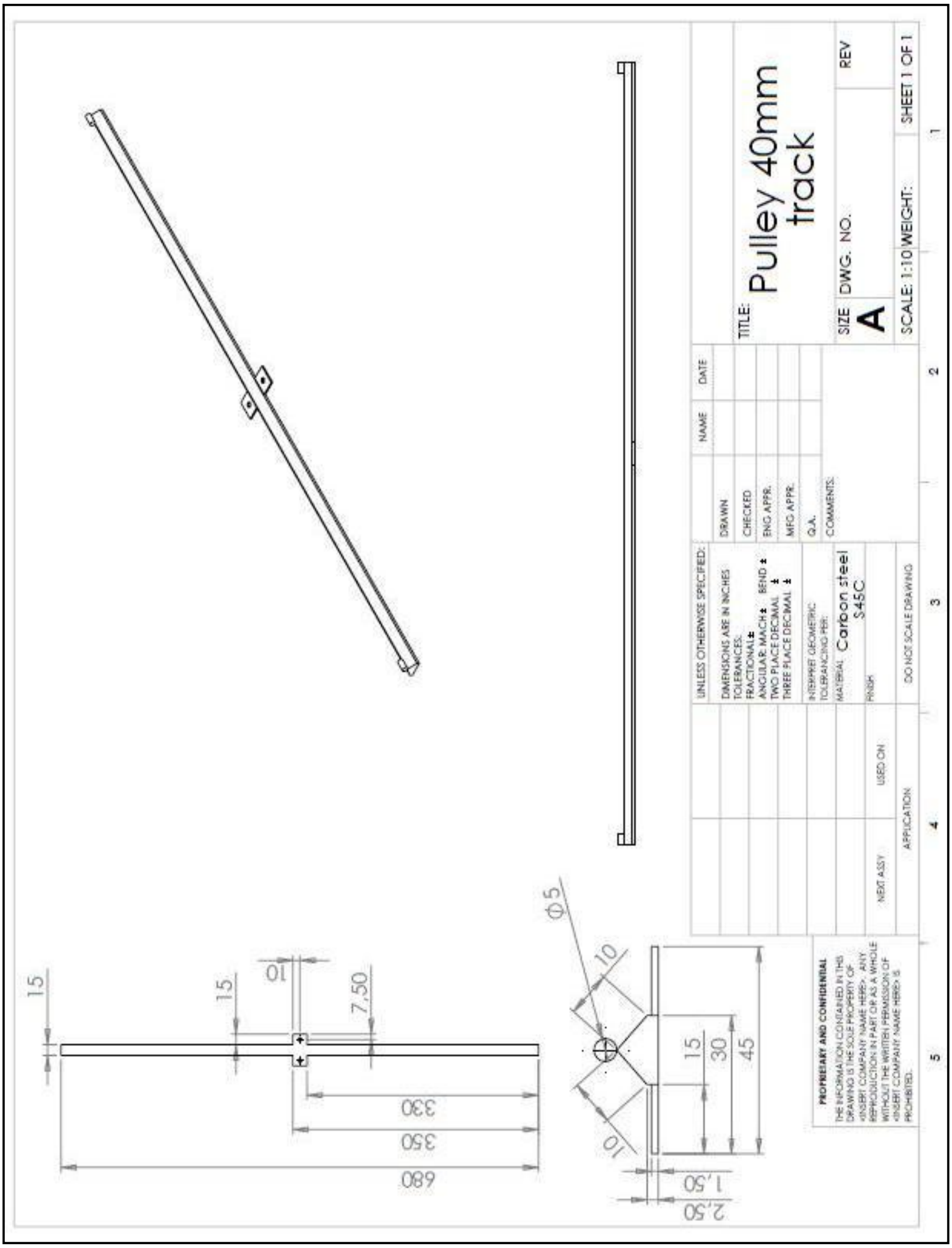

Figure 6.19: Technical drawing for pulley D40 mm track

APPENDIX A20

2D ENGINEERING DRAWING

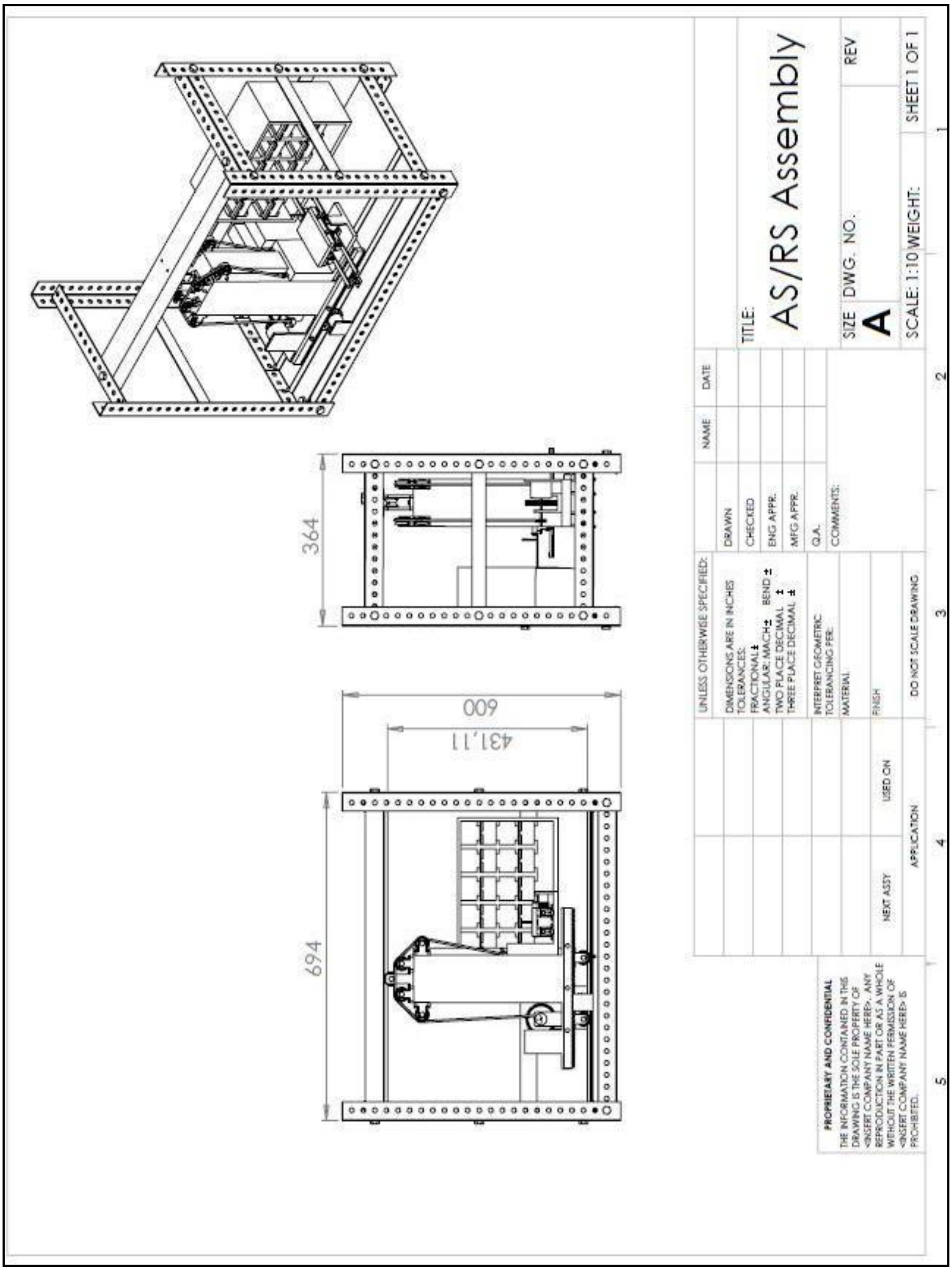

Figure 6.20: Technical drawing for AS/RS assembly

APPENDIX B1

GANTT CHART FOR FINAL YEAR PROJECT 1

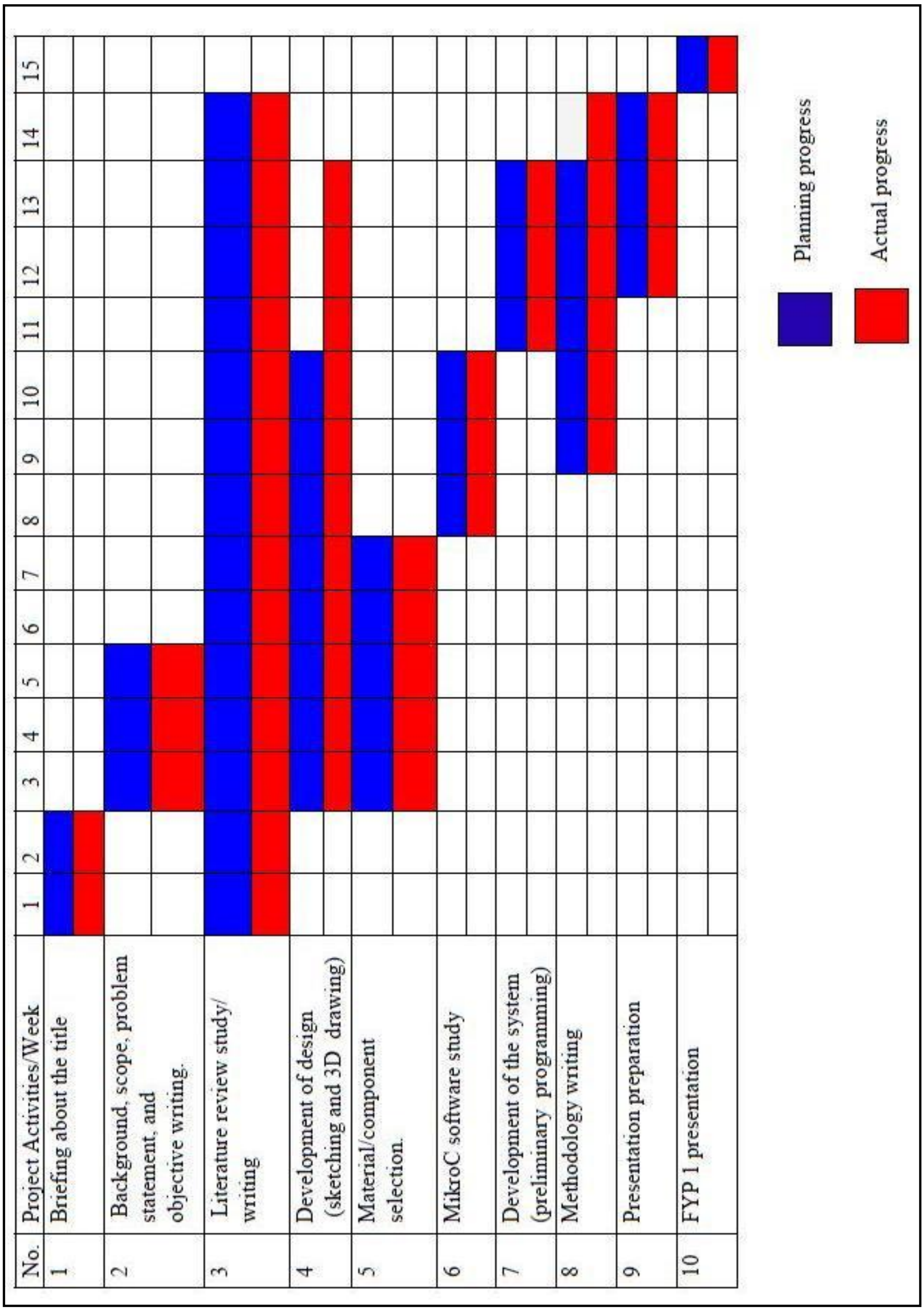

Figure 6.21: Project planning for FYP 1

APPENDIX B2

GANTT CHART FOR FINAL YEAR PROJECT 2

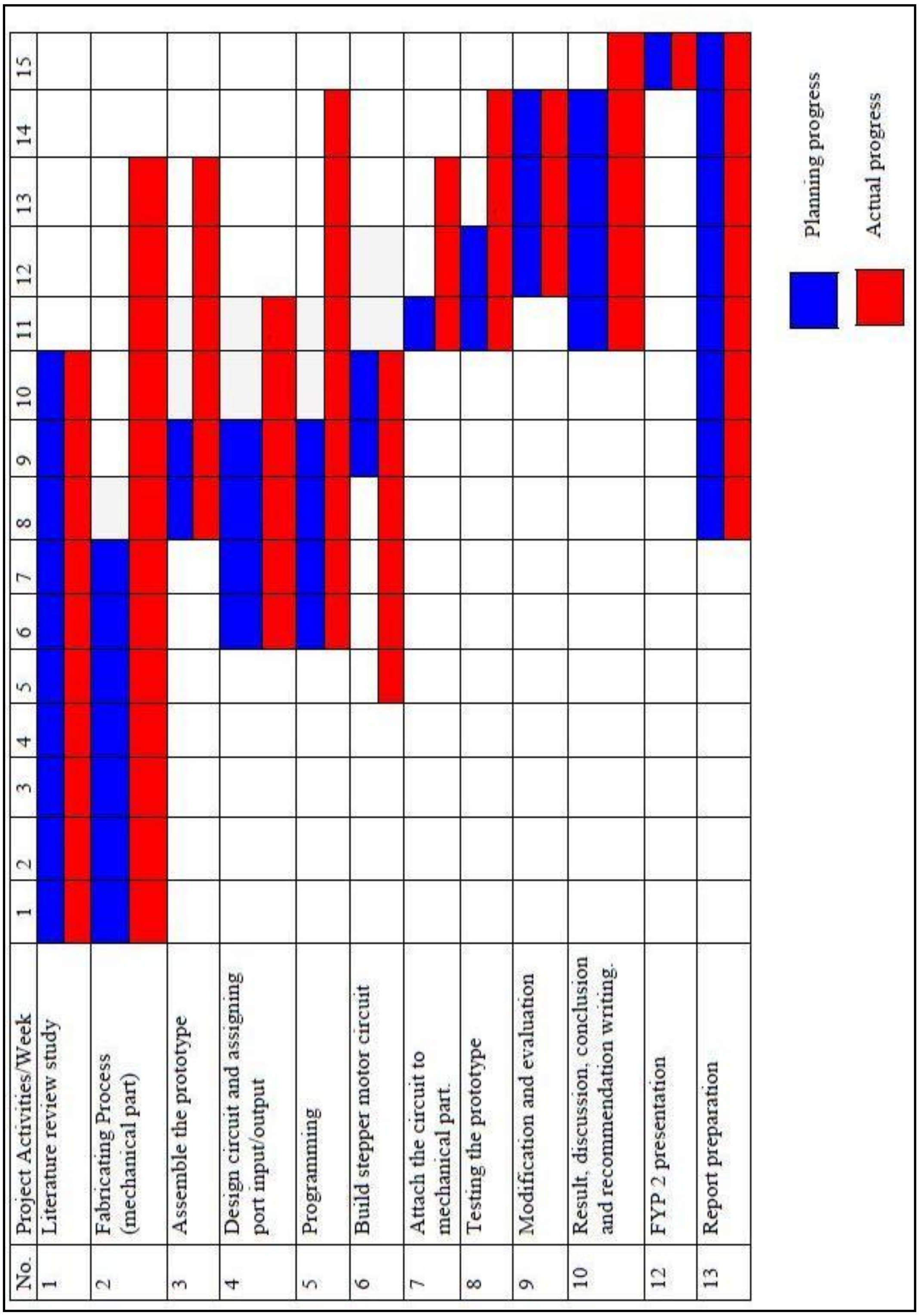

Figure 6.22: Project planning for FYP 2

APPENDIX C1

FINISHED PROTOYPE

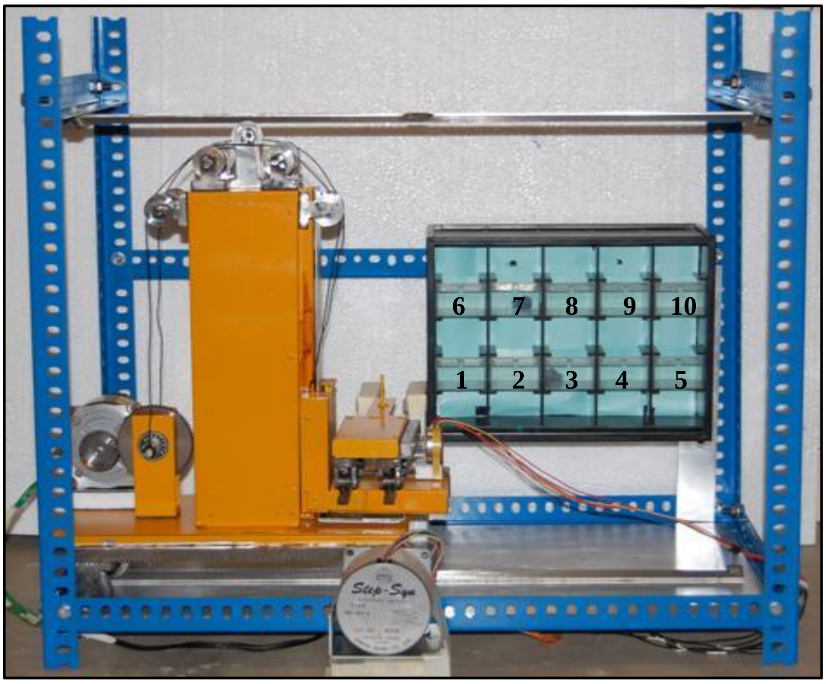

Figure 6.23: Front view of AS/RS prototype

Figure 6.24: Right side view of AS/RS prototype

APPENDIX C2

FINISHED PROTOTYPE

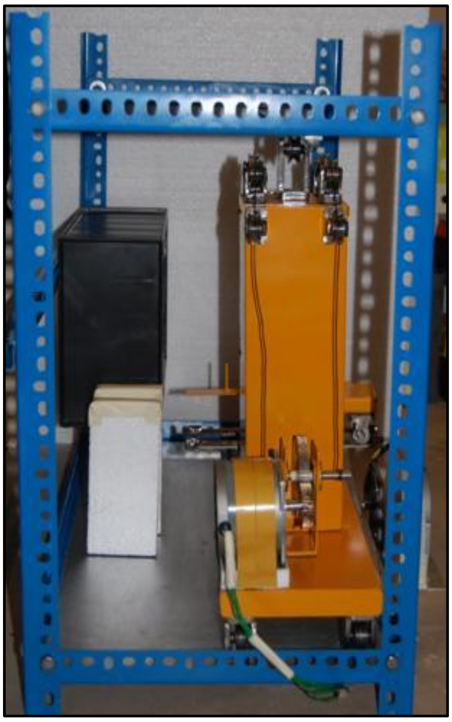

Figure 6.25: Left side view of AS/RS prototype

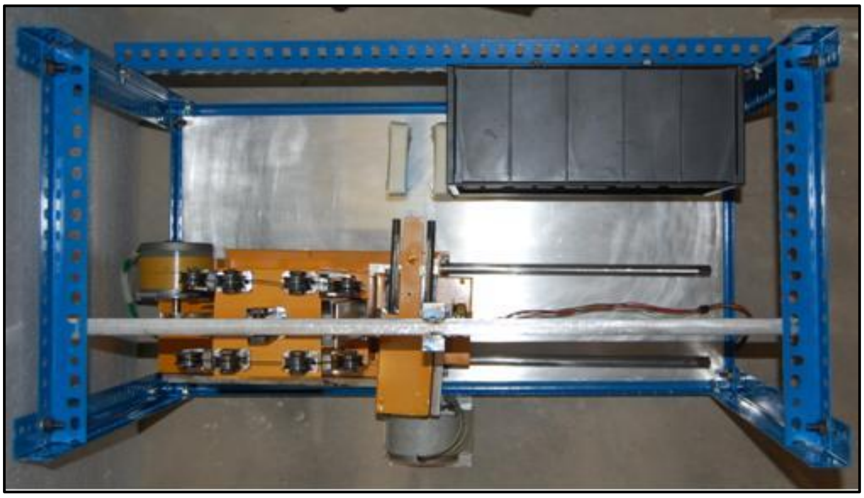

Figure 6.26: Top view of AS/RS prototype

APPENDIX D1

PROGRAMMING FOR DRAWER COORDINATE X=1 AND Y=1, (DRAWER 1)

```
 void main()
{
 int loop;
TRISA= 0;
TRISC= 0;
for (loop=0;loop<35;loop++)
{
portA = 0b11001001;
DELAY_MS(40)
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11001010;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<16;loop++)
{
portC = 0b11001010;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(4500);
for (loop=0;loop<2;loop++)
{
portA = 0b11001001;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11001010;
DELAY_MS(40);
}
DELAY_MS(4500);
for (loop=0;loop<16;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
  DELAY_MS(4500);
for (loop=0;loop<35;loop++)
{
portA = 0b11001010;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11001001;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001010;
DELAY_MS(40)
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(5500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}

}
```

APPENDIX D2

PROGRAMMING FOR DRAWER COORDINATE X=2 AND Y=1, (DRAWER 2)

```
void main()
{
int loop;
TRISA= 0;
TRISC= 0;
for (loop=0;loop<59;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);

for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }

  DELAY_MS(4500);

  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
 DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
}
```

```
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40)
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
  DELAY_MS(4500);
for (loop=0;loop<59;loop++)
{
portA = 0b11001010;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11001001;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001010;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(5500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
}
```

APPENDIX D3

PROGRAMMING FOR DRAWER COORDINATE X=3 AND Y=1, (DRAWER 3)

```
void main()
{
int loop;
TRISA= 0;
TRISC= 0;
for (loop=0;loop<83;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);

for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }

  DELAY_MS(4500);

  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
 DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
}
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40)
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
  DELAY_MS(4500);
for (loop=0;loop<83;loop++)
{
portA = 0b11001010;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11001001;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001010;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(5500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
}
```

APPENDIX D4

PROGRAMMING FOR DRAWER COORDINATE X=4 AND Y=1, (DRAWER 4)

```
void main()
{
int loop;
TRISA= 0;
TRISC= 0;
for (loop=0;loop<107;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);

for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }

  DELAY_MS(4500);

  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
 DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
}
```

```
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40)
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
  DELAY_MS(4500);
for (loop=0;loop<107;loop++)
{
portA = 0b11001010;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11001001;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001010;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(5500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
}
```

APPENDIX D5

PROGRAMMING FOR DRAWER COORDINATE X=5 AND Y=1, (DRAWER 5)

```
void main()
{
int loop;
TRISA= 0;
TRISC= 0;
for (loop=0;loop<131;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);

for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }

  DELAY_MS(4500);

  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
 DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
}
```

```
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40)
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
  DELAY_MS(4500);
for (loop=0;loop<131;loop++)
{
portA = 0b11001010;
DELAY_MS(40);
portA = 0b11000110;
DELAY_MS(40);
portA = 0b11000101;
DELAY_MS(40);
portA = 0b11001001;
DELAY_MS(40);
}
 DELAY_MS(4500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001010;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11001001;
DELAY_MS(40);
}
DELAY_MS(5500);
for (loop=0;loop<14;loop++)
{
portC = 0b11001001;
DELAY_MS(40);
portC = 0b11000101;
DELAY_MS(40);
portC = 0b11000110;
DELAY_MS(40);
portC = 0b11001010;
DELAY_MS(40);
}
}
```

APPENDIX D6

PROGRAMMING FOR DRAWER COORDINATE X=1 AND Y=2, (DRAWER 6)

```
void main()
{
int loop;
TRISA= 0;
TRISB= 0;
TRISC= 0;
for (loop=0;loop<35;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<370;loop++)
  {
  portB = 0b11001010;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(4500);
  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
 }
  DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
    DELAY_MS(4500);
    for (loop=0;loop<370;loop++)
  {
  portB = 0b11001001;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<35;loop++)
  {
  portA = 0b11001010;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
```

```
   portC = 0b11000101;
   DELAY_MS(40);
   portC = 0b11001001;
   DELAY_MS(40);
   }
   DELAY_MS(5500);
   for (loop=0;loop<14;loop++)
   {
   portC = 0b11001001;
   DELAY_MS(40);
   portC = 0b11000101;
   DELAY_MS(40);
   portC = 0b11000110;
   DELAY_MS(40);
   portC = 0b11001010;
   DELAY_MS(40);
   }
}
```

APPENDIX D7

PROGRAMMING FOR DRAWER COORDINATE X=2 AND Y=2, (DRAWER 7)

```
void main()
{
int loop;
TRISA= 0;
TRISB= 0;
TRISC= 0;
for (loop=0;loop<59;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<370;loop++)
  {
  portB = 0b11001010;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(4500);
  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
 }
  DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
    DELAY_MS(4500);
    for (loop=0;loop<370;loop++)
  {
  portB = 0b11001001;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<59;loop++)
  {
  portA = 0b11001010;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
```

```
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(5500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
}
```

APPENDIX D8

PROGRAMMING FOR DRAWER COORDINATE X=3 AND Y=2, (DRAWER 8)

```
void main()
{
int loop;
TRISA= 0;
TRISB= 0;
TRISC= 0;
for (loop=0;loop<83;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<370;loop++)
  {
  portB = 0b11001010;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(4500);
  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
 }
  DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
    DELAY_MS(4500);
    for (loop=0;loop<370;loop++)
  {
  portB = 0b11001001;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<83;loop++)
  {
  portA = 0b11001010;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
```

```
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(5500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
}
```

APPENDIX D9

PROGRAMMING FOR DRAWER COORDINATE X=4 AND Y=2, (DRAWER 9)

```
void main()
{
int loop;
TRISA= 0;
TRISB= 0;
TRISC= 0;
for (loop=0;loop<107;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<370;loop++)
  {
  portB = 0b11001010;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(4500);
  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
 }
  DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
    DELAY_MS(4500);
    for (loop=0;loop<370;loop++)
  {
  portB = 0b11001001;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<107;loop++)
  {
  portA = 0b11001010;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
```

```
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(5500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
}
```

APPENDIX D10

PROGRAMMING FOR DRAWER COORDINATE X=5 AND Y=2, (DRAWER 10)

```
void main()
{
int loop;
TRISA= 0;
TRISB= 0;
TRISC= 0;
for (loop=0;loop<131;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<370;loop++)
  {
  portB = 0b11001010;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
   for (loop=0;loop<16;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(4500);
  for (loop=0;loop<2;loop++)
  {
  portA = 0b11001001;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11001010;
  DELAY_MS(40);
 }
  DELAY_MS(4500);
  for (loop=0;loop<16;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
    DELAY_MS(4500);
    for (loop=0;loop<370;loop++)
  {
  portB = 0b11001001;
  DELAY_MS(40);
  portB = 0b11000101;
  DELAY_MS(40);
  portB = 0b11000110;
  DELAY_MS(40);
  portB = 0b11001010;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<131;loop++)
  {
  portA = 0b11001010;
  DELAY_MS(40);
  portA = 0b11000110;
  DELAY_MS(40);
  portA = 0b11000101;
  DELAY_MS(40);
  portA = 0b11001001;
  DELAY_MS(40);
  }
   DELAY_MS(4500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001010;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
```

```
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11001001;
  DELAY_MS(40);
  }
  DELAY_MS(5500);
  for (loop=0;loop<14;loop++)
  {
  portC = 0b11001001;
  DELAY_MS(40);
  portC = 0b11000101;
  DELAY_MS(40);
  portC = 0b11000110;
  DELAY_MS(40);
  portC = 0b11001010;
  DELAY_MS(40);
  }
}
```