TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

Department of Electrical Power Engineering and Mechatronics

Autonomous Cell with Hirata robots

Autonoomne süsteem Hirata robotitega

MASTER'S THESIS

MECHATRONICS PROGRAM

Student: Amexo Andy Kafui Kwaku
Student code: 177188MAHM

Supervisor: Prof Mart Tamre

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AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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DEPARTMENT OF ELECTRICAL POWER ENGINEERING AND MECHATRONICS THESIS TASK

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1.   Research on the feasibility of components

2.   Design of the automation system in solidworks

3.   Simulation of the system in solid works

4.   Model simulation and analysis in matlab

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Student: Amexo Andy Kafui Kwaku

Supervisor: Prof. Mart Tamre

Contents

PREFACE

The Project topic Autonomous cell with Hirata robot was completed as part of a master's of science mechatronics curriculum. The proposed topic by Prof. Mart Tamre was completed in the second year and final semester of my studies in the course.

I would like to thank God for giving me the strength and wisdom to complete this thesis project. Also, my gratitude goes to my supervisor Prof. Mart Tamre for the guidance and counselling provided through the duration of the project period. Appreciation goes to my friends Shu Taya and Maarjus Kirs for the advice on how the best way to approach some aspects of the project, and to Taltech university Of Technology for accepting me to pursue this course.

Furthermore, special thanks go to my family and friends for supporting me in my endeavours, morally and financially to attain my goal. I hope the research conducted on the Hirata robot would serve its purpose.

Key words: cartesian robot, forward kinematics, Simscape, solidworks

EESSÕNA

Projekti teema Autonoomne rakk koos Hirata robotiga viidi lõpule osana teaduse mehhatroonika õppekava meistrist. Prof. Mart Tamre pakutud teema valmis kursuse teises õppeaastal ja viimasel poolaastal.

Märksõnad: karteesiline robot, ettepoole suunatud kinemaatika, Simscape, Solid Works

LIST OF ABBREVIATIONS AND ACRONYMS

EOAT- End of Arm Tooling

CNC- Computer Numerical Control

IEC- International electrotechnical commission

DO Digital Output

DI   Digital Input

PID- Proportional Integral Deferential

HSC- Hirata Short Conveyor

HC -Hirata Conveyor

PLC -Programmable Logic Controller

1. INTRODUCTION

Robots can be programmed to perform dangerous, dirty and or repetitive tasks with consistent precision and accuracy, industrial robots are increasingly used in a variety of industries and applications. They come in a wide range of models with their reach distance, payload capacity and the number of axes of travel (up to six) of their jointed arm being the most common distinguishing characteristics. The ISO 8373:2012 standard defines an industrial robot as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications [1].

In both production and handling applications, a robot utilizes an end effector or End Of Arm Tooling (EOAT) attachment to hold and manipulate either the tool performing the process, or the piece upon which a process is being performed. [2]

The robot's actions are directed by a combination of programming software and controls. Their automated functionality allows them to operate around the clock and on weekends—as well as with hazardous materials and in challenging environments—freeing personnel to perform other tasks. Robotic technology also increases productivity and profitability while eliminating labour-intensive activities that might cause physical strain or potential injury to workers. [2]

Figure 1.1 Fanuc Delta robots performing tasks in an assembly [3]

1.1. Problem statement

The passage of years has brought numerous variations in assembly line methodologies. These new wrinkles can be traced back not only to general improvements in technology and planning, but to factors that are unique to each company or industry. [4]

The Hirata robots in an enclosure contain outdated controllers there altering the functionality process of the machine is difficult to impossible since modern equipment's are not compatible with the current controllers. Hence renders the whole system dormant in effect student and lectures are unable to use the robots in further research such as assembly technology. Due to these reasons, an assembly autonomous system must be built to use the robots for educational purposes.

1.2. Motivation

The mechatronics lab is home to many industrial robots that perform different functions. The reason for amassing all these different types of robots are for research purposes where the lectures and students can teach and learn the mechanics, software and electrical parts of the robots or machine. Unfortunately, there are no automotive cell robots situated in the department and this is disadvantageous in the sense that one cannot conduct a research in an assembly system the only option he or she has is to ask a company permission to use their system. The bureaucratic processes involved to get to start that research will be very time consuming. Hence driving the motivation to build this system in the Tallinn University of Technology mechatronics lab.

Some outcomes I am hoping to observe are the smooth running of the conveyor line due to perfectly calibrated sensors and also communication between the sensors and actuators should be seamless to establish control in the system. This is essential because in order to avoid collision between the robots these conditions and outcomes should be expected.

1.3. Objectives of the study

The key goal of this project paper is to use prove that the system can be built and used to run with the provided left over materials and peripheral devices from other non-functioning machines. The process in achieving this is as follows:

- Conducting a feasibility study on the materials and devices with the system.
- Realistic CAD design of the existing system with all the other existing machine parts.
- A CAD simulation and Simscape simulation to evaluate the smooth functionality of the system.

1.4. Thesis Structure

Chapter 1

Introduction

Chapter 2:

Literature review and background work

Chapter 3:

Initial design and feasibility studies

Chapter 4:

Developing conceptualised CAD model Solution to problem and comparing two solutions.

Chapter 5:

Final CAD model

Chapter 6:

Motion analysis in Solid Works and Simscape

Chapter 7

Summary: This chapter summarizes the work done in this paper.

2. LITERATURE REVIEW AND BACKGROUND WORK

2.1. LITERATURE REVIEW

The literature review outline includes two taxonomies simulation control and design methods. Analysis on some design methods in robot automation will be conducted to provide clear and compact designs and sensor types and control methods will be broken down in order to find out the accepted and more efficient way to model.

A paper [5] *Design and Implementation Methodology for Autonomous Robot Control Systems,* describes a general design and implementation approach used for programming and controlling complex robotic systems such as remotely operated submersibles, autonomous submersibles, and robotic manipulator systems. It is based on the hierarchical control concepts and event- driven, component-based software. These practices simplify the development process for autonomous control systems. Advantages of hierarchical control system design are that it provides a template for complex control system functional design and that it also allows parallelism in the development process [5].

From *the advanced industrial control technology* [6] page 91 talks about different sensors and how that can be implemented in a machine for optimum performance. From my deduction I presume optical sensors are the ideal solutions in marking the positions of items on the conveyor belt. Although using position encoders will be the perfect solution, they are very expensive to purchase for this project.

Cartesian Control for Robot Manipulators [7] talks about using Jacobean matrix to solve a joint control theory which expresses the relations of position, velocity and acceleration of the robot in its native language, in other words, it describes its movements using the torque and angles necessary to complete the task; In majority of cases, this language is difficult to understand by the end user who interprets space movements in cartesian space easily. Hence using the Jacobean transpose matrix and eliminating the possibility of singularities and giving origin to the cartesian control this solution was proposed by S. Arimoto and M. Takegaki in 1981 [7].

2.1.1. Review on automation assembly system methodology.

Automated assembly refers to the use of mechanized and automated devices to perform the various assembly tasks in an assembly line or cell. The clear majority of automated assembly systems are designed to perform a fixed sequence of assembly steps on a specific product. Automated assembly is considered appropriate if it meets the following conditions [8]. Some advantages of automation assembly system over manual include:

1. *Reliability***:** Processes are reliably executed by automation, relieving operators from hours of tedious, challenging manual tasks. Automation is precise and repeatable. It ensures the product is manufactured with the same specifications and process every time [9].

2. *Quality:* Manual and automated assembly systems can handle multiple tasks in order to meet specific manufacturing requirements. Achieving consistent quality requires the ability to perform detailed production tasks with high repeatability. Automated systems can establish repeatable methods and effectively integrate tasks into a well-balanced production line [9].

3. *Consistency of Output and Throughput:* Robotic assembly and inspection can maximize production and error detection using camera equipped robots for quality evaluation and verification. This helps reduce variability, bottlenecks and provides a consistent output [9].

4. *Labor Savings:* For many manufacturers, the assembly process can signify one of the highest direct labor costs. These costs can be mitigated through automation. Automated processes lead to tighter process control and higher quality standards while keeping costs down [9].

5. *Track & Trace Capabilities:* Automation enables you to track and trace every unit produced through the manufacturing process. If any issues arise, you will be able to review every action that has taken place to locate the source of the issue and resolve it [9].

6. *Greater Volumes:* Automation yields a higher part production rate. This, in turn, produces greater profitability [9].

There are 2 methods of classification of assembly system type which are transfer type and physical configuration

The type of automation varies with the type of work transfer that is used and the 4 main transfers include continuous, synchronous, asynchronous, and stationary transfers [10].

1. The continuous transfer items are identified continuously at a constant rate; therefore, the work heads must sync movement with the moving parts in the transfer. For example, the transfer in packaging and bottling operation where an automated selective actuator sorts the bottles according to bottle sizes. The only advantage is that product that is assembled keeps moving at a steady speed hence deceleration and acceleration problems are avoided.

2. Intermittent or synchronous transfer has a fixed work station and the parts move at a discontinuous motion from one workstation to another where the locations on this work station are registered for further processing. Examples include mechanized assembly and operations involving press workings.

3. The asynchronous transfer system often used as a power and free system allows each work part to advance to the next station where processing at the parts increasing flexibility. The flexibility of the system can be advantageous in certain situations [10], such as production of different batches with different item sizes.

4. In the stationary base part system, the base part is placed in a fixed location where it remains during the entire assembly process. This approach would be preferred when the assembled product is bulky or otherwise difficult to handle for example airplanes, truck containers or recreational vehicles.

System configurations for automated assembly systems include In-line, Dial type, Carousel Assembly System, Single station assembly.

In-line assembly system

This assembly system includes series of automatic workstations located along an in-line transfer system the assembly version of the machining transfer line. Synchronous and asynchronous transfer systems may be used to transport parts from workstation to workstation [8].

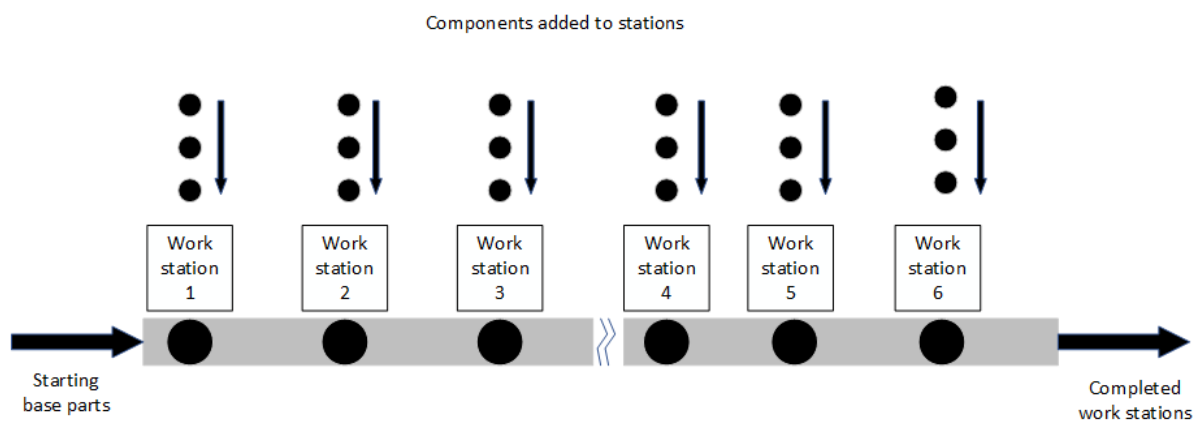Figure 2.1In Line layout configuration [8]

Dial type

Base parts loaded onto fixtures or nests around the periphery of the circular dial, and—as the dial table turns— components are assembled sequentially onto the base part. Synchronous transfer

system in operation, as all nests move at the same time, sometimes through continuous motion, but more often intermittently. [8]
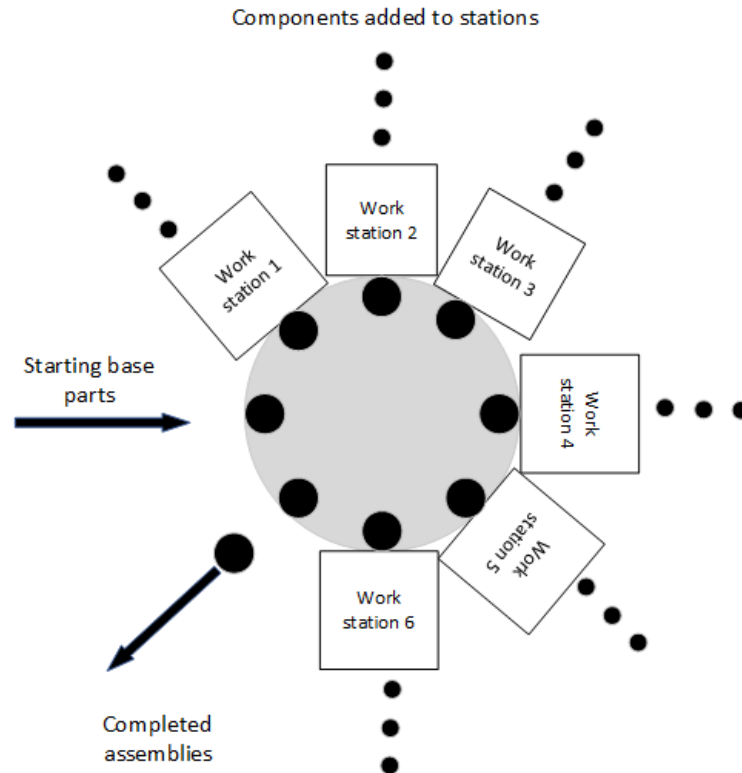

Figure 2.2 Dial layout config [8]

Carousel assembly system

Represents a hybrid between the circular work flow of the dial type assembly machine, and the straight work flow of the in-line system. Carousels can be operated with continuous, synchronous, or asynchronous transfer mechanisms. [8]
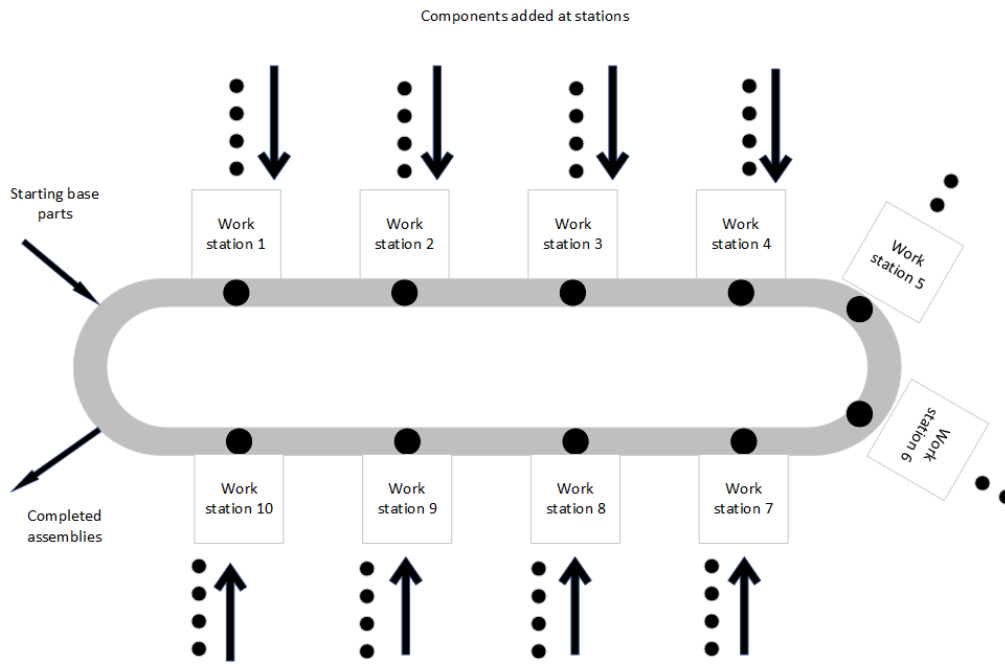
Figure 2.3 Carousel assembly layout [8]

Single station Assembly

Consists of one workstation where components are assembled, successively, onto a base part that has entered the system. Once all the components have been assembled onto the base part, the base part leaves the system. Inherently slower than the other three system configurations, as only one base part is processed at a time. [8]
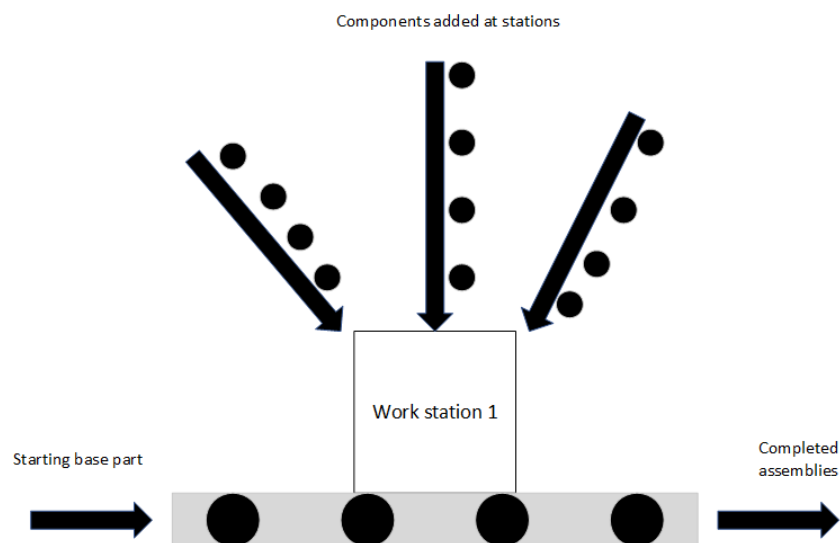

Figure 2.4 Single station assembly layout [8]

2.1.2. Review on Cartesian robots and current Hirata robot design

Cartesian coordinate robots consist of three orthogonal linear sliding axes the manipulator hardware and the interpolator. The control algorithms are similar to those of Computer Numerical Control Machines (CNC) tools. Therefore, the arm Resolution and accuracy will also be of the order of magnitude of machine tool resolution [11].

An important feature of a Cartesian robot is its equal and constant spatial resolution that is the resolution is fixed in all axes of motions and throughout the work volume of the robot arm. This is not the case with other coordinate systems [11].
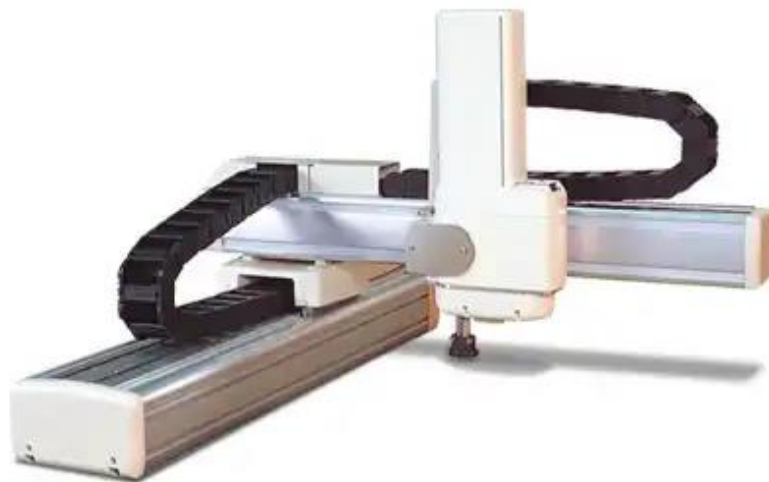
Figure 2.5 Hirata Cartesian Robot [11]

The ability of a robot to run through its exact set position coordinates after each complete process this is very essential since the robot must obtain the same position after every cycle

The robot of interest is the Hirata Robot version CRWQ-H2010AP-1150-700-200-LL as shown in figure 2.5. The Hirata robot is an all metal Cartesian coordinate linear robot with 4 axes (X-Y-Z-W) and are linked by 2 linear joints and 2 rotation joints with a vertical stroke of 200 or 350 mm and can handle a payload of about 5kg [12].

The entire system consists of two Hirata robots parallel to each other, one in the upper rig and the other in lower rig. The entire setup exists in a 180x140x200cm enclosure as seen in the appendix originally controlled by an HNC-544 controller [12].

Table 2.1Hirata cartesian robot specification [12]

Type	Axis	Max Payload	Max speed (/sec)	Stroke	Repeatability	Axis type
CRWQ-H2010AP	X	5	1200 (Compounded speed 1697)	1000,1200, 1500	±0.02	MB-H204AP
	Y			300,500,700		MB-102A
	Z		1000	200	±0.01	HMW-S270
	W		1200°	540°	±0.03°	

The entire system consists of two Hirata robots parallel to each other, one in the upper rig and the other in lower rig. The entire setup exists in a 180x140x200cm enclosure as seen in the appendix originally controlled by an HNC-544 controller. The HNC controller performs automatic operation by exchanging the signals with an external programmable controller through Digital Input (DI)/ Digital Output (DO) interface. Currently the robot is planned to be controlled by a Beckhoff controller.
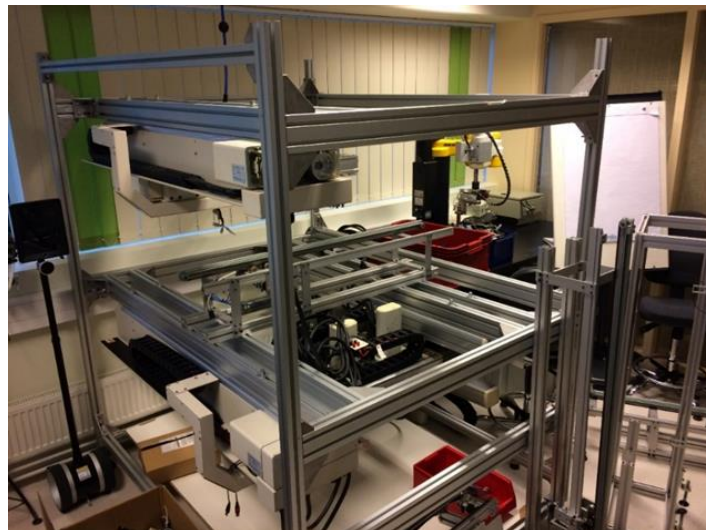
Figure 2.6 Present Hirata robot in the robotics lab

In summary, the review above allows for the appropriate and advised type of assembly system suitable for the proposed task in this project. The physical structure selected is the In-line assembly system. Criteria used in selecting the physical structure was based upon the type and size of items in the work station, the chosen robot type which is a Hirata cartesian robot of the CRWQ series.

The transfer type is asynchronous. The reason for this selection was based upon the operation and functionality of moving parts from work station to work station also, since it's a laboratory autonomous system, much flexibility will be needed to satisfy the operation on many items.

3. THEORITICAL SOLUTION

3.1. General overview over the conceptual solution

The main prerequisite for the project was to use the available non-functional parts from other machines to create a whole new system with the Hirata cartesian robot. After reviewing the various ways on how to identify the physical structure and transfer type suitable for the problem some ideas were generated.

The main idea decided upon was a system with two elevators side by side that will carry the item to and from the lower or first level of the system to the second system shown in the figure below.
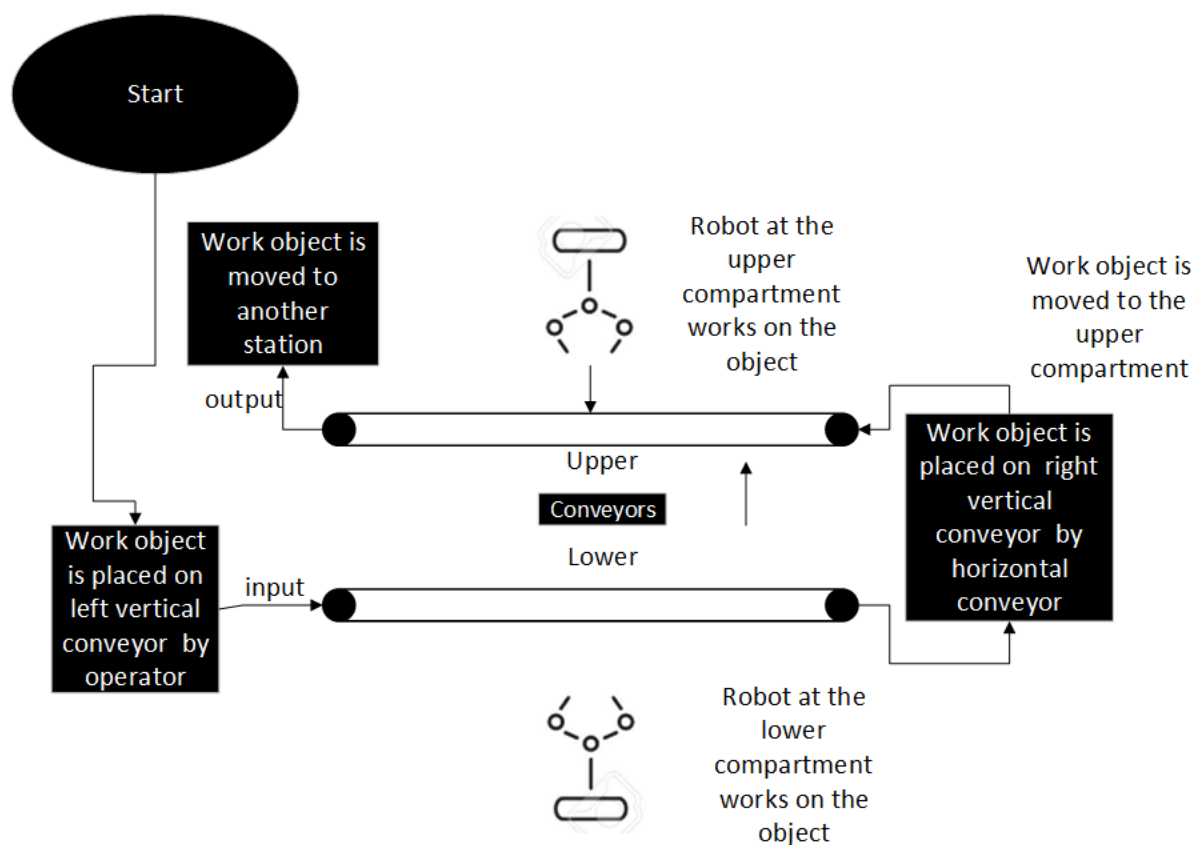
Figure 3.1 General flow process of the assembly system

The idea involves a modified elevator that would initially serve as a feeder onto the lower conveyor of the item has passed through a couple work stations on a conveyor depending on the number of processes the item has to go through. A vertical conveyor then lifts the item to the upper or second level then the conveyor in the lift moves the item on to the main upper conveyor for further processing as seen figure 3.1.

3.2.   Feasibility studies

The entire system consists of so many peripheral parts from other machines as mentioned in the earlier chapters, so the aim was to acquire other dormant machine parts and try to integrate it into the automation system before the actual build of the system. Parts include conveyor belts in their enclosures, lifts, motors and proximity sensors. The task was to find their properties and specifications and build an elementary design to ensure complete and seamless integration between the parts the robot and its enclosure.

3.2.1. Electronic spare devices

The electronic components of the system are very important as they contribute to the accuracy reliability and actuation of the system to perform specific tasks

The selection process begins from the power supply which should be capable of converting an AC voltage of 220 to 240 volts to supply a voltage of 24 volts to a plc. The balluf power supply version number BAE0005 - BAE PS-XA-1W-24-025-002 in figure… is available for this task [14].

Figure 3.2 Balluf 24v power supply [14]

It has a dimension of 40.5 x 90 x 114 mm with a plastic housing and can be mounted on a din rail. It can work in ambient temperature conditions. The rated output current is 2.5A and output voltage is 24V. The Balluff power supply will be used to power the bekhoff CX5010 industrial plc which was explained in chapter 2 section 2.2.

Another device selected was the premotec motor as displayed in figure 3.3, version number 9904 120 15805 the motors. The motors and servos are responsible to the actuation in the system from the conveyors to the movement of the robots.

Figure 3.3 Premotec motor with gear head

The motor operates at a voltage of 24DC which will be powered from the beckhoff industrial PC. It has a nominal speed of over 4200 RPM and operational current of over 1250mA under load. Below is a table of the parts and their necessary specifications. It can maintain a constant torque over 55 Nm.

Selecting the right proximity sensor was a bit tasking due to the fact that the 2 proximity sensors selected were advantageous in certain areas and also beard some disadvantages.

On the left in figure 3.4 in the diagram shows the omron inductive proximity sensor and on the right the sick inductive proximity sensor. Both proximity sensors are activated by a metal target, their switching output is PNP, the omron proximity sensor is normally opened (NO) and the Sick sensor is normally closed (NC), the sensing range for the omron is 0-10mm while the sensing range for the sick proximity sensor is from 0-22mm.
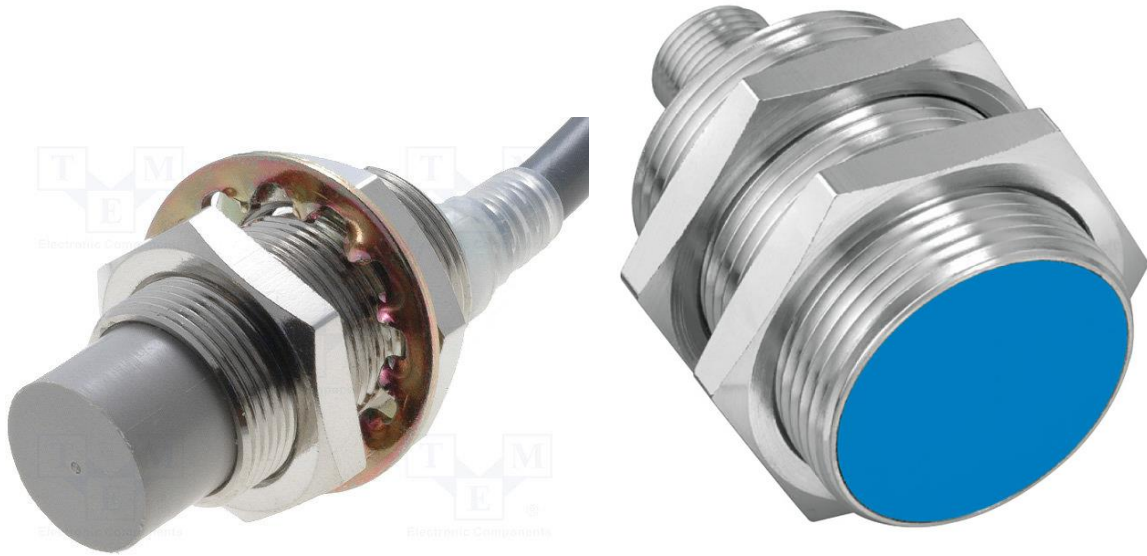
Figure 3.4 PnP induction proximity sensors Omron (left) Sick (right)

The appropriate sensor selected for the detection of items in the automation system is the sick induction proximity sensor. In view of the fact that, the sensing range between the object and the sensor is enough to place the sensor at a comfortable distance from certain parts of the machine to enable smooth   manoeuvrability of the system.

Table 3.1 Electrical available devices

Device (electronic)	model	analogue /digital	input/output	control output	sensing distance	voltage DC/AC	current	Available amount
photoelectric sensor	E3Z- R81	digital	input	PNP- output	4m	12-24 DC	35mA	1
proximity sensor	E2EG- X10MB1	digital	input	PNP- output	10m	12-24 DC	12mA	5
Premotec motor	9904 120 15805	analogue	output	---	---	24 DC	2.9A	8
(Gear Head)	5GN 12.5K	---	---	---	---	230		2
(Motor)	51K40GN- CW	---	---	---	---	220/230		2
Sensor amplifier	E3X-NA41	digital	---	---	---	12-24 DC		6

The criteria for selection in table 3.1 was based on the amount available to cover the working operations in the system, the voltage rating and the structure of the device. From the lot of parts, these parts have the most modular design, can handle voltage from 12 to 24v Volts and their current draw is sustainable taking into consideration the types of cables needed to establish connection between the controller and the electronic devices. The torque of the premotec motor was also enough for its function hence the selection.

Table 3.2 available mechanical parts

Physical mechanical parts	Material	Length	State Good / satisfactory
Horizontal Conveyor enclosure	Aluminium	133 cm	good
Vertical conveyor lift enclosure	Aluminium	140 cm	Satisfactory
Horizontal conveyor for vertical lift	Aluminium	44 cm	good

The selection of the physical mechanical parts as seen in table 3.2 was based on its morphology, material and state of the structure.

The form of the structures is paramount to the system because the length has to be within the defined enclosure of the system. There were two types horizontal conveyors one of approximately 133cm and a shorter version. The conveyor of 133cm was chosen because it fits the required length from the Vertical conveyor lift enclosure to the end of the robot's enclosure. The horizontal conveyor enclosure also fits for its given height. The problem is the guard rails to support and establish movement for the horizontal conveyor for vertical lift so to fix the problem either a new guard rail must be installed or a whole actuated system has to be introduced.

Two elementary designs were generated during the feasibility study to check if all the structures would fit. Also, whether the combination would oblige to the ISO standards that govern the construction of such structures.

3.3. Review on control

The is an Embedded PCs from the CX5000 series based on Intel®Atom™ processors and differ only by the CPU version. The CX5010 has a 1.1 GHz Intel®Atom™ Z510 processor. Its compact form as shown in figure 2.7 aids in the easy fitting onto systems [13].
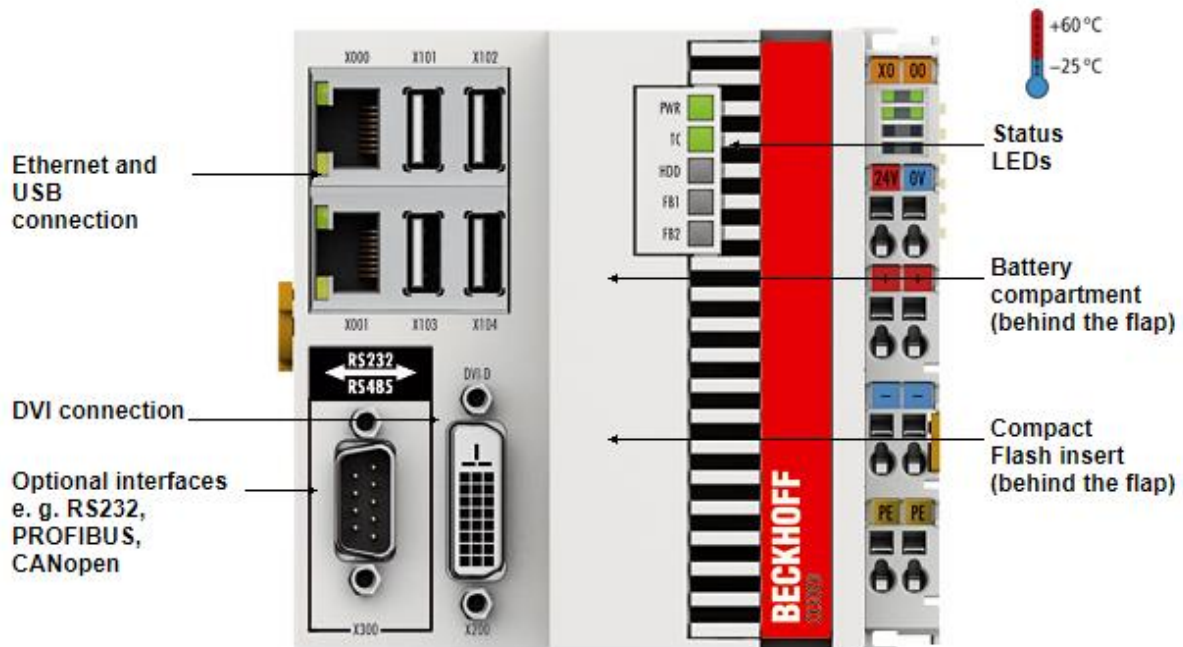

Figure 3.5 Top view of a CX5010 is an Embedded Pc [13]

Technical data on the CX5010 are it has a 24-volt power supply and a maximum of 2A current supply. The CX5010 will replace the Hirata HNC-544 controller The HNC controller performs automatic operation by exchanging the signals with an external programmable controller through Digital Input (DI)/ Digital Output (DO) interface [13].

Currently the HNC controller cannot be used and there the preferred solution will be to use the CX5010 controller. The advantage the CX5010 has over the HNC is that it has an intel processing core while the HNC controller is controlled using numeric control by a microprocessor [12] therefore, has a higher speed than the HNC controller. Another advantage is the vibrations, the bekhoff controller has a shock rating that conforms to international electrotechnical commission (IEC) environmental testing guidelines IEC EN 60068-2-6/EN 60068-2-27.
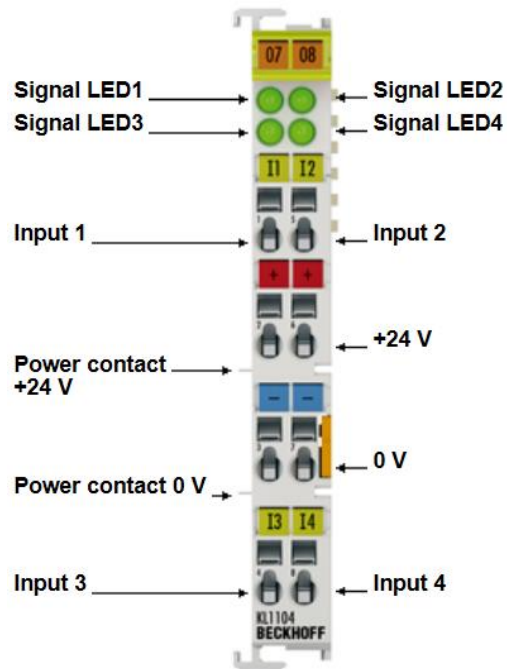
Figure 3.6 Top view of 24 V DC i/o bus

The industrial PC includes input output (IO) buses for sensors stepper motors and dc motors. Theses busses deliver from 12- 24 volts. The digital input terminal acquires the binary control signals from the process level and transmits them, in an electrically isolated form, to the higher-level automation unit. The Bus Terminal contains four channels that indicate their signal state by means of light emitting diodes.

4. INITIAL DESIGN SOLUTIONS

4.1. Proposed solution

As mentioned in chapter 3 two conceptual solutions were generated to solve the problem at hand.

- The solution involving two AC driven servo motors to drive a vertical platform from bottom to top and vice versa. This component is key to the system because it actuates the horizontal feeding platform. The motor requires an ac voltage from 220-240 volts to operate. Also, it needs a frequency inverter to be able to be controlled. The problems associated with this solution is that it takes too much space when installed considering the space allocated to the robot on the lab and how big the enclosure is. It renders the design very difficult to implement since it leaves little or no space to move around in the laboratory. Another problem encountered with the solution was that the link between the belt of the ac motor and the horizontal platform might result in an unbalance distribution of force while lifting the horizontal platform in the vertical enclosure of the lift.
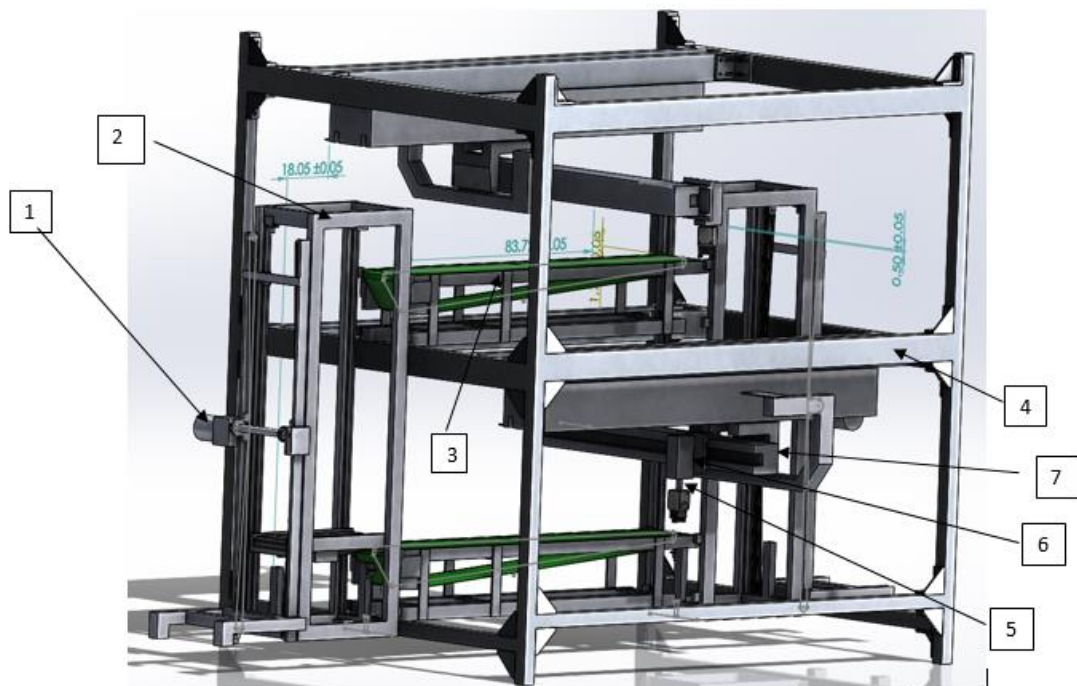

Figure 4.1 Initial design of the autonomous assembly system

Finally, to control the AC motors speed frequency inverters are needed and this increases the budget for this project by a very high amount.

Label

1- AC motor

2- Vertical lift frame

3- Horizontal Conveyor enclosure

4- Hirata robot enclosure frame

5- Y- axis stroke for Hirata robot

6- X– axis for Hirata robot

7- Z – axis for Hirata robot

The final solution involves the removal of the AC motor and its accessories and replacing the entire actuation for vertical movement. The solution was generated to solve space management and reduce cost of electromechanical actuator system to move the horizontal platform vertically. In order to manage space, I had to use the empty space available round the frame for the vertical lift for actuation. The electromechanical system discovered for this kind of task was a linear guard rail actuated by stepper motors.
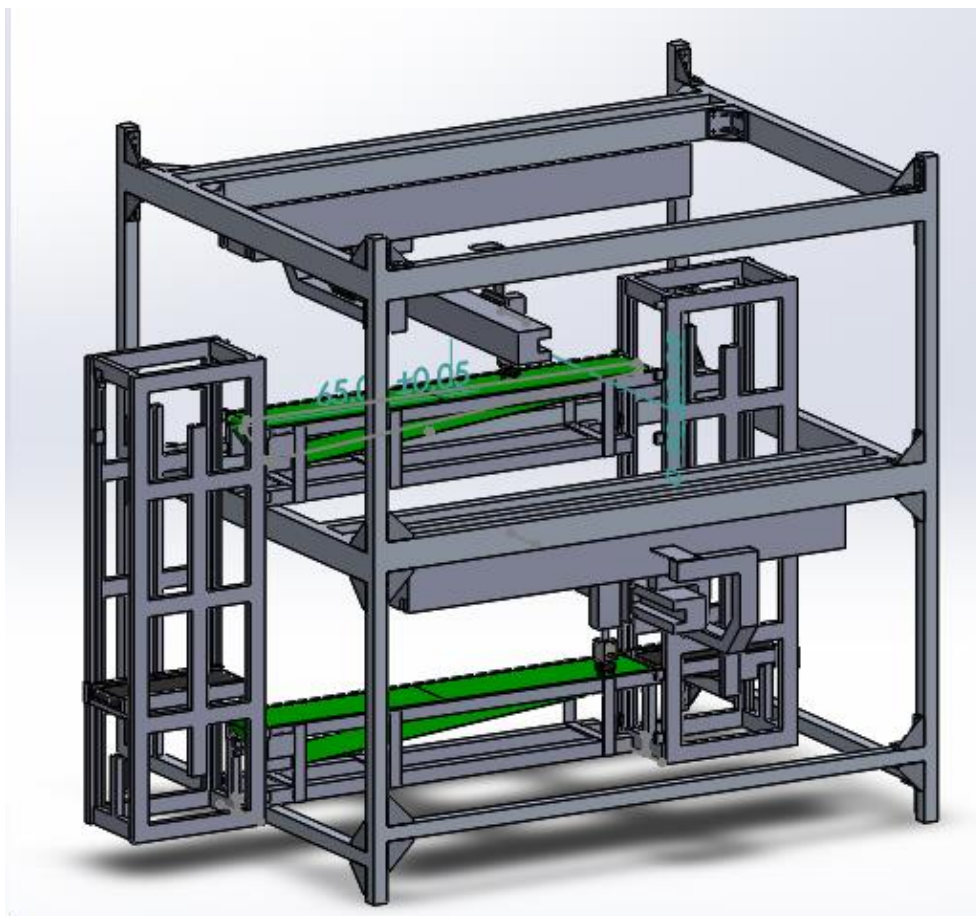

Figure 4.2 Final conceptual assembly of the autonomous system

4.2. Rationalisation on selected solution

The advantage over these set up utilises little space within the frame and its very cheap considering the dc motors drivers and the entire set up to be purchased. Again, mountain the setup on the sides of the frame poses a great advantage to structural integrity of the system because the forces of the setup with the horizontal platform are evenly distributed therefore the system. The motors used are dc stepper motors the advantage it has over the servo motors is its repeatability and ability to line up with the horizontal conveyor is far more accurate than the servo motors.

Figure 4.3 Ac motor vertical lift (left) and DC stepper motor (right)

The diagram above is a conceptual drawing off the vertical lift extracted from figure 4.1 and 4.2 respectively. Comparing both figures its seen there is a decrease in the size of the system as well as an increase in compatibility.

Some disadvantages involved with this design are related to base supports because the attached frames are at different sizes therefore, a uniform base structure must be created in the form of a big base for the entire system to rest on or using single extrusion supports to balance the system at the base.

5. FINAL CAD DESIGN MODEL

5.1. Model design decisions

In chapter 4 designs were created and their strengths and weaknesses were discussed. In this chapter the cad design will be developed based on the identified weaknesses in the previous chapter
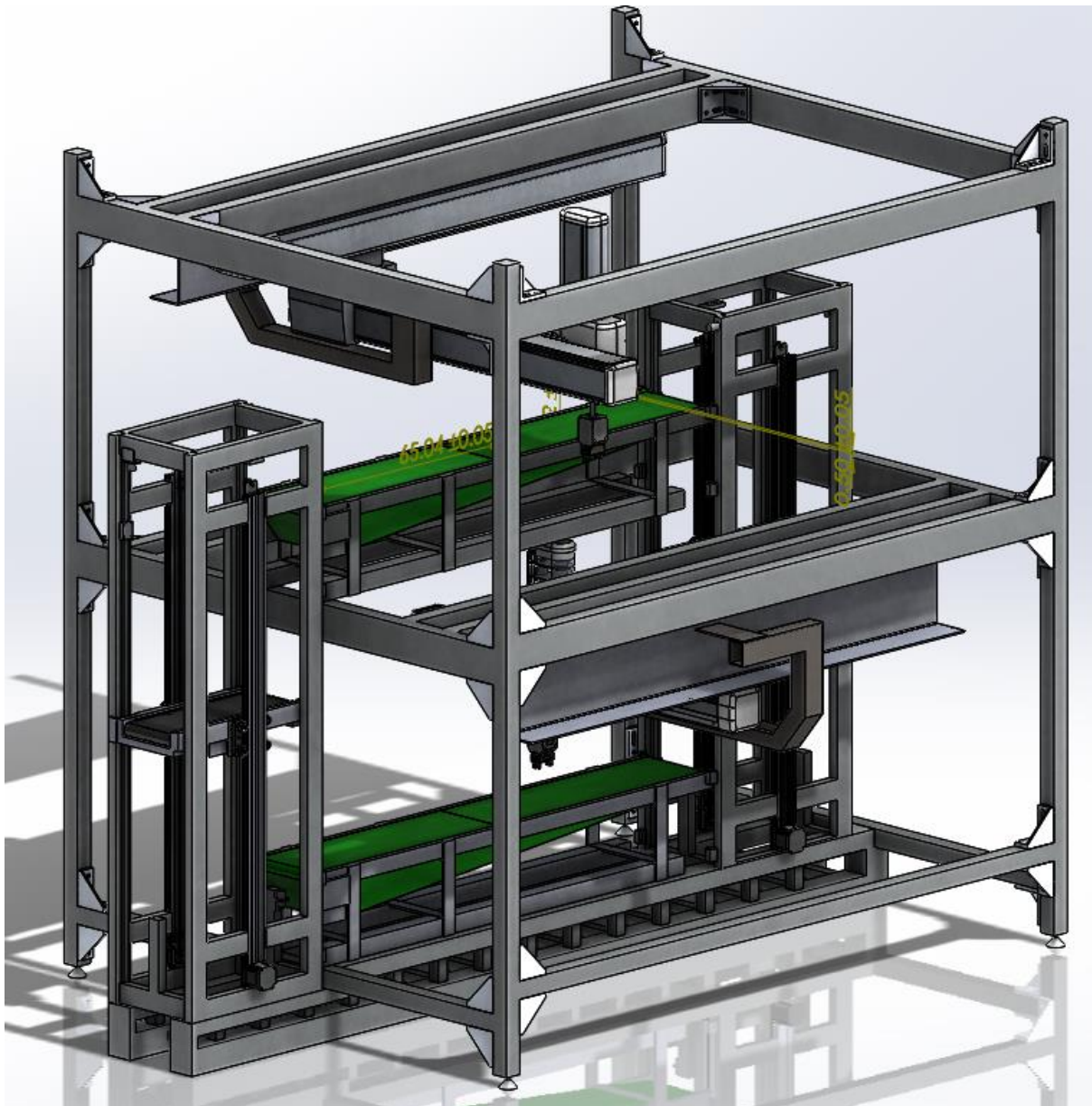

Figure 5.1 Final design for Hirata Automation Cell

The final design of the system has been generated by solving problems based on structural weaknesses. The base of the automation system was supported with a long hollow base to ensure the additional machines on the enclosure are well reinforced to prevent excessive physical vibrations that might compromise the overall efficiency system. The base support was constructed in a hollow format to reduce the excess weight of the entire system.   The   Automation Cell system is divided into 2 parts namely the vertical lift conveyor system which is responsible for transporting the item to the next layer and the second is the work area environment which contains a horizontal conveyor belt each part contains 2 each, meaning 2 vertical lift conveyors and 2 horizontal work stations.

5.2.   Torque calculations

5.2.1. Torque calculation for vertical lift

The vertical lift enclosure was fitted with a linear guard rail as stated earlier in chapter 3, stepper motor type Nema 23 - 02PD - AMT112S was selected to lift the feeding tray to the required work station.
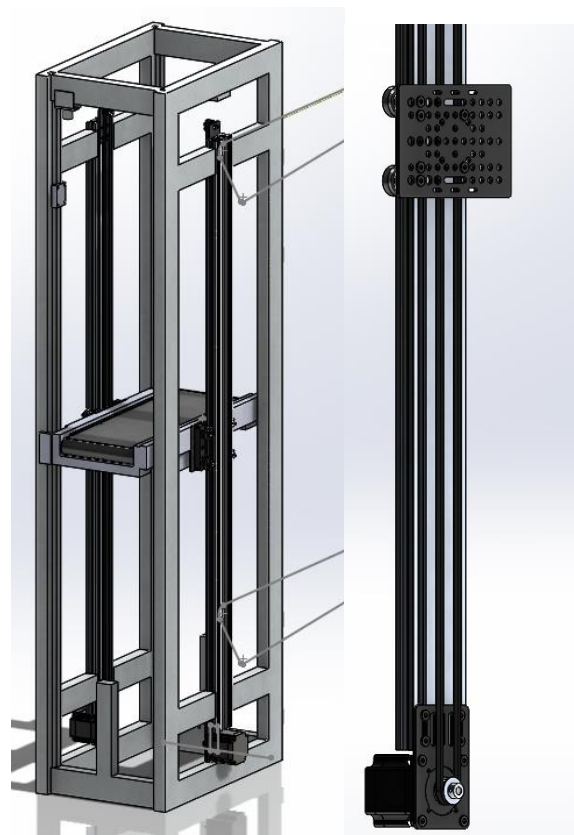
Figure 5.2 vertical enclosure (left), actuated guard rail (right)

The criteria for selecting the motors to actuate the system was conducted through calculations. The main aim was finding the appropriate torque needed to lift the load of at least 3 Kg along a height spanning over 500 mm and selecting a model that is capable of handling it.

Wire belt drive loads are usually adopted by relatively long-distance drives such as conveyors jet ink machines, plotters, assembly lines. This is a very important component in the automation industry because it's the main mode of transporting and placing work objects in work stations [15].

Figure 5.3 Forces acting on the horizontal feeder

Figure 5.2 depicts the drive unit in a vertical position with load on it. Data acquired for this calculation were mass of the feeding tray, speed of the stepper motor, weight of the pulley, diameter of the wheel and inertia of the motor.

Calculation process:

- The acquisition of mass of the feeding tray was conducted by weighing the feeding tray and all its external parts to get a net mass of the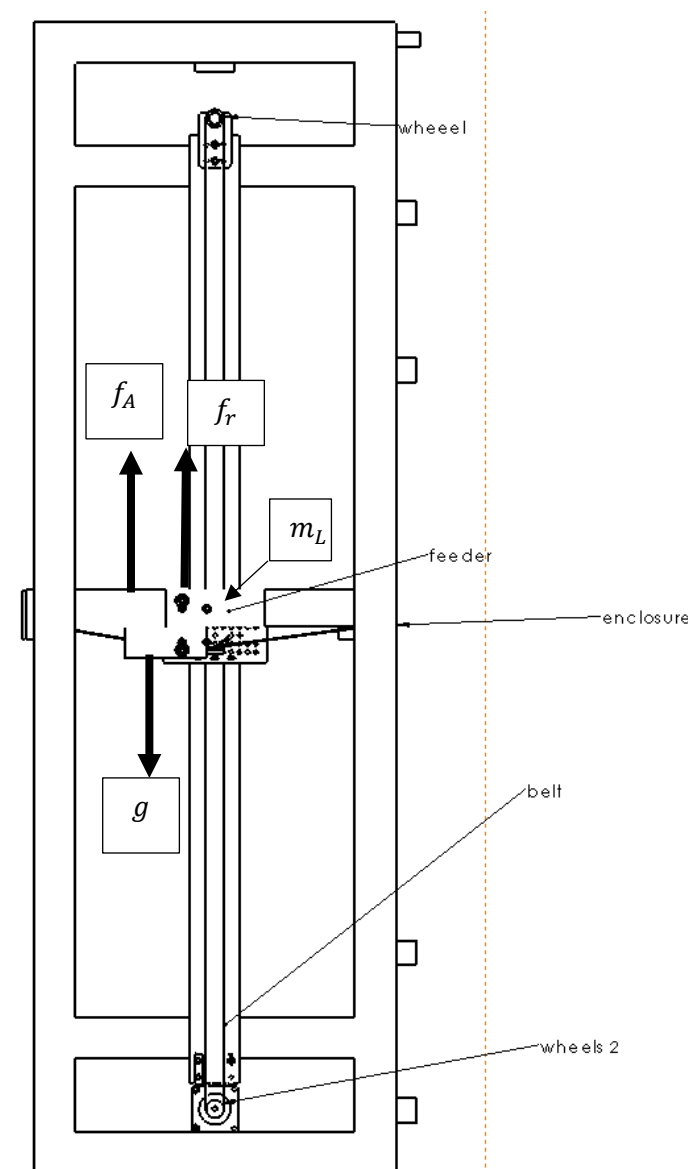 feeder. The result showed a 2.06 kg in mass. Yet for calculation purposes the net mass will be used that is the mass of the feeder and the proposed maximum mass attached.
- The speed of the motor was acquired from data sheets which is 9 RPS converted to 54 rad/s [16]
- The mass of the basic pulley is 0
- The diameter of the wheels was measured in the solid works software because it was an already prepared model from an open build site drawn to scale.
- Inertia of the motor was acquired from the motors data sheet

A series of calculations were made on different motors to determine the right amount of torque needed to lift the feeder.

The load is at rest on the cable so first the inertia of the net load of the feeder is determined.

$$J_L = \frac{1}{4} \cdot m_L \cdot D^2 \tag{5.1}$$

Where:

J_L= inertia of the load [kg m^2]

m_L= mass of the load [kg]

D=diameter of the wheel [m]

Solving for J_L

$$J_L = \frac{1}{4} \cdot 6 \cdot 0{,}0175^2 = 4{,}59 \cdot 10^{-4} \; kgm^2 \tag{5.1}$$

Next calculation on the inertia of the pulley system was conducted because we assume in the initial state the pulley system does not move and in a basic pulley system newton's second law, F (force) = M (mass) x A (acceleration) assumes the pulley has no friction and you ignore the pulley's mass.

Newton's third law says that for every action there is an equal and opposite reaction, so the total force of the system F will equal the force in the rope or T (tension) + G (force of gravity) pulling at the load [17]. Therefore, we assume pulley mass =0

$$J_P = \frac{1}{8} \cdot m_P \cdot D^2 \qquad (5.2)$$

Where:

J_P= Inertia of the pulley [kg.m^2]

m_P= Mass of the pulley [kg]

Solving for J_P

$$J_p = \frac{1}{8} \cdot 0 \cdot 0.0175^2 = 0 \; kgm^2 \qquad (5.2)$$

The next step is to calculate for inertia of the belt the mass of the belt was determined by using the mass function in solid works cad software. All realistic parameters such as material type were added to the belt to get a pragmatic mass to aid in further calculations.

$$J_B = \frac{1}{4} \cdot m_B \cdot D^2 \qquad (5.3)$$

Where:

J_B= Inertia of the belt [kg.m^2]

m_B= Mass of the belt [kg]

Solving for J_B

$$J_B = \frac{1}{4} \cdot 0.02966 \cdot 0.0175^2 = 2.2703 \cdot 10^{-6} \; kgm^2 \qquad (5.3)$$

Next the inertia of the motor is determined [J_M]

$$J_M = 2.743 \cdot 10^{-5} \; kgm^2 \qquad (5.4)$$

Summing up all inertia to get total inertia of the system

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$$J_T = J_L + J_P + J_B + J_M \tag{5.5}$$

Solving for J_T

$$J_T = 4{,}59 \cdot 10^{-4} + 0 + 2{,}2703 \cdot 10^{-6} + 2{,}743 \cdot 10^{-5} = 4{,}887 \cdot 10^{-4} \ kgm^2 \tag{5.5}$$

Calculating the accelerated torque needs data such as initial speed final speed and time change between the speeds assuming the connection is made from the power source to the motor without any controller time change from initial speed 0m/s to final speed 24 RPS or 150.796 rad/s therefore,

$$T_a = J_T \cdot a = (J_L + J_P + J_B + J_M) \cdot \frac{\omega_1 - \omega_0}{t} \tag{5.6}$$

Where:

T_a= Acceleration torque

ω_1=Final velocity of the motor

ω_0= Initial velocity

t= Time for velocity change

Solving for T_a

$$T_a = 4{,}887 \cdot 10^{-4} \cdot \frac{56 - 0}{1} = 2{,}737 \times 10^{-4} \ Nm \tag{5.6}$$

Further calculations are made to find the load torque

$$T_L = \frac{m_L \cdot g \cdot D}{2 \cdot \eta} \tag{5.7}$$

Where:

T_L= Load torque

M_L=Mass of the load

g= acceleration due to gravity

D= Diameter of the wheel

η= Efficiency (Reference Value is 0,85 to 0,95.)

It is assumed the motor is new there for calculation purposes the ideal efficiency was used which was 0,95.

Solution

$$T_L = \frac{6 \cdot 9,8 \cdot 0,0175}{2 \cdot 0,95} = 0,542 \, Nm \tag{5.7}$$

The next step is to calculate the total torque

$$T_T = T_L + T_a \tag{5.8}$$

Where:

T_T = Total Torque

Solution for T_T

$$T_T = 0,542 + 2,737 \times 10^{-4} = 0,542 \tag{5.8}$$

Finally, the required torque for the motor is calculated

$$T_M = K_s \cdot T_T \tag{5.9}$$

Where

T_M = Required torque for motor

K_s = Safety factor (Reference Value is 1,5 to 2,0.)

Again, calculation was conducted according to the best conditions there for the ideal safety factor was taken into consideration.

Solution

$$T_M = 2,0 \cdot 0,5423 = 1,0846 \, Nm \tag{5.9}$$

The required torque for the motor for the vertical lift should be 1,0846 Nm or 11,06 kg.cm. There are 2 motors in each vertical lift therefore the torques are added $11,06 \cdot 2$ which is equivalent to 22,12 kg.cm. which mean that the motor selected should be able to lift a load from 2,06- 22 kg. The results acquired from these calculations was used to find the appropriate servo motor (Nema 23 - 02PD - AMT112S) to lift loads up to 6 kg with a torque of 1,200Nm (12,24 kgcm)

5.2.2. Torque calculation for horizontal conveyor

In calculating the torque required to move load along the horizontal conveyor, the same formulas were used to arrive at the overall torque needed in the system to move the load. In section 5.2.1 torque required to lift the load in the vertical conveyor was calculated. Net load was used in calculating the torque required, which comprises of short horizontal feeder at mass 2.06kg added to a specific load of 4kg. In this section the use of a 4kg load will be used in the determination of the required toque to move the load.
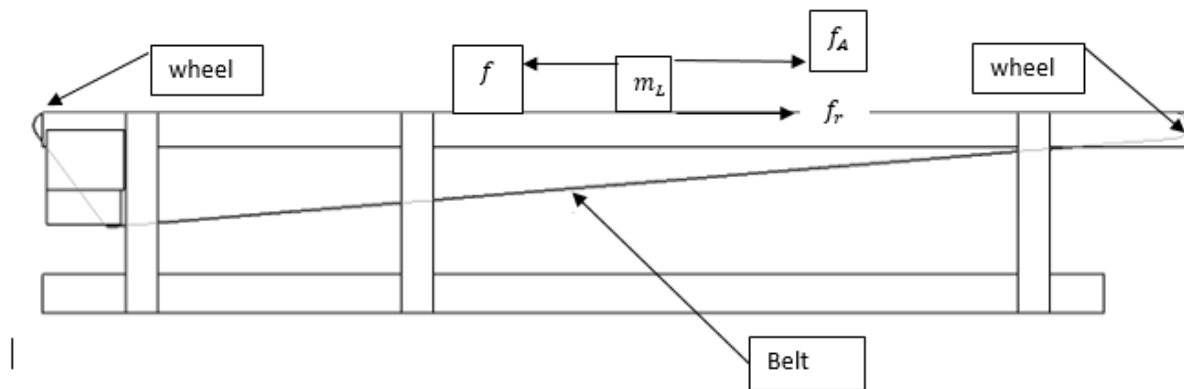
Figure 5.42d drawing of the horizontal conveyor system

Calculating the load is at rest on the cable so first the inertia of the load on the conveyor.

$$J_L = \frac{1}{4} \cdot m_L \cdot D^2 \qquad (5.10)$$

Where:

J_L= inertia of the load [kg m²]

m_L= mass of the load [kg]

D=diameter of the wheel [m]

Solving for J_L

$$J_L = \frac{1}{4} \cdot 4 \cdot 0{,}03^2 = 9 \cdot 10^{-4} \ kgm^2 \qquad (5.10)$$

Again, it is assumed that in the initial state the pulley system does not move and in a basic pulley system newton's second law, F (force) = M (mass) x A (acceleration) assumes the pulley has no friction and you ignore the pulley's mass. Therefore, the mass =0

$$J_P = \frac{1}{8} \cdot m_P \cdot D^2 \qquad (5.11)$$

Where:

J_P= Inertia of the pulley [kg.m²]

m_P= Mass of the pulley [kg]

Solving for J_P

$$J_p = \frac{1}{8} \cdot 0 \cdot 0{,}03^2 = 0 \; kgm^2 \qquad (5.11)$$

The next step is to calculate for inertia of the belt the mass of the belt was determined by using the mass function in solid works cad software. All realistic parameters such as material type were added to the belt to get a pragmatic mass to aid in further calculations.

$$J_B = \frac{1}{4} \cdot m_B \cdot D^2 \qquad (5.12)$$

Where:

J_B= Inertia of the belt [kg.m²]

m_B= Mass of the belt [kg]

Solving for J_B

$$J_B = \frac{1}{4} \cdot 0{,}5266 \cdot 0{,}03^2 = 1{,}185 \cdot 10^{-4} \; kgm^2 \qquad (5.12)$$

Next the inertia of the motor is determined $[J_M]$

$$J_M = 3 \cdot 10^{-8} \; kgm^2 \qquad (5.13)$$

Summing up all inertia to get total inertia of the system

$$J_T = J_L + J_P + J_B + J_M \qquad (5.14)$$

Solving for J_T

$$J_T = 9 \cdot 10^{-4} + 0 + 1{,}185 \cdot 10^{-4} + 3 \cdot 10^{-8} = 1{,}019 \cdot 10^{-3} \; kgm^2 \qquad (5.14)$$

Calculating the accelerated torque needs data such as initial speed final speed and time change between the speeds assuming the connection is made from the power source to the motor without any controller time change from initial speed 0m/s to final speed of 0,9 rad/s although the maxoimum speed is 150.796 rad/s or 24 RPS 0,9 rad/s because of the distance time graph used in analysing its motion. This will be displayed in chapter 6. Therefore,

$$T_a = J_T \cdot a = (J_L + J_P + J_B + J_M) \cdot \frac{\omega_1 - \omega_0}{t} \qquad (5.15)$$

Where:

T_a= Acceleration torque

ω_1=Final velocity of the motor

ω_0= Initial velocity

t= Time for velocity change

Solving for T_a

$$T_a = 1{,}019 \cdot 10^{-3} \cdot \frac{0{,}9 - 0}{1} = 9{,}171 \times 10^{-4} \; Nm \qquad (5.15)$$

Further calculations are made to find the load torque

$$T_L = \frac{m_L \cdot g \cdot D}{2 \cdot \eta} \qquad (5.16)$$

Where:

T_L= Load torque

M_L=Mass of the load

g= acceleration due to gravity

D= Diameter of the wheel

η= Efficiency (Reference Value is 0.85 to 0.95.)

It is assumed the motor is new there for calculation purposes the ideal efficiency was used which was 0.95.

Solution for T_L

$$T_L = \frac{4 \cdot 9{,}8 \cdot 0.03}{2 \cdot 0.66} = 0{,}891 \; Nm \qquad (5.16)$$

The next step is to calculate the total torque

$$T_T = T_L + T_a \qquad (5.17)$$

Where:

T_T =Total Torque

Solution for T_T

$$T_T = 0,891 + 9,171 \times 10^{-4} = 8,17 \times 10^{-4} \tag{5.17}$$

Finally, the required torque for the motor is calculated

$$T_M = K_s \cdot T_T \tag{5.18}$$

Where:

T_M= Required torque for motor

K_s= Safety factor (Reference Value is 1,5 to 2,0.)

Again calculation was conducted according to the best conditions there for the ideal safety factor was taken into consideration.

Solution for T_M

$$T_M = 2,0 \cdot 8,17 \times 10^{-4} = 1,634 \times 10^{-3} \, Nm \tag{5.18}$$

The required torque for the motor for the long horizontal conveyor should be $1,634 \times 10^{-3}$Nm or 0,0166 kgcm. There are 2 motors in each vertical lift therefore the torques are added $0,0166 \cdot 2$ which is equivalent to 0,0332 kg.cm. which mean that the motor selected should be able to move at load from 0- 4 N. According to the results, the maxonn motor has enough torque to move this load and handle other forces. In conclusion the valid motor that should be used in the in the system are the Nema 23 - 02PD - AMT112S and the premotec motors. The premotec motors were installed on the short horizontal feeders and after calculations it was concluded that they were valid in handling the load. Therefore, it is paramount that different powerful motors or gear spurs with higher torque and reasonable speed is used.

6. MOTION ANALYSIS

6.1. Animation Motion Analysis

In this chapter motion studies are going to be conducted to simulate the motion and of the automation system. In chapter 5 a final design of the system created based on the problems and solutions generated at every development process.

To start the simulation knowledge on what aspect to investigate and analysis must be taken into consideration. For this project analysis will be based on:

- Overall operation and maneuverability of the automation system with solid works motion analyzer
- Distance time graphs with a PID controller with Simulink in mat lab

6.1.1. Overall flow process

An overall flow process was fabricated to observe the logic operation of the automation system with its the available sensors, actuator and controller components. The process begins from feeding in the item or material for example a box or batteries and arranging or assembling in a particular order.

In order to start the process, the necessary electrical components such as the controller must be initialized including having gone through the pre-required set up process of the machine. An operator places an item (box) into the feeder.

Sensor1(S1), which is an induction proximity sensor is supposed to detect the box and if the box detection is affirmative, the Feeder Motor (FM) runs the horizontal short conveyor 1 (HSC1) till it the box is detected by another induction proximity sensor (S2) which confirms or denies the box position on the short conveyor based on feedback from the controller.

If S2 detects the box, a parallel process begins which is, the conveyor on the feeder runs for an allocated amount of time in this case 3 seconds, while the Horizontal conveyor motor on the first layer is initialized to run its conveyor. The motor runs till it reaches its first work station, which is affirmed by a 3rd sensor (S3). At sensor 3 the Hirata robot is activated to perform its operation based on the way points and speed set for it to follow. After completion, it moves to the second workstation. Another sensor is activated the Hirata robot is signaled again to perform an operation on that work

station. The number of workstations determines how many sensors will be needed to activate the Hirata robot to perform.

After the working process performed by the Hirata robot the packed items are moved by the horizontal conveyor out onto that horizontal short conveyor 2 (HSC2) that will be lifted to the second level. Sensor 5 (S5) and sensor 6 (S6) makes sure the box is positioned on the HSC2. S5 activates and the HCM is run for 3 seconds while the HSC 2 starts to run, and this happens in parallel. S6 gets activated after some time to stop the conveyor from moving thereby positioning the box. After this process, the lift motor is activated based on a timer after S6 has been activated. Sensor 7 (S7) is activated when the conveyor HSC is in line with the Horizontal Conveyor HC on level 2. The motor then moves in reverse to place the box on the horizontal conveyor 2 (HC2). When Sensor 8 (S8) is activated the motor in HSC WORKS FOR 3 seconds and the HC2 motor starts to work. At sensor 9 the HC2 conveyor stop moving and the Hirata robot on level 2 starts to perform its operation. After the operation the conveyor starts to move. the vertical lifts 1 also begins to move at the same time and is stopped when sensor 10 is activated. At sensor 11 on the HC2 the conveyor on HC2 moves for an extra 3 seconds while HSC1 moves for an amount of time say 5 seconds to put the box in place. The flow chart below summarizes the entire working cycle of the automation system. Assuming all decision-making processes made by the controller were affirmative.
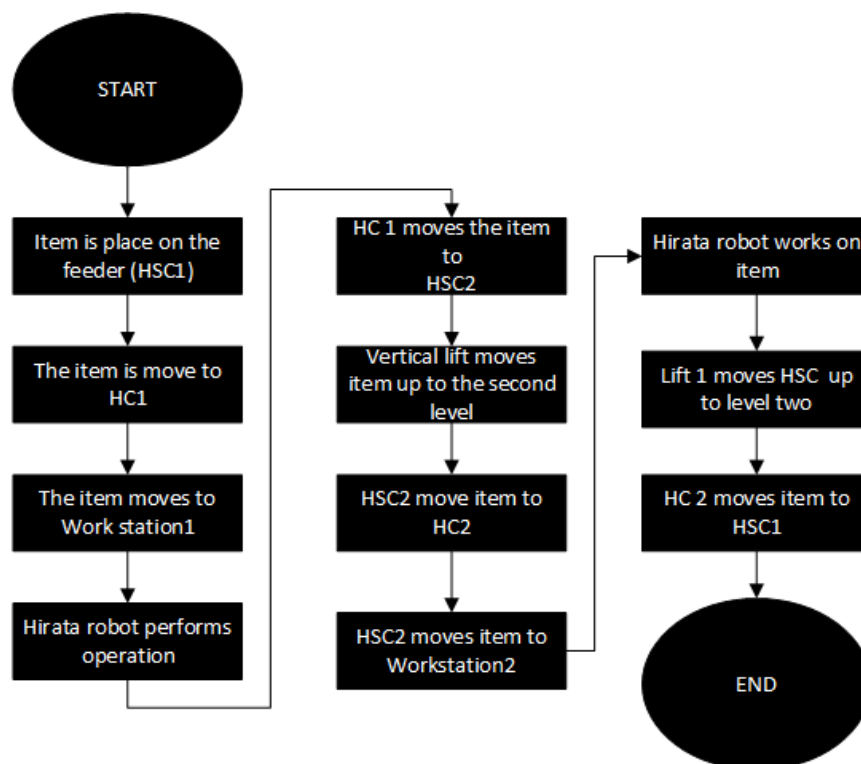

Figure 6.1 summary of flow process

6.1.2. Solid works motion analysis

Solid works motion studies are graphical simulations of motion for assembly models. You can incorporate visual properties such as lighting and camera perspective into a motion study.

Motion studies do not change an assembly model or its properties. They simulate and animate the motion you prescribe for a model. SOLIDWORKS mates can be used to restrict the motion of components in an assembly when you model motion.

In the solid works model, distance and time were used to simulate both sensor activation and mechanical actuation.
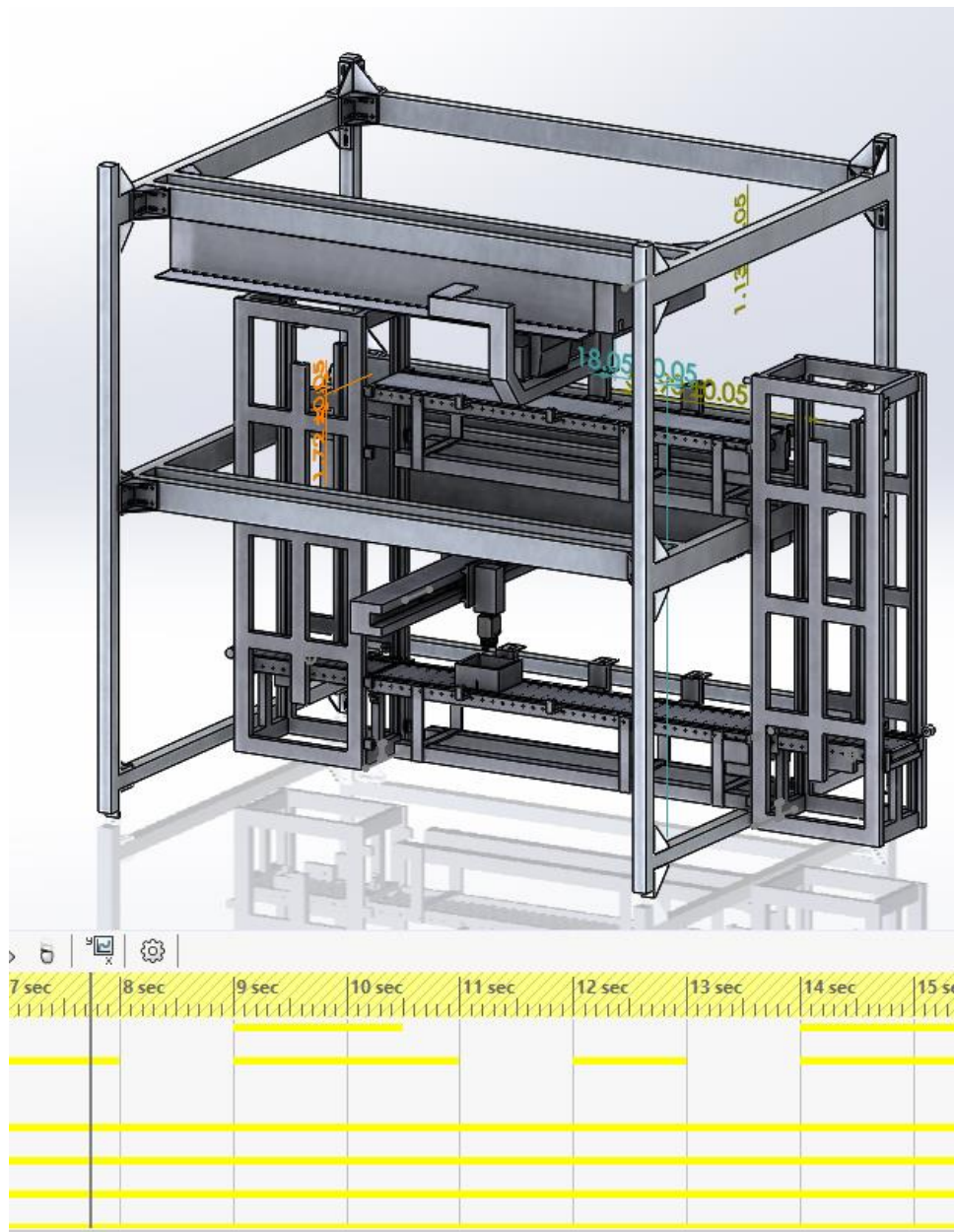

Figure 6.2 Hirata motion analysis showing the system and time viewer

In this animation simulation, distances were locked in and special mates were also established for the main aim of simulating the way the system would operate according the specified distances. In an animation simulation, the motion manager is one of the most important tools in solid work motion analysis. The Motion Manager has a key frame-based timeline and controls motors, gravity, and springs based on time. With a single setup, you can see how an assembly moves and how components interact, create presentations, and obtain component velocities and accelerations for validation purposes [18]. The motion manager is used to plan the working process and events the robot would go through for example, moving the robot in a set path to reach the final position.

The motion manager in this project marked out all the working paths with distance and the time it used to cover those distances. Torque and other physical parameters were not applied. The maneuverability of the robot was what was analyzed.
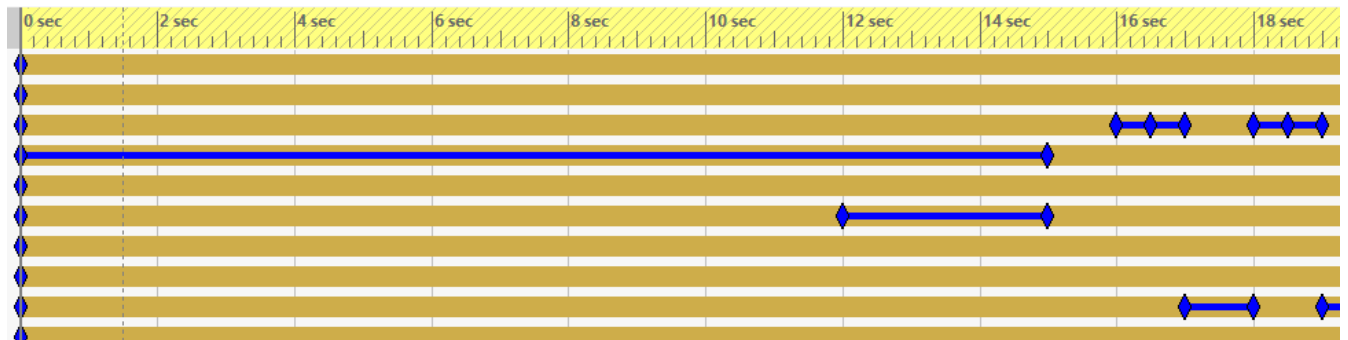

Figure 6.3 motion profile of distance with time

After setting up the motion profile in the motion manager workspace as shown in figure 6.3, a run function is selected, and the motion simulation starts. The criteria for inspecting if the robot run smoothly was to check if all the mates and mated parts were successfully rebuilt without any errors. The system seemed to have fulfilled all the required procedures without any errors.

6.1.3. Simulink simulation analysis.

Simulink is a block diagram environment for multi domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis [19].

Simulink was used to create a model that outputs distance time graph the PID controller was introduced to ensure the system follows the reference path created by the signals from each device. The use of the distance time graph was to simulate how the system would react with the given maximum mass, expected to be lifted. The area of concentration in this part of the simulation is to observe the adaptation of the PID controller to the reference point.

PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special-purpose control systems. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing. Many sophisticated control strategies, such as model predictive control, are also organized hierarchically [20].
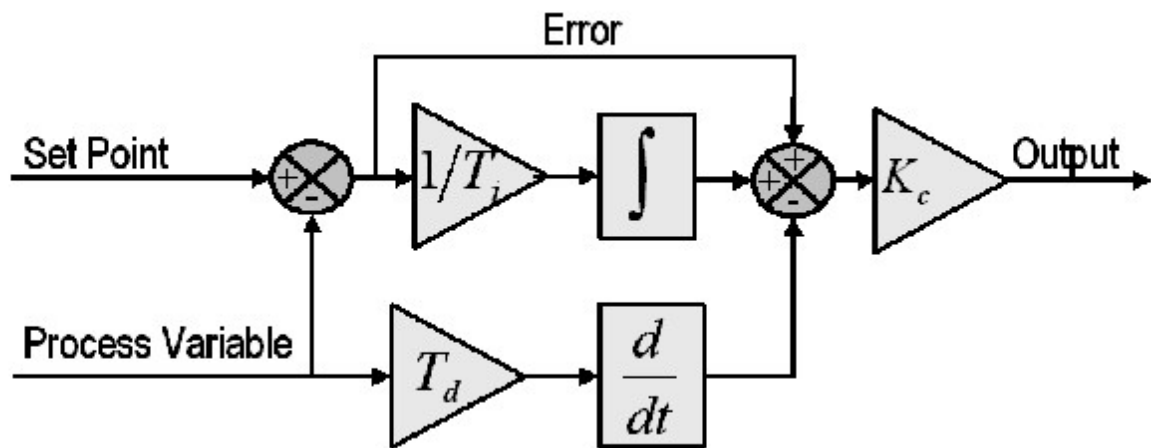

Figure 6.4Block diagram of a basic PID control algorithm [20]

In the PID theory the proportional response depends on the difference between the set point and the process variable. The difference is referred to as the error term and the proportional gain determines the output response to the error signal increasing the proportional gain will increase the response of in the system. Further increase in the proportional gain would result in an unstable system [21].

The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero [21].

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing

the *derivative time (T_d)* parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response [21].

6.1.4. Work flow in simulink

To start the simulation a signal builder block was selected, and multiple signals were built to represent the various electrical devices such as the vertical lift HSC and HC. The times at which the signals were initialised matched the times in the solid works motion window. the control system used is a closed loop system, the process variable in the control loop system was distance (m). The position port on the motion control sensor was used as feedback in the closed loop as shown in the diagram below

Figure 6.5 Controller for feeder (Horizontal Short Conveyor)

The signal builder sends data (reference path or set points) to the controller as shown in figure 6.6

Figure 6.6 Input set point by feeder

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The ideal torque sends value based on the data sent by the signal builder through the controller. The wheel and axle components convert the signals and the Simulink components to physical signals. The physical signals are sent to the motion sensor which sends the real position of the feeder to the controller as feedback. Both the input signal and the control signal are outputted onto a graph as shown in figure 6,7 similar characteristics were shown by the controller of other parts of the system.
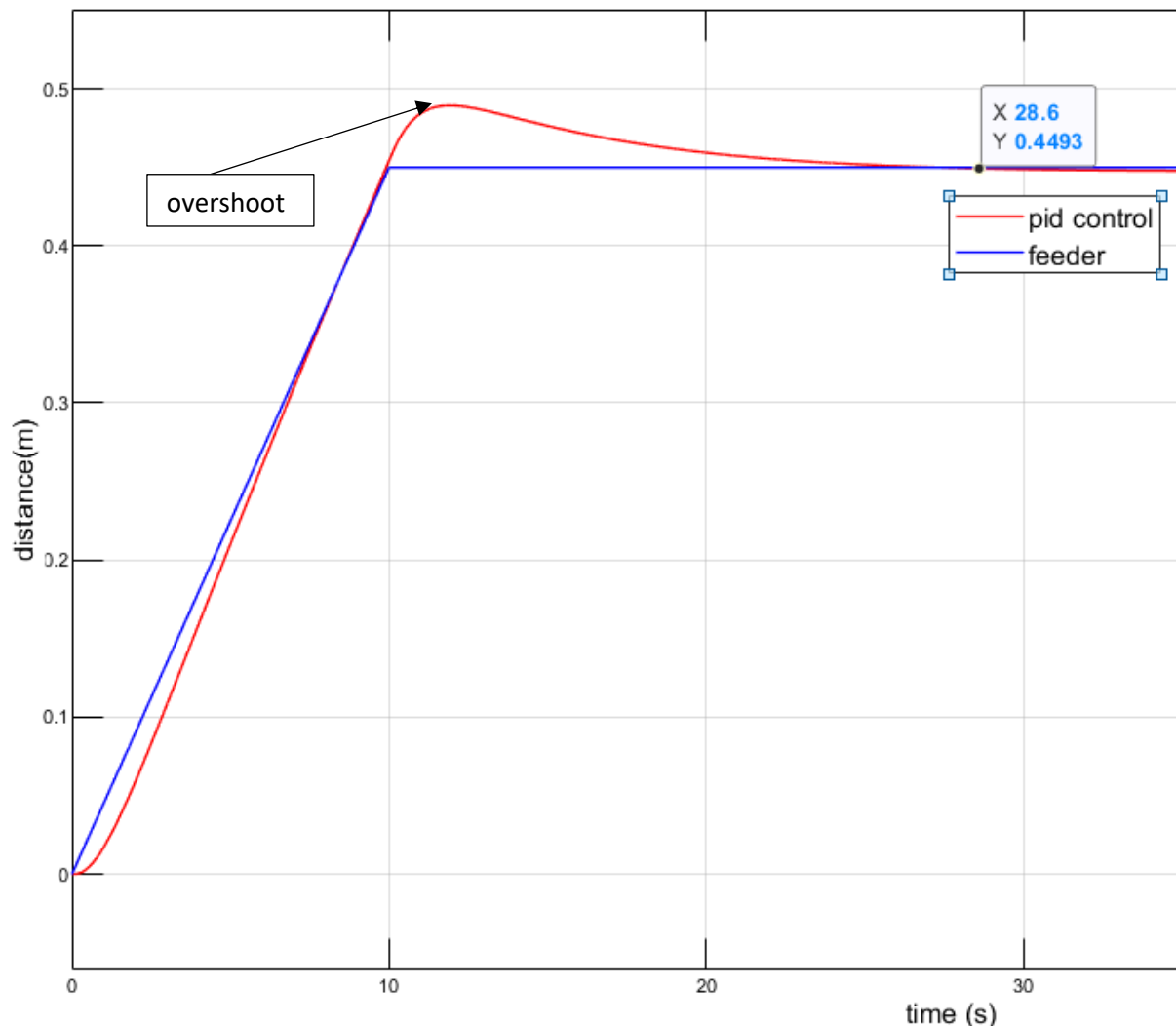

Figure 6.7 controlled output of the feeder

The graph shows the PID adaptation characteristics with the set point 0,45 m at x time= 9,9seconds and y of distance 0,4496 the controller begins to over shoot at x time=21,89seconds and y distance =0,4556 the controller begins achieves steady state. At x time=28,8 seconds the system achieves a steady state y distance= 0,4492 the steady state error =0,45-0,4492= 0,0008 before reaching 30 sec.

The brief analysis of the graph shows that the steady state error is close to 0 this proves the stability of the system. This is not the optimum tuning response and I believe the controllers response can be

improved further. Adjusting the proportional and integral gain parameters will guide the controller's response along the set reference points created by the input processes. Observing the diagrams in appendix 4 and appendix 5, the steady state error was minimized to 0 there was no overshoot therefore the PID self-generated calculated values by the controller has a robust and fast response to the system which is observed in majority of the graphs

6.2. Cost Estimation

An approximation of the probable cost of a product, program, or project computed on the basis of available information [22]. It involves forecasting the cost of completing a project with a defined scope. It involves the primary element of project cost management, a knowledge area that involves planning, monitoring, and controlling a project's monetary costs.

In this chapter cost estimations were made on the needed products that are unavailable. Two solutions were provided in chapter 3, as a result, two cost estimations were drawn but one was chosen upon discussions.

The costs are categorized as to how many components are needed in each section of the automation system. A ball park figure or rough estimation of the total cost was derived due to other miscellaneous items needed to support the main systems. Table 6.1 shows the cost estimations of the initial design.

Table 6.1 Initial design cost estimation

Using AC motor	Amount needed	Cost (€) + tax and shipping
Gear Head	2	0,00
Motor	2	0,00
Servo controller	1	945,5
Cytron DC motor driver	4	64,16
total		1009,66

Ball park estimation of the total cost will be around 1200 plus miscellaneous cost including screws and other little mechanical and electrical components. Below is the cost estimation of the Final design

Table 6.2 Final design cost estimation

Using DC stepper Motor	Amount Needed	Cost (€) + tax and shipping
Nema23	4	56,96
Belt and fixtures	4	55,76
Citron DC motor driver	4	64,16
Polulu A4988 Driver	4	23,80
Total		200,68

Ball park estimation of the total cost will be around 300 plus miscellaneous cost including screws and other little mechanical and electrical components.

Comparing the two estimations and looking at their pros and cons:
Cost Evaluation on the initial design involves no advantages just cons its very bulky, needs an extra controller and the controller (inverter) is very expensive.

The final design involves a customizable aluminium profile, small and compact no expensive controller is needed and a dc stepper motor is required therefore there are less electrical configurations as compared to the ac inverter needed for the initial design. The only disadvantage is that a powerful motor is needed to lift the load from one level to another.

6.3. Future developments

The Hirata Robots located in the lab have performed so many tasks in the past and has aided students in understanding certain principles in robotics. The future developments for this project include a lot of practical hands on reconstruction. Involving the mechanical software and electronics aspects.

The mechanical parts of the system need to be fitted with the required parts as per the chosen design. This includes the aluminium extrusion expanding the conveyor belts to hold the items, purchasing and attaching the actuated guard rail to the lift enclosure as shown in the design, finding a suitable base support that is light and strong as well.

In the software section, the practical aspects needed to be concentrated upon are the type of software used to program the plc which will depend on the type of PLC software. Control design would also be implemented in the practical aspect.

The electronic branch involves measuring signals from sensors and actuators for conversion and interpolation. This is very essential because the automation system needs to operate on a harmonious and synchronic level which in effect will prevent lags as well as over voltages for delicate components.

SUMMARY

The main objective in this project is to prove the system can be built and run with the provided left over materials and peripheral devices from other non-functioning machines. The goal was achieved in 3 ways:

- Conducting a feasibility study on the materials and devices with the system
- Realistic cad design of the existing system with all the other existing machine parts
- A CAD simulation and Simscape simulation to evaluate the smooth functionality of the system
- Development of a simulation software that can be used for further design optimizations.
- Development of an algorithm for further detailed PLC programming.

Conducting a feasibility study on the materials and devices with the system, this involved research on available components comparing existing component data sheets and searching for unavailable but needed components both mechanical and electrical. The successful sub goal was achieved by confirming the part with my supervisor.

Realistic CAD design of the existing system with all the other existing machine parts, detailed design of the parts and the entire automation system was designed using and MCAD software solid works. First initial designs were generated, and based on these designs, a final complete cad design was created to suit the requirements of the project at a lower cost.

A CAD simulation and Simscape simulation to evaluate the smooth functionality of the system, two simulation software were used in the motion analysis of the system. Firstly, the motion analysis tool box in solid works was used to visualise the manoeuvrability and operation of the automation system. Secondly the use of Simulink and Simscape was used to examine the controller's reaction during dynamic signal points in the signal builder. The designed controller ensured the system followed the setpoints provided by the input signal builder. The steady state error was close to zero for all the subsystems in the automation system therefore it can be said the system was stable.

Development of the algorithm as shown in appendix 2 for the entire system, took 2 days to create. After running through the algorithm and making sure all loops and processed were connected, simulation software was developed which could be enhanced for programming the actual plc to start performing tasks.

KOKKUVÕTE

Projekti põhieesmärk on tõestada, et süsteemi saab ehitada ja käivitada koos teiste mittetöötavate masinate materjalide ja välisseadmetega. Eesmärk saavutati kolmel viisil:

• Süsteemiga seotud materjalide ja seadmete teostatavusuuring
• Olemasoleva süsteemi realistlik kujundus kõigi teiste olemasolevate masinaosadega
• CAD simulatsioon ja Simscape'i simulatsioon süsteemi tõrgeteta funktsionaalsuse hindamiseks
• simulatsioonitarkvara väljatöötamine, mida saab kasutada edasiste disaini optimeerimiseks.
• Algoritmi väljatöötamine edasiseks üksikasjalikuks PLC programmeerimiseks.

Süsteemiga teostatavate materjalide ja seadmete teostatavusuuringu läbiviimine hõlmas olemasolevate komponentide uuringuid, mis võrdlevad olemasolevaid komponendi andmelehti ja otsivad kättesaadavaid, kuid vajalikke mehaanilisi ja elektrilisi komponente. Edukas alameesmärk saavutati, kinnitades osa minu juhendajaga.

Olemasoleva süsteemi realistlik CAD-disain koos kõigi teiste olemasolevate masinaosadega, osade detailne konstruktsioon ja kogu automatiseerimissüsteem kavandati kasutades MCAD-i tarkvara tahkeid töid. Esialgselt loodi esimesed esialgsed disainilahendused ning nende kujunduste põhjal loodi lõplik täielik kujundus, mis vastab projekti nõuetele madalama hinnaga.

Süsteemi liikumise analüüsis kasutati süsteemi simulatsiooni ja Simscape'i simulatsiooni süsteemi sujuva funktsionaalsuse hindamiseks. Esiteks kasutati automaatikasüsteemi manööverdusvõime ja toimimise visualiseerimiseks tahkete tööde liikumisanalüüsi tööriistakasti. Teiseks kasutati Simulinki ja Simscape'i kasutamist kontrolleri reaktsiooni uurimiseks dünaamiliste signaalpunktide ajal signaali ehitaja juures. Kavandatav kontroller tagas, et süsteem järgib sisendsignaali ehitaja poolt antud seadeväärtusi. Püsiseisundi viga oli automatiseerimissüsteemi kõigi allsüsteemide puhul peaaegu null, seega võib öelda, et süsteem oli stabiilne.

Kogu süsteemi jaoks lisas 2 esitatud algoritmi väljatöötamine võttis aega 2 päeva. Pärast algoritmi läbimist ja kõigi silmuste ja töödeldud ühenduste loomist töötati välja simulatsioonitarkvara, mida saaks täiendada tegeliku plc programmeerimiseks, et alustada ülesannete täitmist.

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APPEDDICES

Appendix 1

**2D drawing final design of the Hirata Robot**
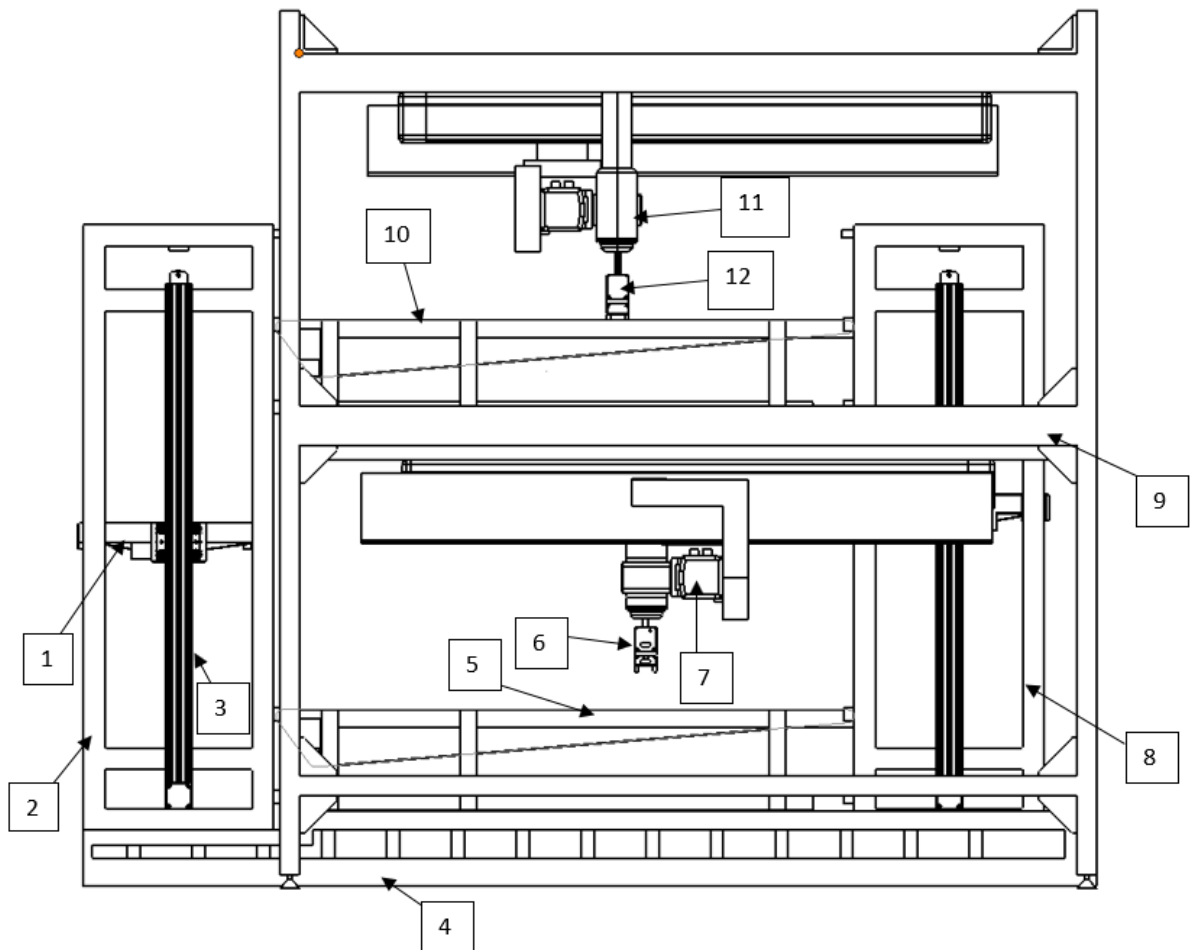
Legend

|	
1- Horizontal Short Conveyor (HSC)	7-Hirata Robot (1)
2- Vertical elevator enclosure (1)	8-Vertical elevator enclosure (2)
3- Vertical actuated guard rail	9-Hirata robot enclosure
4- Support base structure	10- Long Horizontal conveyor (2)
5- Long Horizontal conveyor (1)	11- Hirata Robot (2)
6- End Effector Gripper (1)	12- End Effector Gripper (2)

Appendix 2

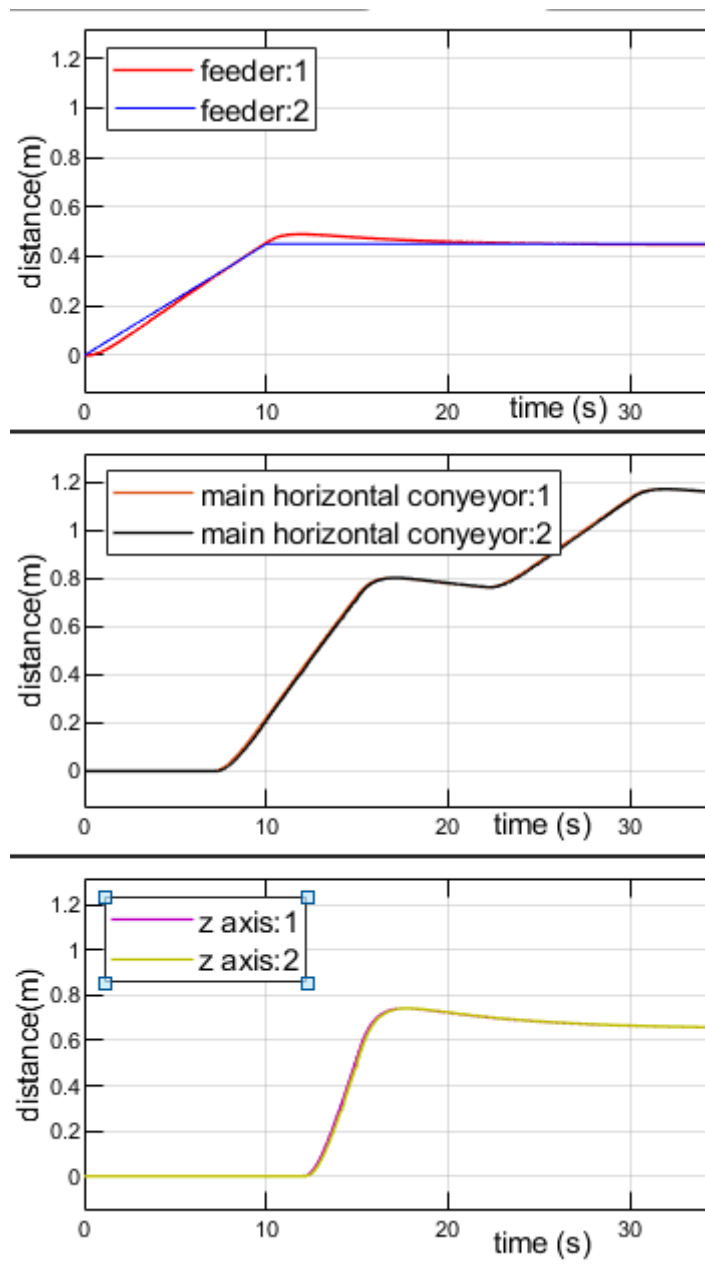# A detailed flow of chart of the Hirata automation system
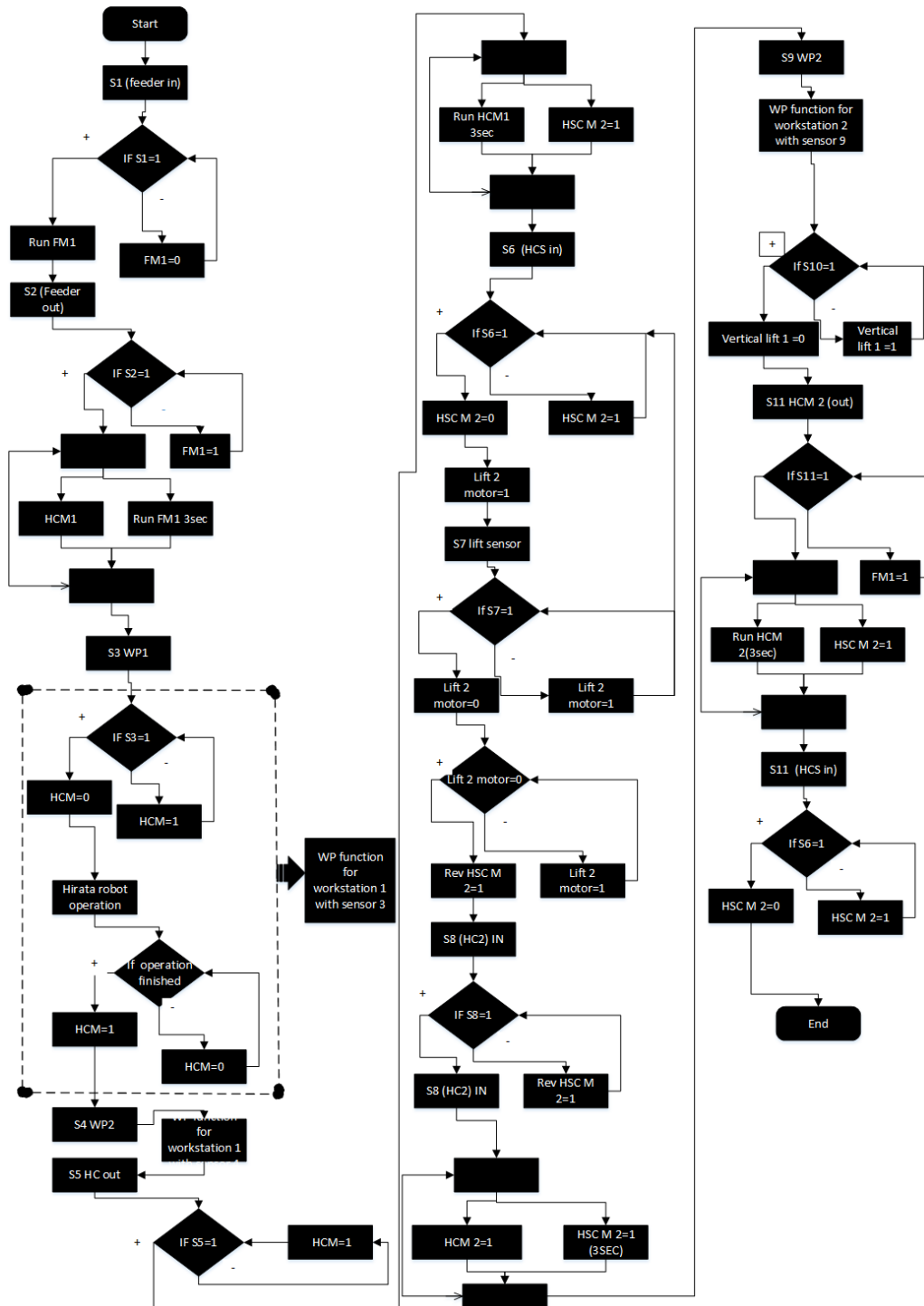
Appendix 3

Inputs signals for all actuated sections of the automation system
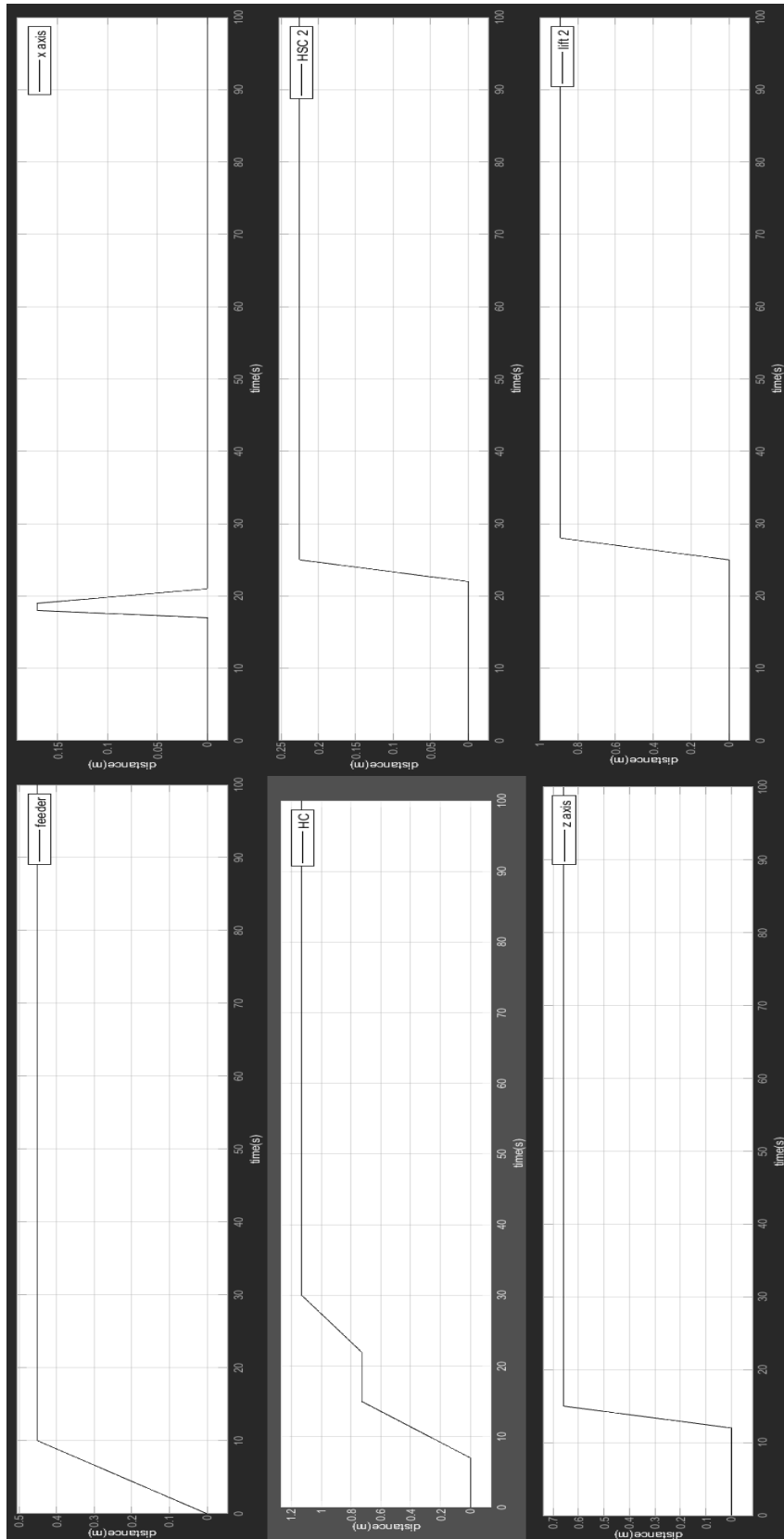
Appendix 4

Controlled output with input. 1- input, 2- output in the automation system

Appendix 5

Controlled output with input .1- input, 2- output in the automation system