RAMAIAH INSTITUTE OF TECHNOLOGY

(Autonomous Institute, Affiliated to Visvesvaraya Technological University, Belagavi)

Bangalore-560 054

Mini Project Report on

ASSEMBLY AND PALLETIZING OF MODULAR SPACE FRAME USING FANUC-M10iD/12 6-AXIS ROBOT

Submitted in Partial Fulfillment of the Requirement
For the Award of

BACHELOR OF ENGINEERING
In
MECHANICAL ENGINEERING

Submitted by

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2019-20

CERTIFICATE

Certified that the mini project work entitled "**ASSEMBLY AND PALLETIZING OF MODULAR SPACE FRAME USING FANUC-M10iD/12 6-AXIS ROBOT"** is a bonafide work carried out by the following students, Achintya S (1MS17ME008), Aditya KN (1MS17ME011), Rajatsurya M (1MS17ME133) and Sanket Bora (1MS17ME150) in partial fulfillment of the award of the Degree of Bachelor of Engineering in Mechanical Engineering during the year 2020. It is certified that all corrections/suggestions indicated for continuous internal assessment have been submitted to the department. To the best of our knowledge, this report does not contain any work which has been previously carried out by others and the report has been approved as it satisfies the academic requirements in respect of Mini Project work prescribed for the Bachelor of Engineering Degree.

Dr. HEMAVATHY HS	Dr. RAJI GEORGE	Dr. N.V.R NAIDU
Guide	**Head of the Department**	**RIT Principal**

Signature of External Examiners:

Name Signature

1. ____________________________ ____________________________

2. ____________________________ ____________________________

DECLARATION

We hereby declare that the entire work embodied in this mini project has been independently carried out by us under the supervision of our internal guide **Dr Hemavathy S,** Assistant Professor, Department of Mechanical Engineering, **Ramaiah Institute of Technology, Bangalore** in partial fulfillment of the requirement of the **Bachelor of Engineering** in **Mechanical Engineering.** We further declare that the mini project has not been submitted either in parts or in full to any other university for the award of any sort of Degree.

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ABSTRACT

Inspired by the rapid progress of industrial processes and operations owing to robots, this project seeks to explore the area of automation, specifically with a view on industrial application. Having chosen to automate the hitherto largely manually done processes of assembly and palletization of frames and structures, this project seeks to simplify and diversify the same, cutting costs and downtime as well as increasing output and productivity. For this purpose, the FANUC M-10iD/12 robot will be taught to assemble and palletize a couple of custom-fabricated “space frames”. With the current trends in Indian industry gradually curving towards automated assembly lines and warehouses, the team members, through this project, seek to establish an understanding of automotive processes.

Keywords:

Automation, Robot, FANUC, M-10iD/12, Assembly, Palletization, Space Frame, Industrial Application.

Table of Contents

List of Tables & Figures

1 Introduction

1.1 Context of the Project

The world of technology is swiftly evolving. The pace of change is itself increasing. In other words, it takes a shorter period of time for any technology to become obsolete or antiquated than five years ago. It is essential, therefore, that an ambitious economy familiarizes itself with the tools and techniques required to keep all its stakeholders afloat and abreast of its competition. One such field in technology witnessing mammoth leaps is manufacturing. Human labour is being gradually replaced with robots. This has been, from a strictly efficiency standpoint, very successful. Cuts in spending concerned with health & safety, paid leaves, strikes, etc combined with increased output and better reliability have largely made up for the initial costs of investment in large industries. The design, mastery and upkeep requirements of the robots have created new employment opportunities, as well as areas of interest with respect to research and development.

The need to prepare for a transition to an automation-centred manufacturing industry, or at least an automation-aided one is apparent. It was this conviction that inspired this project. The aim of the project was, and remained till fruition, to completely automate a hitherto mostly manual process using existing popular robots and accessories (simulation softwares, teaching aids, etc), with specific focus on the contemporary Indian scenario.

To this end, the robot chosen was the FANUC M-10iD/12. And the processes to be automated were the assembly and palletization of a "space frame". The details of each of the above are as follows.

1.2 The FANUC M-10iD/12:

The FANUC M-10iD/12 robot is used for the purposes of this project. It is a versatile 6-axis robot with high axis speeds and precision. It has a payload capacity of 12kg while the robot, itself, weighs just 145kg. It also boasts a reach of 1441mm. It has a repeatability of 0.02mm and an articulated structure. It has floor, upside-down and angle mount capabilities.

Figure 1.1 : FANUC M-10iD/12 Robot

The M-10iD/12 has the highest axis speeds and acceleration in its class making it highly efficient in pick and place applications of lighter payloads. This increased speed optimizes throughput and reduces the cycle time for various applications. The M-10 series' heavy-duty wrists and high wrist movements make it ideal for loading and unloading operations. Its hollow or in-line wrist design increases its strength and stability. Since it has a cable integrated arm with a slim wrist interference radius, it can be integrated into small work cells and can easily operate even in confined workspaces. Internal cable routing is provided through J3 and J6 arms which decreases risk of cable interference and increases cable life. An additional mounting facility is also provided on the J3 arm which enables close mounting of end effector control equipment. Integrated air and electrical services consisting of 8 inputs and 8 outputs are provided as standard. These features enable the robot to give a full working envelope, reach, and stroke even in narrow workspaces or when mounted upside down. The IP67 waterproof wrist and J4 arm also make it suitable for water jet and die casting applications. Its sealed bearings and brushless, maintenance free AC motors improve reliability and lifetime.

Controlled axes	Repeatability (mm)	Mechanical weight (kg)	Motion range (°)						Maximum speed (°/s)						J4 Moment/ Inertia (Nm/kgm²)	J5 Moment/ Inertia (Nm/kgm²)	J6 Moment/ Inertia (Nm/kgm²)
			J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6			
6	± 0.02*	145	340 (370)	235	455	380	360	900	260	240	260	430	450	720	26.0/0.90	26.0/0.90	11.0/0.30

Table 1.1 : M-10iD/12 Robot Properties

The M-10iD/12 robot in the lab comes fitted with the following grippers as standard.

- Electromagnetic Gripper
- Vacuum Gripper

- 2-Jaw Gripper
- 3-Jaw Gripper

However, owing to the material considerations of the frames and tables, explained in Sections 6.1 & 6.2, we will be utilizing only the electromagnetic gripper and vacuum gripper for the purposes of this project.

The robot uses an R-30iB Plus controller. With its advanced integrated hardware and more than 250 software functions, it facilitates easier use and automation of robots. It has been designed for increased processing capability and minimal energy consumption. Its high-performance PMC has access to the entire robot I/O system which enables easy and

Figure 1.2 : FANUC R-30iB Plus Controller

asynchronical control of peripheral devices with no detrimental effects on robot performance. R-30iB controllers come ready with intelligent functions such as vision, force, and interference check as standard. The Teach Pendant or iPendant is intuitive and simple to use which makes the use of the controller easy. The new user interface (iHMI) is user-friendly which decreases set-up time and makes offline programming much easier. The increased memory (DRAM increased from 256MB to 1GB) results in increased productivity.

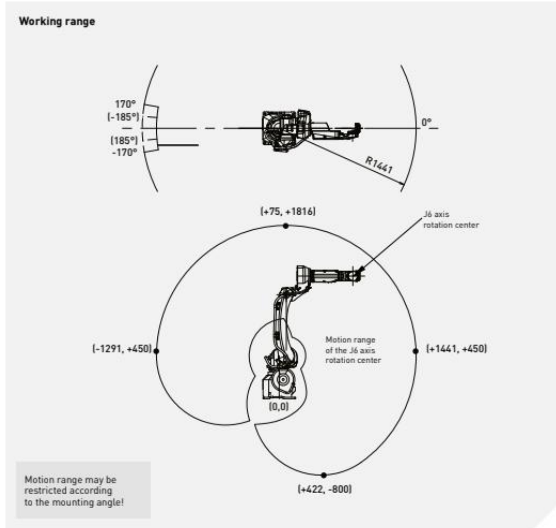

Figure 1.3: Range of the Robot

1.3 Space Frame:

A space frame is a modular and robust structure which can be used as a unit of assemblage for fences, panels, cages, tiles, etc. It can also be used as support structures during construction work. They have potentially higher resistance towards varying temperature & wear and can have the capacity to withstand high loads, given the right design, fabrication and securing mechanism. It can also have a high degree of reusability, as well as easy maintenance and repair.

A space frame in its design and material properties can vary according to the purpose it is required to serve. For example, an application necessitating easy assembly and disassembly requires that the mechanism by which the frame is held together comes easily undone. Magnetic locks can be used in this context. However, an application that necessitates a resistance to changing temperature can't use magnets and therefore can have mechanically actuated or permanent joints. In this way a space frame can be designed and fabricated to suit a wide variety of applications, and therefore proves to be very versatile.

Another important aspect of the space frame is the high degree of freedom with which individualistic choices can be implemented with respect to the frame's design and aesthetics. This makes the space frame a more marketable and customizable alternative to traditional construction.

Figure 1.4: Isometric View of Space Frame Design

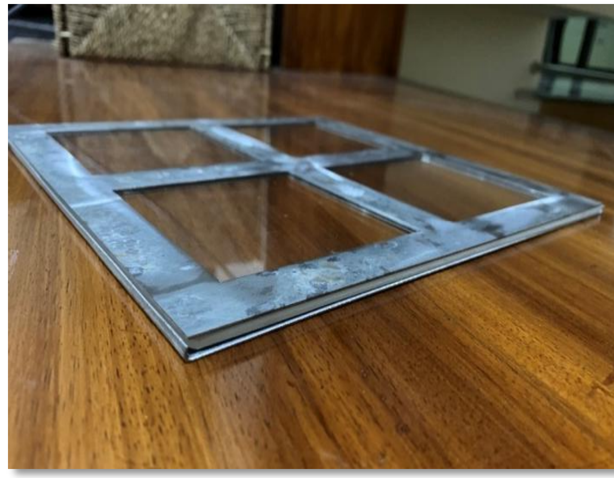

Figure 1.5: Fabricated Space Frame

The prerequisite information regarding the current methods and level of automation relevant to the current project was obtained through a literature review which is as detailed in the next section.

2 Literature review

The information that decided the path this project took can be divided as pertaining to the need for the project, the current level of automation in the relevant field, the options available for automation processes. They are elaborated upon in the following subsections. Links to all source material are provided in the "References" section.

2.1 Need for the Project

Primarily, automation serves the following purposes: increasing productivity, increasing output, reducing workers' work time, improving workers' health and safety, and reducing delivery time.[1] As the International Society of Automation puts it "Think about any modern convenience or necessity. Just about anything you can think of is the result of complex processes....[and] without automation..., our world and our future would be very different". It also helps indirectly; driving down costs and helping developing economies compete better with legacy capitalisms.

2.2 Contemporary Automation

The literature regarding palletization-related automation is advanced, owing to the same being a necessary feature of manufacturing and storage processes even during the prominence of assembly lines, much before complex robots became the primary source of automation, and owing to the fact that the process itself is more often than not, straightforward.[2]

The literature regarding the grippers and their functionality is fairly recent, but reliable nonetheless. To make matters easier, the manufacturers of the robot FANUC themselves also make and supply grippers whose detailed specification they make available easily.[3]

On the whole, assembly and stacking of frames of any kind either used wooden parts and/or used human labour along with a "co-bot" (robots working in tandem with humans).[4] Completely automated processes involving modular frame design, therefore, seemed a novel project choice.

2.3 Automation Options

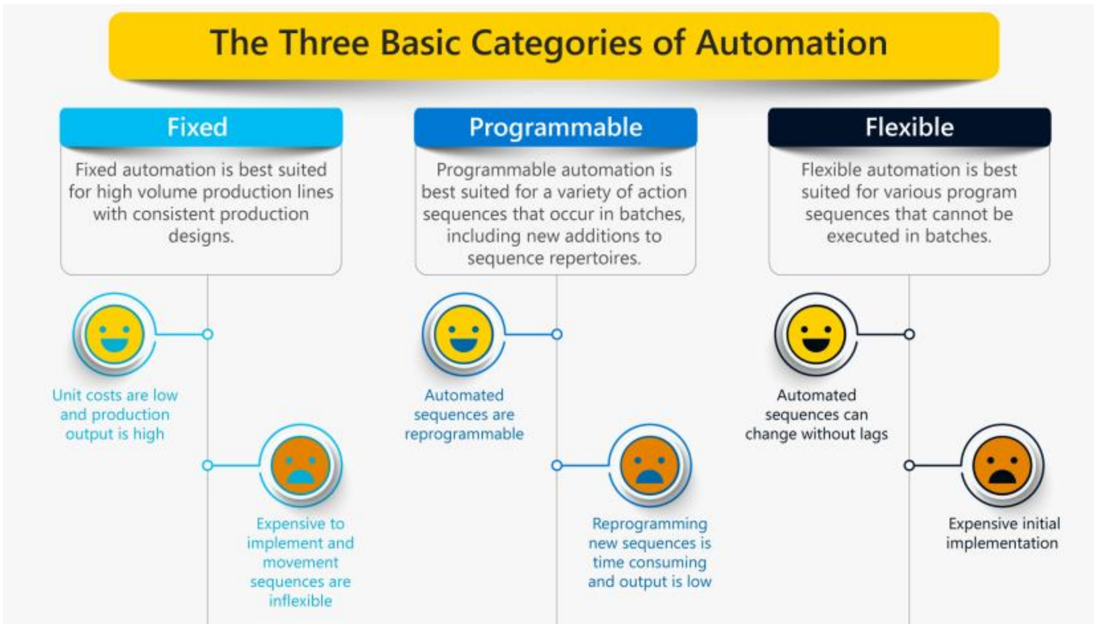

Figure 2.1: Categories of Automation

The options available for the processes of automation were a robot arm, 3D printing, CNC, and aerial robot.

3D printing, though precise and repeatable, on a large scale is not yet cost effective to the point of replacing human labour.[5] CNC machining, while capable of fabrication, requires additional work for the assembly and stacking processes. Aerial robots, while highly efficient, lack the levels of expertise in its usage and maintenance on a large scale in the Indian context when compared to the other alternatives, not to mention a want of their production adapted for manufacturing needs, as opposed to the usual defense, R&D and transportation purposes.[6]

On all these grounds, as well as popular appeal, cost effectiveness and a wealth of knowledge regarding simulation softwares, the robot arm, specifically the FANUC

M10i/D12, was chosen as the most suitable option through to carry out the automation.

It was concluded that the above literature justified the nature of our project. The problem formulation is described next.

3 Problem Formulation

The formulation of a problem when done correctly encapsulates all the aspects that need looking at, and considers and factors in all the criteria that need fulfilling in order that the project be considered a success.

The criteria considered were: the modularity of space frame, ease of access and use of simulation software, ease of transposition of simulation to real world application and repeatability & adaptability of process for multiple and varied processes.

Therefore the problem can be formulated as follows:

The project seeks to address the need for automation in manufacturing through the process automation of assembly and palletization of a versatile and modular "space frame" using a popular robot whose simulation is easily comprehensible and doable, with the same being readily transferred to the real robot assembly environment able to accommodate changes in frequency and variability of the process.

4 Objectives

The objectives of the project can be categorised as being pertinent to the following:

- Design and fabrication of space frame
- Design and fabrication of suitable fixtures for work environment
- Simulation of process using an easy-to-use and accessible simulation software
- Transposition to real-world process environment

Each of the objectives was considered and executed separately. However, each objective, in its execution, was considerate of the other objectives and the project as a whole. For maximum accuracy of the process, the methodology used was linear and sequential. The methodology itself is described next.

5 Methodology

5.1 Design of space frame:

The design of the space frame had to be done considering the constraints we were dealt with. The available work volumes in the laboratory, the grippers available for use, the payload of the robot, material costs, ease of fabrication, and suitability for industrial application were the chief criteria that determined the design of the space frame. The same is detailed in Section 6.1.

5.2 Design of Fixtures:

The default fixtures and layout of the laboratory work environment necessitated the inclusion of separate fixtures on which to carry out the assembly and palletization processes. The weights of the individual parts and assembled frames, dimensions of the parts and the frames, magnetic properties, dimensions of work environment, distance from robot and material costs were the design considerations.

5.3 Fabrication:

The designs were submitted to an independent third-party contractor. The fabrication was done as a joint effort by the aforementioned professionals and the members of the project team under their supervision.

5.4 Simulation:

The simulation had to be done using user-friendly and accessible software. The software chosen for this was FANUC’s own ROBOGUIDE 9.10. Not only was it realistic and customizable to a high degree, the program written on the computer was directly transferable to the real robot, which needed only fine-tuning afterward.

The implementation of each of the above is described in the next section.

6 Implementation

6.1 Design of Space Frame:

The space frame had to be designed in such a way that, the frame had to be modular, compact and impact resistant. A magnetic locking mechanism was devised to lock the different parts of the frame having considered ease of assembly and the gripper options. Neodymium magnets were used to achieve the magnetic locking mechanism. In order to reinforce the locking mechanism, the material used to fabricate the frame had to be magnetic in nature. To make the frame cost effective the material used to construct the frame was mild steel (the list of other materials which can be used is shown in the figure). Also while determining the dimensions of our frame the work volume of the robot M10iD/12 had to be taken into consideration, as well as the maximum load it could lift- 12kg, and the maximum dimension the robot grippers could handle- 30*30 sq cm. Considering all these constraints, the parts of the space frame were designed as follows.
(The space frame parts were designed and assembled using Catia V5 version 19)

The different parts of the space frame are:

(i) Bottom face: The bottom face has a dimension of 25*25 sq cm and it has a 3mm projection to accommodate the neodymium magnets, acrylic sheet and the top face. Four 9.5cm length squares are blanked on the bottom frame. The bottom face has a weight of 1 kg.

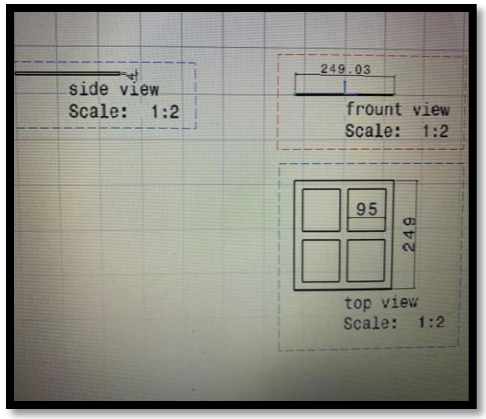

Figure 6.1: 2D View of Bottom Plate

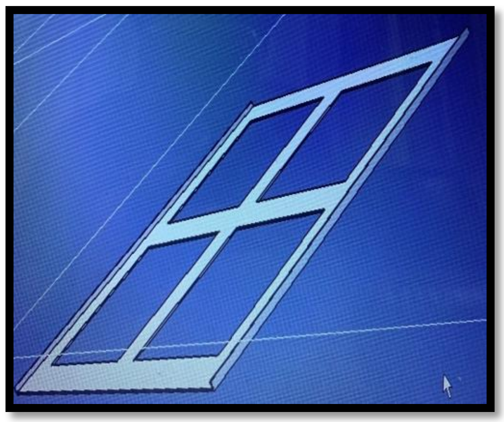

Figure 6.2: Isometric View of Bottom Plate

(ii) Acrylic sheet: The second part of the space frame is the acrylic sheet which is sandwiched between the two faces of the space frame. The acrylic sheet was designed to have a dimension of 25*25 sq cm and a thickness of 2mm with a weight of 200 g.

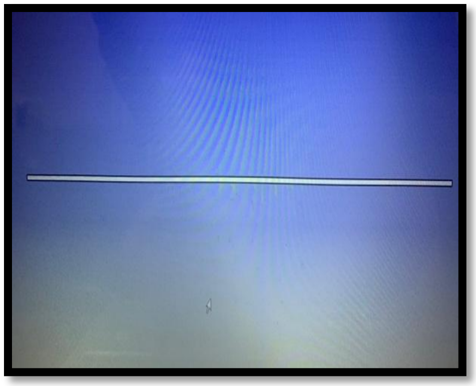

Figure 6.3: Side View of Acrylic Sheet

Figure 6.4: Top View of Acrylic Sheet

(iii) Top face: The top face has the same dimensions as that of the bottom face and it weighs the same. The 3 mm projections do not exist for the top face.

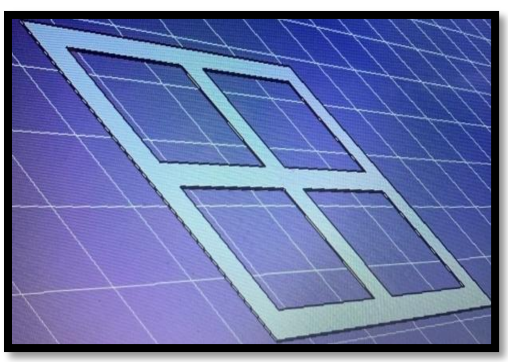

Figure 6.5: Isometric View of Top Plate

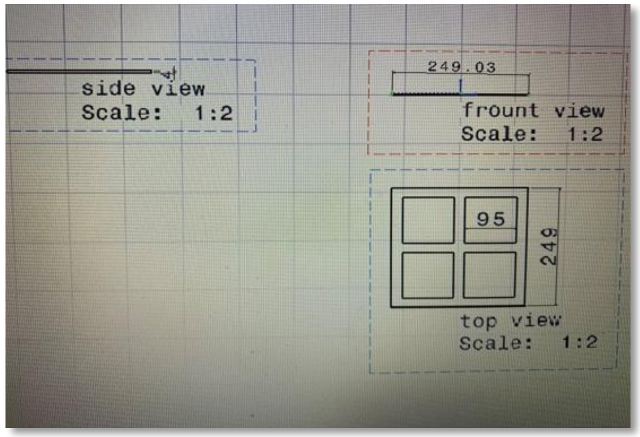

Figure 6.6: 2D Views of Top Plate

6.2 Design of Fixtures

Three tables had to be designed to achieve the assembly of the Space Frame and they were as follows:

1. Material table: The parts of the space frame are spread across the material table.
2. Assembly Table: The assembly of the space frame is carried out on this table.
3. Palletizing Table: After the frames are assembled on the assembly table, the robot picks up the completely assembled frames and palletizes them on this table.

6.2.1 Material Table Design

The material table is the biggest table. This is because each part of the space frame had to be laid out individually so that the grippers could grab the part with ease, and there were two frames which had to be assembled and palletized which further increased the size of the table. From the layout, dimensions of the Material table were formulated as:

Length = 83 cm

Breath = 56 cm

Height = 123.3 cm

The dimensions were arrived at as follows:

Length: The bottom face, top face and the acrylic sheet of the frame had to be placed one after the other in an ordered manner with a 2 cm gap after each part to accommodate a set of vertical holders, thus the length of the table came out to be 83 cm.

Breath: Two frames had to be assembled and palletized, therefore two rows of the same parts had to be placed with a 2 cm gap between them to accommodate another set of horizontal fixtures thus the breath came out to be 56 cm.

Height: As mentioned earlier in the constraints faced while designing the layout, two standard tables were bolted in front of the robot therefore our material table had to stand a foot taller than these tables in order to slide over them. Thus the height of our table came out to be 123.3 cm.

Holders were added to the table- the ‘+’ shaped projections seen in Figure 14. The magnetic gripper is used to pick the top and bottom halves of the frame up during assembly, as well as the whole frame during stacking. Because the magnetic gripper has a magnetic field which spans a particular region of space, there is a high possibility that the gripper attracts the intended target before it comes in contact with it at the designated coordinates. To avoid this potential source of error and inconvenience during the operations, these holding fixtures were added. These fixtures were given a thickness of 2 mm. Each holder was given 5 cm length and 2 cm width. They are present on the four corners of the frames and parts, and they do not span the whole length of the frame. This is done in order to save material and in turn reduce the cost of fabrication.

The table had to be sturdy enough to withstand the forcers exerted on it by the robot, hence each leg of the table was given a 4.5 cm square crosssection and was 120 cm long .The legs of the material table were made to be long, in order to make our tables a foot taller than the standard tables but the drawback of this design was that the table had very less stability due to moment forces exerted by the robot while lifting the parts of the space frame. In order to overcome this minor inconvenience the legs of the material table are tied to the standard tables due to which stability is drastically improved.

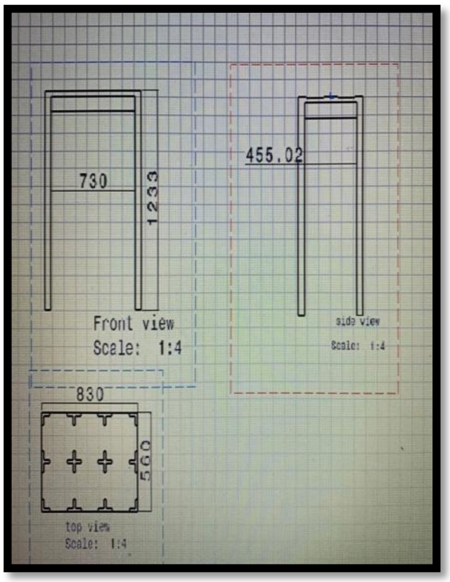

Fig 6.7: 2D Views of the Material Table

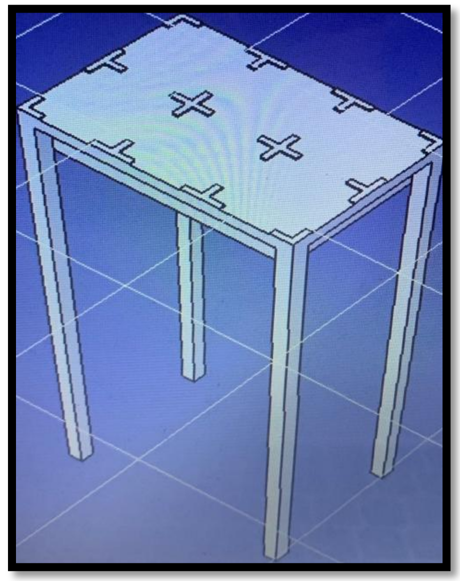

Fig 6.8: Isometric View of the Material Table

6.2.2 Assembly/Stacking Table Design

The assembly and stacking tables are identical. They need enough space to accommodate one face of the frame on their top surface. They were given the dimensions as shown in Figure 16.

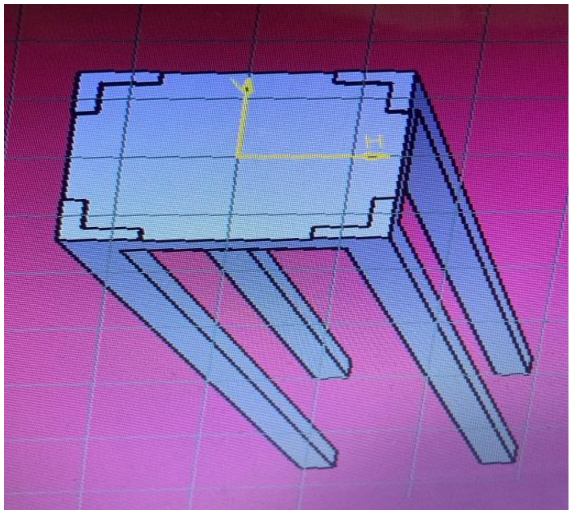

Figure 6.9: Isometric View of Stacking/Assembly Table

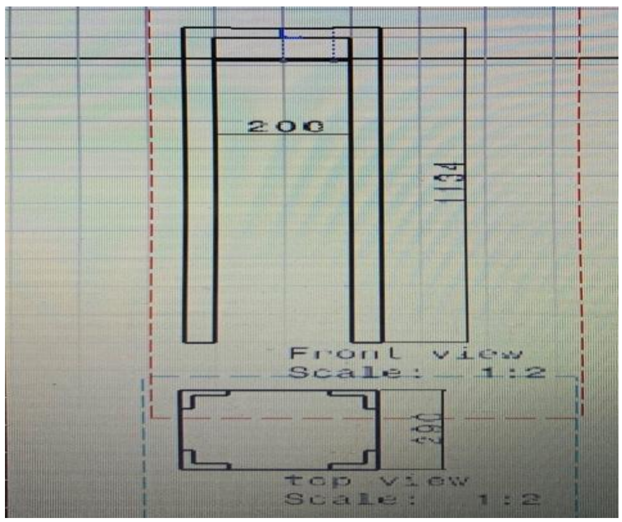

Figure 6.10: 2D Drawings of Stacking/Assembly Table

6.3 Work Environment Layout Design

Any articulated arm robot has a work volume and any operations involving the robot has to be carried out inside this volume. The work volume of a robot lies between the maximum and minimum reach of the robot. In a perfect world the complete work volume of the robot is available to assemble the space frame but we had additional constraints; some of the noteworthy ones are as follows:

- The maximum reach of the M10iD/12 robot was specified to be 1.441180 meters but the protective cages were bolted well before this limit as shown in the Figure 17, due to which our work volume was significantly reduced.
- The robot M10iD/12 could carry out certain standard pick and place operations for demonstrative purposes using its various grippers, for which certain standard tables were fabricated and bolted in front of the robot. This further limited the available space in the work volume of the robot.
- The space behind the robot was ominously occupied by the wires connecting the control system and the pneumatic compressors which are used to operate the two jaw and three jaw grippers. Therefore the operations of the space frame were possible only in front of the robot.

Hence a layout had to be designed which factored in all these additional constraints. The space available was determined following certain measurements within the work volume necessary to design the layout. The measurements which were taken are as follows:

1. Distance between Front cage to grippers= 111 cm
2. Distance between Side cage to grippers= 99 cm
3. Distance between Ground to grippers= 98 cm
4. Standard Table height= 110 cm
5. Standard Table length= 55 cm
6. Standard Table width= 26 cm
7. Reach= 144.1180 cm radial
8. Work length towards the left of the robot= 136 cm
9. Distance between Front cage to Standard table= 34 cm
10. Distance between the two side cages from left to right= 216 cm

11. Distance between standard tables to the cage to the left of the robot= 46 cm

12. Work length towards the right of the robot= 72 cm

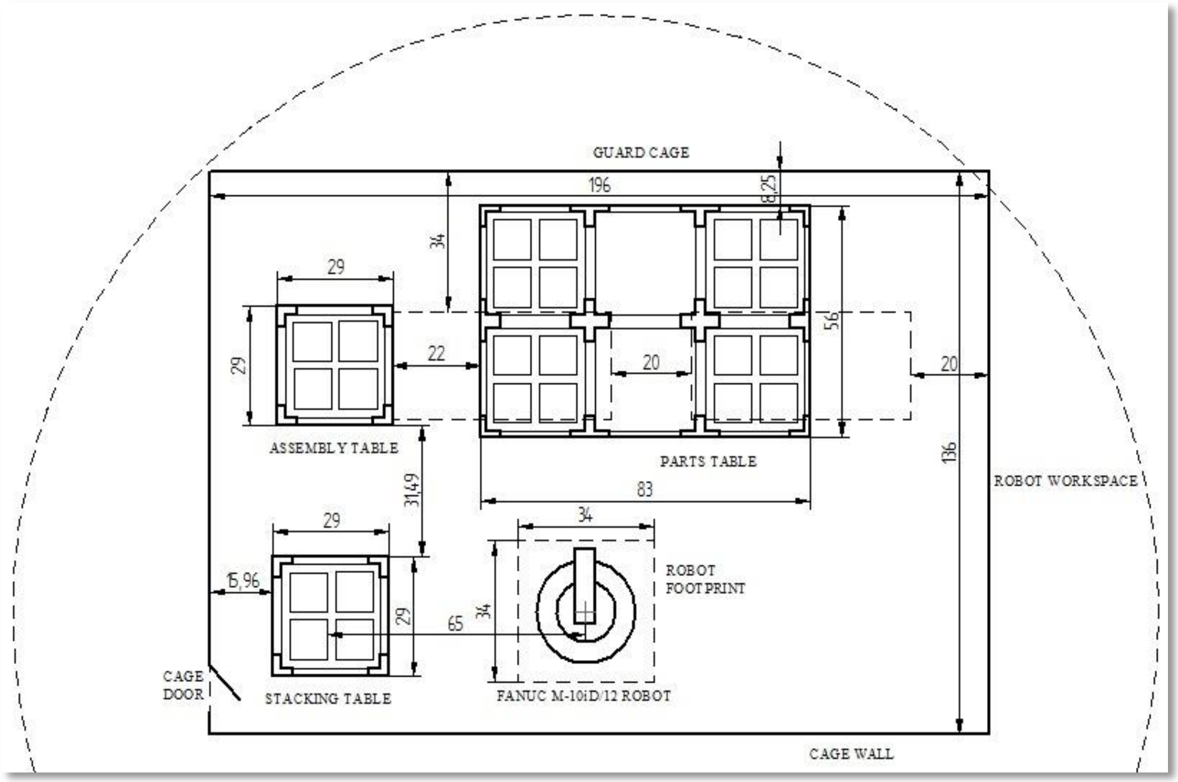

Figure 6.11: Layout of Work Environment

6.4 Fabrication

6.4.1 Fabrication of the Metal Parts

The two faces of the frame were fabricated using sheet metal forming to a

Figure 6.12: Fabricated Bottom Plate

dimension of 25*25 sq cm and four 9.5 cm side length squares were blanked on the surface of the metal using sheet metal cutting processes. Neodymium magnets are fitted on the four corners using adhesives.

Sheet Metal Forming:

Sheet metal forming is a process where pieces of sheet metal are modified to the desired geometry by applying forces rather than removing any materials. In this process a force is generated such that the material is stressed to deform. This in turn gives the possibility to bend or stretch the sheet of metal to a variety of complex shapes.

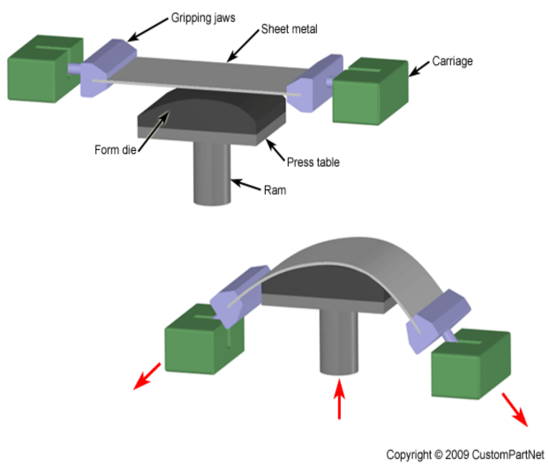

Figure 6.13: Sheet Metal Forming Process

Sheet Metal cutting:

Cutting processes are those in which a piece of sheet metal is separated by applying a great enough force to cause the material to fail. The most common cutting processes are performed by applying a shear force, and are therefore sometimes referred to as shearing processes. When a great enough shearing force is applied, the shear stress in the material will exceed the ultimate shear strength and the material will fail and separate at the cut location. This shearing force is applied by two tools, one above and one below the sheet. Whether these tools are a punch and die or upper and lower blades, the tool above the sheet delivers a quick downward blow to the sheet metal that rests over the lower tool. A small clearance is present between the edges of the upper and lower tools, which facilitates the fracture of the material.

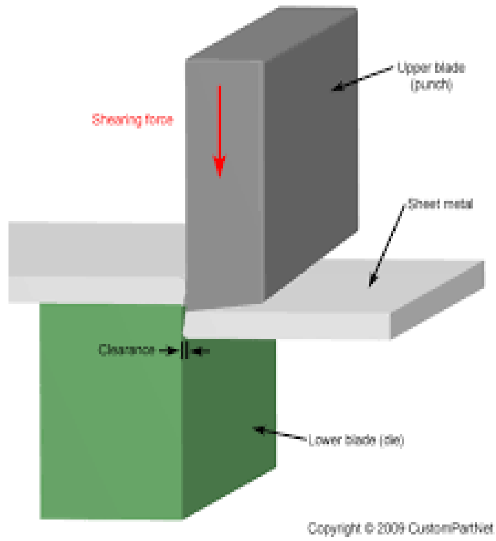

Figure 6.14: Sheet Metal Cutting Process

Neodymium Magnets:

Neodymium magnets (aka NdFeB, NIB or Neo magnet) are the most widely used rare earth magnets. They are permanent magnets made from an alloy of neodymium, iron, and boron to form the $Nd_2Fe_{14}B$ tetragonal crystalline structure. These magnets are the strongest permanent magnets available commercially. Because of different manufacturing processes, they are divided into two subcategories, namely sintered NdFeB magnets and bonded NdFeB magnets. They have replaced other types of magnets in many applications in modern products that require strong permanent magnets, such as electric motors in cordless tools, hard disk drives and magnetic fasteners. These magnets have a high resistance to temperature when compared to other magnets. They have a high degree of impact resistance and do not lose their magnetism after suffering great magnitudes of impact forces.

Therefore when these magnets are used to construct the locking mechanism of the space frame, the sturdiness and the rigidity of the frame are drastically increased.

Figure 6.15: Neodymium Magnets

6.4.2 Fabrication of the Acrylic Sheet

The acrylic sheet was cut to a dimension of 25*25 sq cm using laser cutting operations and four circular holes had to be drilled to the dimensions of the neodymium magnets so that the magnets could fit through the acrylic sheet.

Figure 6.16: Fabricated Acrylic Sheet

Laser Cutting Operations:

Laser cutting is a technology that uses a laser to slice materials. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated. A commercial laser for cutting materials uses a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish.

Figure 6.17: Laser Cutting Process

6.4.3 Assembly of the Space Frame Parts

- The robot uses its magnetic gripper to pick and place the bottom face of the space frame containing the magnets.
- Then the acrylic sheet is picked up using the vacuum gripper and is placed on top of the bottom face such that the magnets on the bottom face coincide with the drilled holes of the acrylic sheet.
- Then the top face is placed on the acrylic sheet using the magnetic gripper and the two faces of the frame are held together by the magnetic locking mechanism.

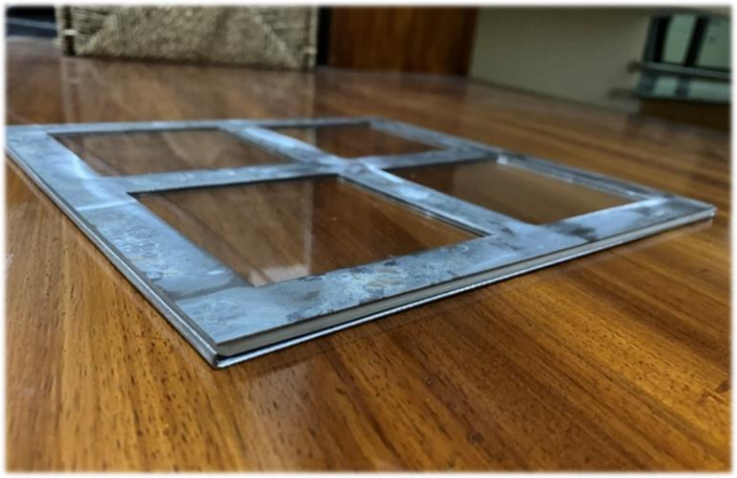

Figure 6.18: Fabricated and Assembled Space Frame

6.5 Simulation & Program Transfer

6.5.1 Introduction to ROBOGUIDE

FANUC ROBOGUIDE is a robot simulation software that simulates both the robot's motion and application commands. FANUC ROBOGUIDE version 9.1 is used to simulate the robot for this project. It allows for easy design and creation of the workspace layout and the placement of required elements within it to achieve the desired application. The robot can be programmed offline and the program can be transposed to physical applications. The simulations carried out in ROBOGUIDE maintain accuracy in relation to the real-world application. On a larger, industrial scale, this reduces downtime and reduces losses in production. Path planning of robot motion is intuitive and accompanied by simple animations. The CAD data of designed components, parts and fixtures can be directly imported to ensure accuracy and realism. Alternatively, ROBOGUIDE itself contains an extensive library of highly efficient, application specific tools to simplify programming efforts.

Using these features, simulation cells can easily be created and tested. The ability to create three-dimensional work cells saves the need to build a physical work cell. It eliminates the risk of investing and installing an actual work cell by enabling visualization of robot layouts.

FANUC ROBOGUIDE offers different options of work cells based on the type of application.

- HandlingPRO
- ChamferingPRO
- PaintPRO
- WeldPRO
- PalletPRO
- iRPickPRO

Since this project involves a material handling application, HandlingPRO work cell is used. HandlingPRO is used for applications including loading, packaging, assembly, and material removal. Features of this work cell include CAD to path programming, conveyor line tracking and machine modelling.

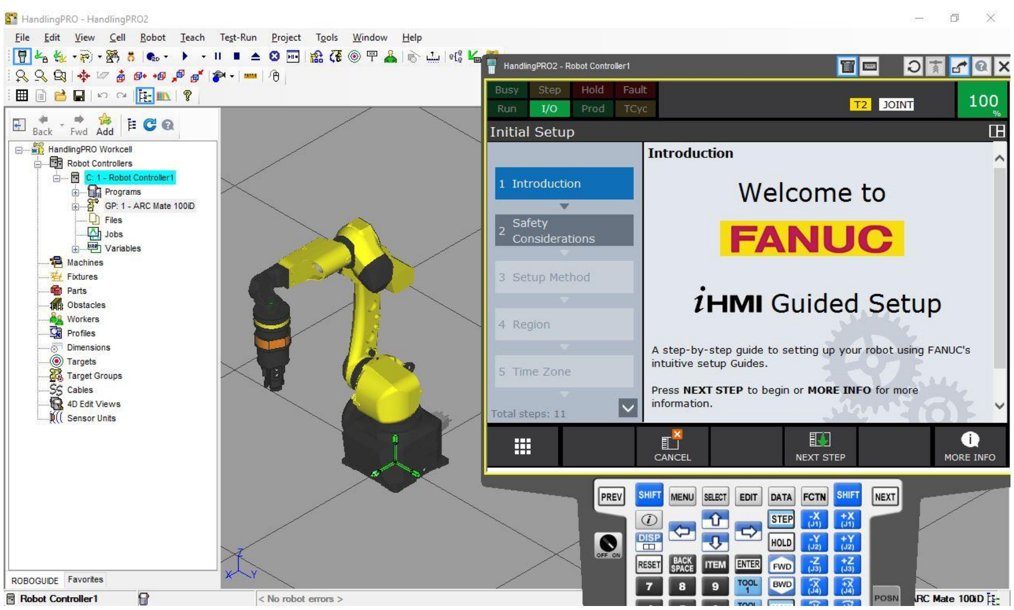

Figure 6.19: The ROBOGUIDE HandlingPRO Environment

6.5.2 Design of layout

For any robot simulation to be meaningful and transposable to real world applications, the arrangement of various components in the three-dimensional environment of the robot must be at ideal locations within the robot's reach. This type of arrangement enhances accuracy and optimizes the performance of the robot. FANUC ROBOGUIDE is used to design the layout and environment of the robot. This design is done in accordance to the physical measurements and dimensions taken directly from the college lab in which the FANUC M-10iD/12 is housed. However, a preliminary design is prepared initially using Solid Edge version 19 2D drafting software.

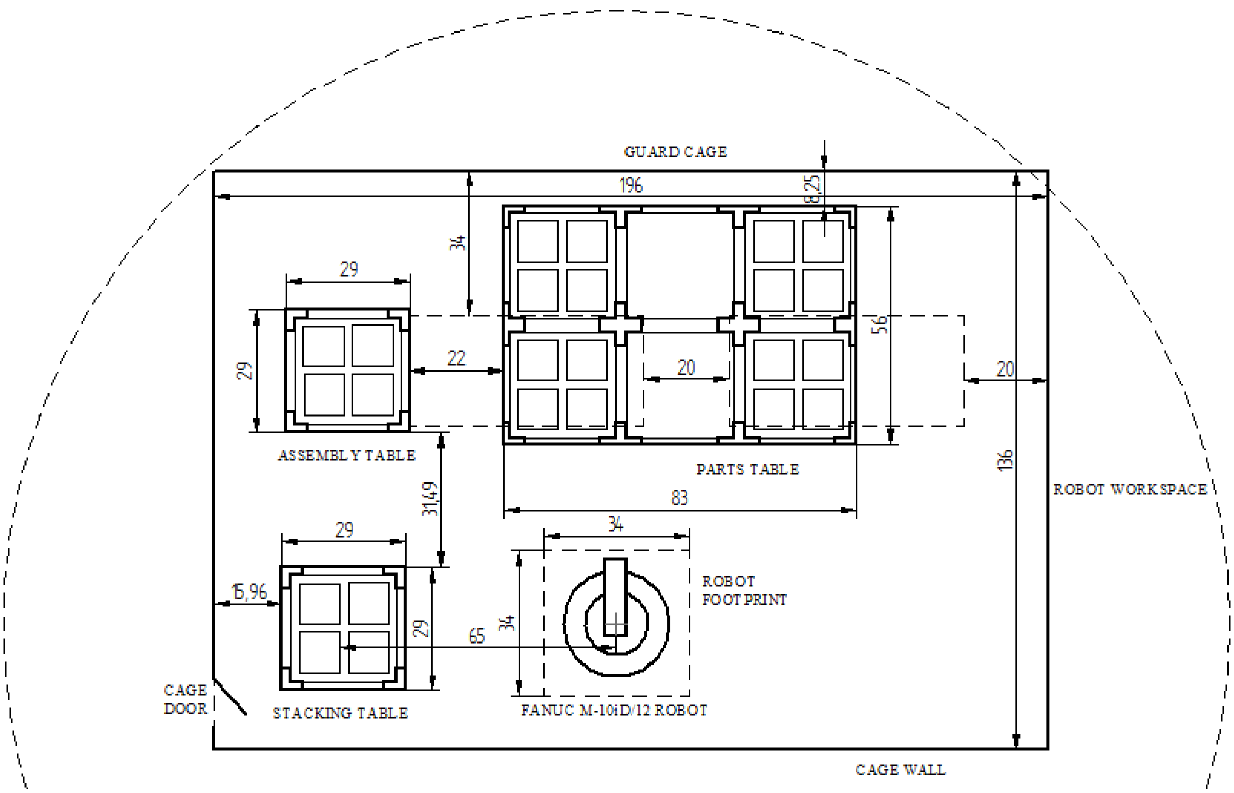

Figure 6.20: CAD design of Layout in (in centimetres)

Many of the components that constitute the layout such as, Parts table, Assembly table, stacking table are designed using CATIA version 19 and the respective CAD files are generated. These CAD files are then directly imported into ROBOGUIDE and integrated into the layout. The remaining components required for the simulation are sourced from ROBOGUIDE's extensive library of application specific parts and fixtures. These components are then arranged in three-dimensional space at ideal locations within the reach of the robot to optimize its performance.

6.5.3 Creation of Robot Work Cell Using ROBOGUIDE Work Cell Creation Wizard

The desired work cell is created using the ROBOGUIDE Work cell Creation Wizard.

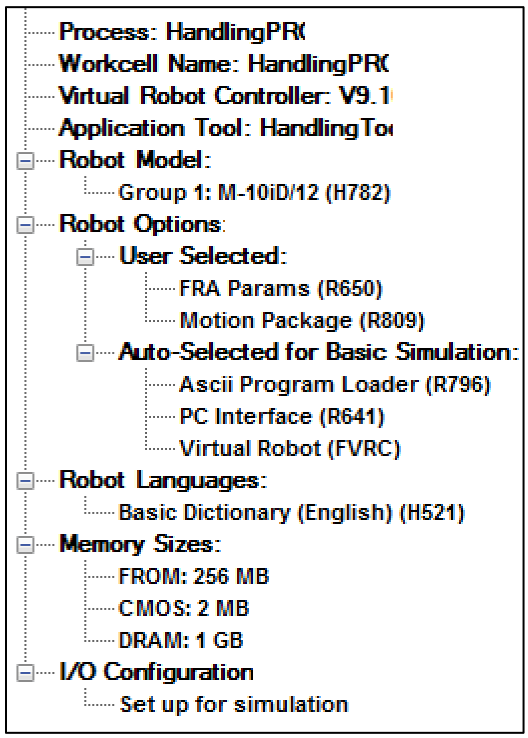

Figure 6.21: Work Cell Summary in ROBOGUIDE

Process selection:

This step selects the process this work cell will perform. A HandlingPRO work cell is used. This type of work cell allows for simulation and testing material handling processes and conduction of feasibility studies for robot application.

Work cell name

The new HandlingPRO work cell is named 'FrameSim'

Robot Creation method

A new robot with default HandlingPRO configuration is created.

Robot Software Version

The software version V9.10 – R – 30iB Plus, 9.10145.19.05 is loaded onto the robot.

Robot application/tool

No application/tool package is loaded onto the robot in this stage. The EoAT (End of Arm Tooling) is set later in the simulation.

Group 1 Robot Model

FANUC M-10iD/12 of Order number H782 is selected.

Additional Motion groups

No additional motion groups are selected.

Robot Options

The robot software option of Motion Package (R809) is selected. On selecting the aforementioned parameters, the Work Cell Creation Wizard provides a summary (Figure 27) of the selected parameters before it begins to create the Virtual Robot Simulator. In the Group 1 initialization Phase, the following settings are selected in the Teach Pendant.

- Flange Type : Normal Flange
- Cable Dress-Out Type Setting: Cable Integrated J3 Arm
- J1 Motion Range Setting: -185° to 185°
- Brake Type Setting: All Axes Brake
- Cable Setting: Standard (J2+J3: -90° to 222°)

The selection of these settings ends the robot set-up and the desired work cell is created.

6.5.4 Components of the Work Cell:

The components of the work cell constitute the various elements in the arrangement around the robot in three-dimensional space. Many of these components are designed (represented by '*') in CATIA version 19 and directly imported into the work cell. The remaining components are taken from the ROBOGUIDE's own library.

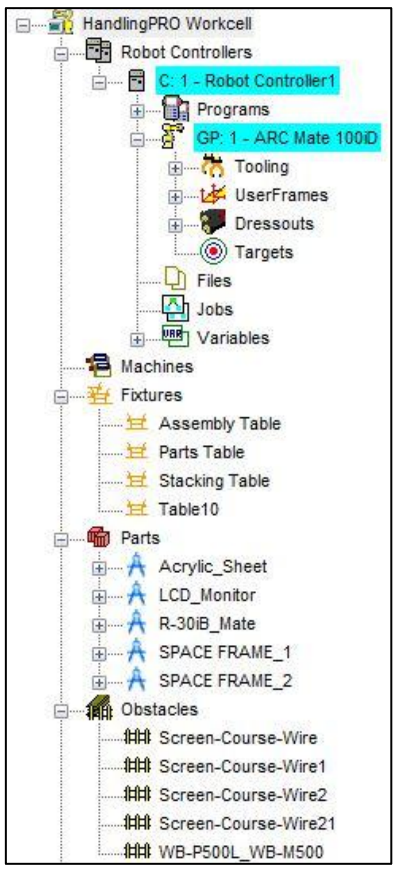

Figure 6.22: Cell Browser from ROBOGUIDE

The main components of the work cell can be divided broadly as follows.

Tooling:

Tooling refers to the grippers and associated fixtures used by the robot for the required application and is also called EOAT (End of Arm Tooling). Here, a single fixture that connects to both the Electromagnetic and Vacuum gripper is used. Each of these is added as a link in the first EOAT slot.

- Link 1 *: This is the fixture that holds both the Electromagnetic gripper and Vacuum gripper on each of its arms. It has the ability to rotate 360° through the joint of the robot in order achieve an ideal orientation such that both grippers can be functional.
- Link 2 *: This is the Electromagnetic gripper. It is used in the picking and placing of the space frames. It is mounted on one of the arms of Link 1.
- Link 3 *: This is the Vacuum gripper. It is used in the picking and placing of the acrylic sheets. It is also mounted on Link 1 but on the arm opposite to the Electromagnetic gripper.

Parts:

These are components that can be picked up directly by the component. They are assigned to fixtures and their position and orientation on the fixture can be altered. They are also assigned to the grippers of the robot in order to teach the robot the orientation with which to grip the part. The visibility of parts varies between Teach-Time (The time in the simulation during which positions and motion paths are recorded into the robot) and Run Time (The time in the simulation during which the robot actually executes the required motion and functions).

- Space Frame_1 *: This part is the top half of the space frame. It is meant to be placed over the bottom half and the acrylic sheet during the assembly.
- Space Frame_2 *: This part is the bottom half of the space frame. It contains narrow grooves through which the acrylic sheet can be accommodated.
- Acrylic_Sheet * : This part is the transparent sheet that is placed between the top and bottom halves of the space frame during assembly

- LCD Monitor: Sourced from ROBOGUIDE library required for motion control.
- R-30iB_Mate: R-30iB Plus controller sourced from ROBOGUIDE. Also required for motion control.

Fixtures:

These are structural components that cannot be picked up by the robot. Parts can be assigned to fixtures. The freedom and behaviour of parts are dictated by the properties of the fixtures they are assigned to. Fixtures offer a platform for parts from which they can be picked and placed.

- Parts Table *: This fixture is the table on which both sets of frames, top and bottom, and both sets of acrylic sheets are placed. The robot picks the frames and sheets from this table for assembly. Parts assigned to this table are visible at both teach time and run time.
- Assembly Table *: This fixture is the table on which the parts picked by the robot from the parts table are assembled into a space frame. The robot returns to this fixture to pick up the assembled space frame for stacking application. Parts assigned to this table are visible only during run time.
- Stacking Table *: This fixture is the table on which the assemble space frames are stacked one on top of the other. Parts assigned to this table are visible only during run time.
- Table 10: This fixture is a standard table sourced from the ROBOGUIDE library. The controller and the LCD monitor required for the motion control of the robot are placed on this fixture.

Obstacles

These are components that serve no real purpose in the functioning or assembly carried out by the robot. They are usually used in motion planning and collision avoidance of autonomous or mobile robots. In this case, however, they are used in the construction of the protective guard cage around the robot.

- Screen-Course-Wire: It is wire frame sourced from ROBOGUIDE. It constitutes the protective cage around the robot.
- WB-P500L_WB-M500: It is an auxiliary control unit used in motion control.

6.5.5 Layout in ROBOGUIDE

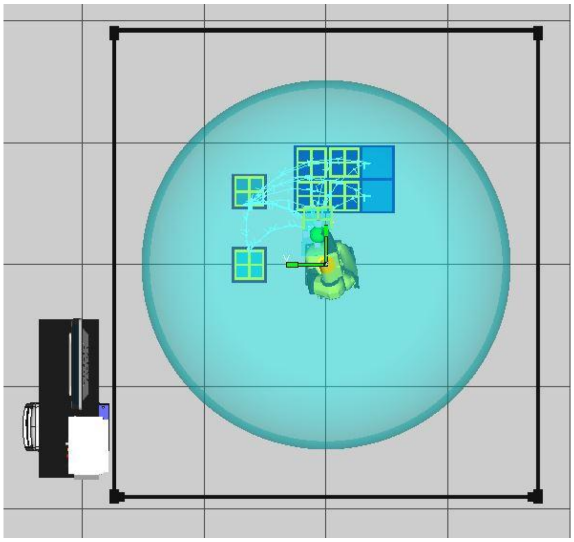

Figure 6.23: Top view of Simulation Layout

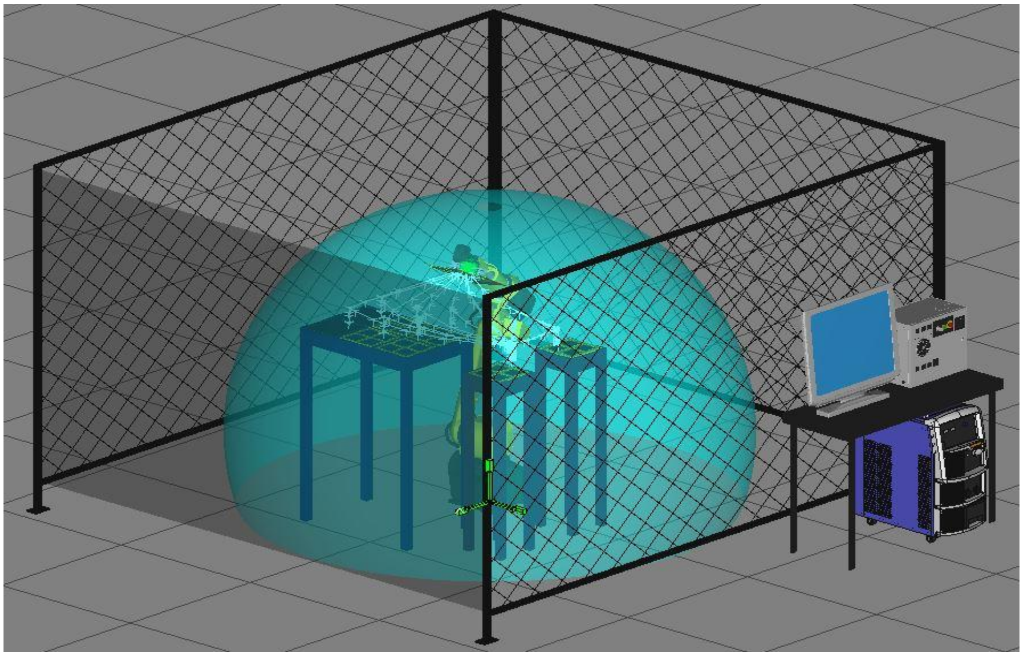

Figure 6.24: Isometric View of Simulation Layout

Figure 30 shows the completed layout designed in ROBOGUIDE. It is done in accordance to the initial CAD design (Figure 25). However, the dimensions of the guard cage are increased in order to sufficiently accommodate the work volume of the robot. This is only a recommended correction, and the simulation is **not** dependent on it; in other words, it will work in exactly the same way in the artificially constrained environment of the college laboratory. Once the design of the layout is complete, the robot is programmed to execute the required assembly as explained in Section 6.5.6. During the assembly, the robot will first pick up the bottom half of the space frame and place it on the assembly table using the electromagnetic gripper. The robot then repeats this motion first using the vacuum gripper for the acrylic sheet followed by the electromagnetic gripper for the top half of the space frame. The entire assembled frame is then picked and stacked on the stacking table. This entire process is repeated for the subsequent set of frames.

6.5.6 Programming of Robot Motion

The programming of the M-10iD/12 robot is done on the Teach Pendant using the multitude of functions offered by the controller. Certain simulation programs are also defined directly in the simulator to supplement the functioning of the robot. These are mainly the pick and place programs that inform the robot about the locations and grippers with which each part is to be picked and placed.

Payload configuration:

The robot payload can be defined as the total weight a robot arm can lift. This includes the weight of the end of arm tooling. The setting of the payload is done using the Teach Pendant. Since the mass of the frame coupled to the gripper and its fixture is much less than 12 kg (which is the payload of the robot) the robot is well within its operational limits. Here, the payload of 12 kg is given the index number ‘1’ and is named ‘Test’.

Position Registers:

Position registers are memory allocations that store positional values and coordinates. They are used to record and store coordinates of points within the work cell to which the robot must move in order to perform the desired operation. The locus of these points forms the motion path of the robot. In order to record these positions, either the robot is moved manually to the desired point using the 'Jog' command or the 'Move To' option is used to move the gripper of the robot directly onto a part. The corresponding point is then recorded by holding the 'SHIFT' key and pressing 'RECORD'. The list of values stored in the position register along with their purpose is listed in the table below.

Reg. No.	Register Name	Register Function
1	Home	Homing location of robot
2	Frame1p	Pickup location of 'Space Frame_1' from 'Parts Table'
3	Frame1d	Drop location of 'Space Frame_1' onto 'Assembly Table'
4	Frame2p	Pickup location of 'Space Frame_2' from 'Parts Table'
5	Frame2d	Drop location of 'Space Frame_2' onto 'Assembly Table'
6	Acrp	Pickup location of 'Acrylic_Sheet' from 'Parts Table'
7	Acrd	Drop location of 'Acrylic_Sheet' onto 'Assembly Table'
8	zofst150	Coordinates for offset of 150mm
9	Stack	Stacking location on 'Stacking Table' for first assembled frame
10	zofst250	Coordinates for offset of 250mm
11	Frame_1p	Pickup location of second set 'Space Frame_1' from 'Parts Table'
12	Frame_1d	Drop location of second set 'Space Frame_1' onto 'Assembly Table'

13	Frame_2p	Pickup location of second set ‘Space Frame_2’ from ‘Parts Table’
14	Frame_2d	Drop location of second set ‘Space Frame_2’ onto ‘Assembly Table’
15	Acr_p	Pickup location of second set ‘Acrylic_Sheet’ from ‘Parts Table’
16	Acr_d	Drop location of second set ‘Acrylic_Sheet’ onto ‘Assembly Table’
17	Stack_2	Stacking location on ‘Stacking Table’ for second assembled frame

Table 6.1: Position Registers

Simulation Programs:

Simulation programs are programs that are defined directly in the simulator. These programs allow the addition of instructions such as ‘Pickup’ and ‘Drop’. They are mainly utilized in the stage of the simulation where the gripper is required to actuate to pick up or place a part. In the actual working of the robot, however, the ‘RO[]’ function would be used to actuate the gripper. When we try to edit a simulation program in the Teach Pendant, the message ‘ROBOGUIDE generated this TPP’ is displayed. Thus, they can only be edited in the simulator. A list of simulation programs and their purposes are listed in the table below.

Program Name	**Source / Target**	**Link**	**Part**
Pickup1	Parts_Table	Link 2	Space Frame_1
Pickup11	Assembly_Table	Link 2	Space Frame_1
Pickup12	Assembly_Table	Link 2	Space Frame_2
Pickup13	Assembly_Table	Link 2	Acrylic_Sheet
Pickup2	Parts_Table	Link 2	Space Frame_2

Pickupacr	Parts_Table	Link 3	Acrylic_Sheet
Pickup_1	Parts_Table	Link 2	Space Frame_1
Pickup_11	Assembly_Table	Link 2	Space Frame_1
Pickup_12	Assembly_Table	Link 2	Space Frame_2
Pickup_13	Assembly_Table	Link 2	Acrylic_Sheet
Pickup_2	Parts_Table	Link 2	Space Frame_2
Pickup_acr	Parts_Table	Link 3	Acrylic_Sheet
Place1	Assembly_Table	Link 2	Space Frame_1
Place11	Stacking_Table	Link 2	Space Frame_1
Place12	Stacking_Table	Link 2	Space Frame_2
Place13	Stacking_Table	Link 2	Acrylic_Sheet
Place2	Assembly_Table	Link 2	Space Frame_2
Placeacr	Assembly_Table	Link 3	Acrylic_Sheet
Place_1	Assembly_Table	Link 2	Space Frame_1
Place_11	Stacking_Table	Link 2	Space Frame_1
Place_12	Stacking_Table	Link 2	Space Frame_2
Place_13	Stacking_Table	Link 2	Acrylic_Sheet
Place_2	Assembly_Table	Link 2	Space Frame_2
Place_acr	Assembly_Table	Link 3	Acrylic_Sheet

Table 6.2: Simulation Programs

Controller Programs:

These are programs directly entered into the teach pendant. They utilize the various software functions that come with the controller. These can be directly edited in the Teach Pendant. Many of the simulation programs are called from within controller programs.

Key functions used in controller programs:

- UFRAME_NUM: This function is used to set user frame number. Since no tool frames are being used, it is set to zero.
- UTOOL_NUM: This function is used to set user tool number. Since only one tool is used, it is set to one.
- PAYLOAD: It allows for selection of payload. Here, a single payload of 12kg is defined.
- OVERRIDE: This allows the user to increase or decrease the speed of robot motion without altering the program.
- CALL: It allows for programs stored in the memory to be called.
- J PR[] 200mm/sec CNT 25 : This function denotes joint movement of the robot to the position specified in the position register 'PR[]'. '200mm/s' denotes the speed with which the robot arm is to move. 'CNT' represents continuous motion.
- L PR[] 200mm/sec CNT 25: This is similar to the previous function. However, 'L' denotes linear movement. Thus, a linear path is created to the position specified in the position register 'PR[]'.
- WAIT: This is a function that specifies the time (in sec) the robot must remain in the current position before the next command is executed.

There are only two controller programs used for this application as described below. Note that all lines starting with a '!' character are comments. Refer to

Table 2 and Table 3 for position register numbers and simulation program names.

Homing

1. ! A program to return the robot to home position.
2. J PR [1 : Home] 100 % FINE

Main

3. ! The main program that defines the robot motion.
4. ! Basic pre processors
5. UFRAME_NUM = 0
6. UTOOL_NUM = 1
7. PAYLOAD [1 : Test]
8. OVERRIDE = 30 %
9. CALL HOMING

10. ! Pickup of Space Frame 2 (bottom)
11. J PR [4 : Frame2p] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]
12. L PR [4 : Frame2p] 2000mm/sec CNT25
13. WAIT .50 (sec)
14. CALL PICKUP2
15. WAIT .50 (sec)

16. L PR [4 : Frame2p] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

17. ! Placing of Space Frame 2 (bottom)

18. J PR [5 : Frame2d] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

19. L PR [5 : Frame2d] 2000mm/sec CNT25

20. WAIT .50 (sec)

21. CALL PLACE2

22. WAIT .50 (sec)

23. L PR [5 : Frame2d] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

24. CALL HOMING

25. ! Pickup of Acrylic Sheet

26. J PR [6 : Acrp] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

27. L PR [6 : Acrp] 2000mm/sec CNT25

28. WAIT .50 (sec)

29. CALL PICKUPACR

30. WAIT .50 (sec)

31. L PR [6 : Acrp] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

32. ! Placing of Acrylic Sheet

33. J PR [7 : Acrd] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

34. L PR [7 : Acrd] 2000mm/sec CNT25

35. WAIT .50 (sec)

36. CALL PLACEACR

37. WAIT .50 (sec)

38. L PR [7 : Acrd] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

39. CALL HOMING

40. ! Pickup of Space Frame 1 (top)

41. J PR [2 : Frame1p] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

42. L PR [2 : Frame1p] 2000mm/sec CNT25

43. WAIT .50 (sec)

44. CALL PICKUP1

45. WAIT .50 (sec)

46. L PR [2 : Frame1p] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

47. ! Placing of Space Frame 1 (top)

48. J PR [3 : Frame1d] 100 % CNT25

```
        Tool_Offset , PR [ 8 : zofst150 ]
49.     L    PR [ 3 : Frame1d ]    2000mm/sec    CNT25
50.     WAIT    .50 (sec)
51.     CALL  PLACE1
52.     WAIT    .50 (sec)
53.     L    PR [ 3 : Frame1d ]    2000mm/sec    FINE
        Tool_Offset , PR [ 8 : zofst150 ]
54.     CALL  HOMING
55.     ! Stacking of first assembled frame
56.     J    PR [ 3 : Frame1d ]    100 %    CNT25
        Tool_Offset , PR [ 8 : zofst150 ]
57.     L    PR [ 3 : Frame1d ]    2000mm/sec    CNT25
58.     WAIT    .50 (sec)
59.     CALL  PICKUP11
60.     CALL  PICKUP12
61.     CALL  PICKUP13
62.     WAIT    .50 (sec)
63.     L    PR [ 3 : Frame1d ]    2000mm/sec    FINE
        Tool_Offset , PR [ 8 : zofst150 ]
64.     J    PR [ 9 : Stack ]    100 %    CNT25
        Tool_Offset , PR [ 8 : zofst150 ]
```

65. L PR [9 : Stack] 2000mm/sec CNT25

66. WAIT .50 (sec)

67. CALL PLACE11

68. CALL PLACE12

69. CALL PLACE13

70. WAIT .50 (sec)

71. L PR [9 : Stack] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

72. CALL HOMING

73. ! Pickup of Space Frame 2 (bottom) set 2

74. J PR [13 : Frame_2p] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

75. L PR [13 : Frame_2p] 2000mm/sec CNT25

76. WAIT .50 (sec)

77. CALL PICKUP_2

78. WAIT .50 (sec)

79. L PR [13 : Frame2_p] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

80. ! Placing of Space Frame 2 (bottom) set 2

81. J PR [14 : Frame_2d] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

82. L PR [14 : Frame_2d] 2000mm/sec CNT25

83. WAIT .50 (sec)

84. CALL PLACE_2

85. WAIT .50 (sec)

86. L PR [14 : Frame_2d] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

87. CALL HOMING

88. ! Pickup of Acrylic Sheet set 2

89. J PR [15 : Acr_p] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

90. L PR [15 : Acr_p] 2000mm/sec CNT25

91. WAIT .50 (sec)

92. CALL PICKUP_ACR

93. WAIT .50 (sec)

94. L PR [15 : Acr_p] 2000mm/sec FINE

    Tool_Offset , PR [8 : zofst150]

95. ! Placing of Acrylic Sheet set 2

96. J PR [16 : Acr_d] 100 % CNT25

    Tool_Offset , PR [8 : zofst150]

97. L PR [16 : Acr_d] 2000mm/sec CNT25

98. WAIT .50 (sec)

99. CALL PLACE_ACR

100. WAIT .50 (sec)

101. L PR [16 : Acr_d] 2000mm/sec FINE

Tool_Offset , PR [8 : zofst150]

102. CALL HOMING

103. ! Pickup of Space Frame 1 (top) set 2

104. J PR [11 : Frame_1p] 100 % CNT25

Tool_Offset , PR [8 : zofst150]

105. L PR [11 : Frame_1p] 2000mm/sec CNT25

106. WAIT .50 (sec)

107. CALL PICKUP_1

108. WAIT .50 (sec)

109. L PR [11 : Frame_1p] 2000mm/sec FINE

Tool_Offset , PR [8 : zofst150]

110. ! Placing of Space Frame 1 (top) set 2

111. J PR [12 : Frame_1d] 100 % CNT25

Tool_Offset , PR [8 : zofst150]

112. L PR [12 : Frame_1d] 2000mm/sec CNT25

113. WAIT .50 (sec)

114. CALL PLACE_1

115. WAIT .50 (sec)

116. L PR [12 : Frame_1d] 2000mm/sec FINE

Tool_Offset , PR [8 : zofst150]

117. CALL HOMING

118. ! Stacking of second assembled frame

119. J PR [12 : Frame_1d] 100 % CNT25

Tool_Offset , PR [8 : zofst150]

120. L PR [12 : Frame_1d] 2000mm/sec CNT25

121. WAIT .50 (sec)

122. CALL PICKUP_11

123. CALL PICKUP_12

124. CALL PICKUP_13

125. WAIT .50 (sec)

126. L PR [12 : Frame_1d] 2000mm/sec FINE

Tool_Offset , PR [8 : zofst150]

127. J PR [17 : Stack_2] 100 % CNT25

Tool_Offset , PR [8 : zofst150]

128. L PR [17 : Stack_2] 2000mm/sec CNT25

129. WAIT .50 (sec)

130. CALL PLACE_11

131. CALL PLACE_12

132. CALL PLACE_13

133. WAIT .50 (sec)

134. L PR [17 : Stack_2] 2000mm/sec FINE

Tool_Offset , PR [8 : zofst150]

135. CALL HOMING

One controller program can also be called inside another. In this case, ‘Homing’ is called multiple times inside ‘Main’. Various simulation programs are also called inside ‘Main’. Once the above programs have been entered into the Teach Pendant, the program ‘Main’ is run to complete the required simulation.

The same code is fed into the control system of the robot in order to achieve the final objective of automation of the assembly and stacking operations. Screenshots of the complete simulation are shown below:

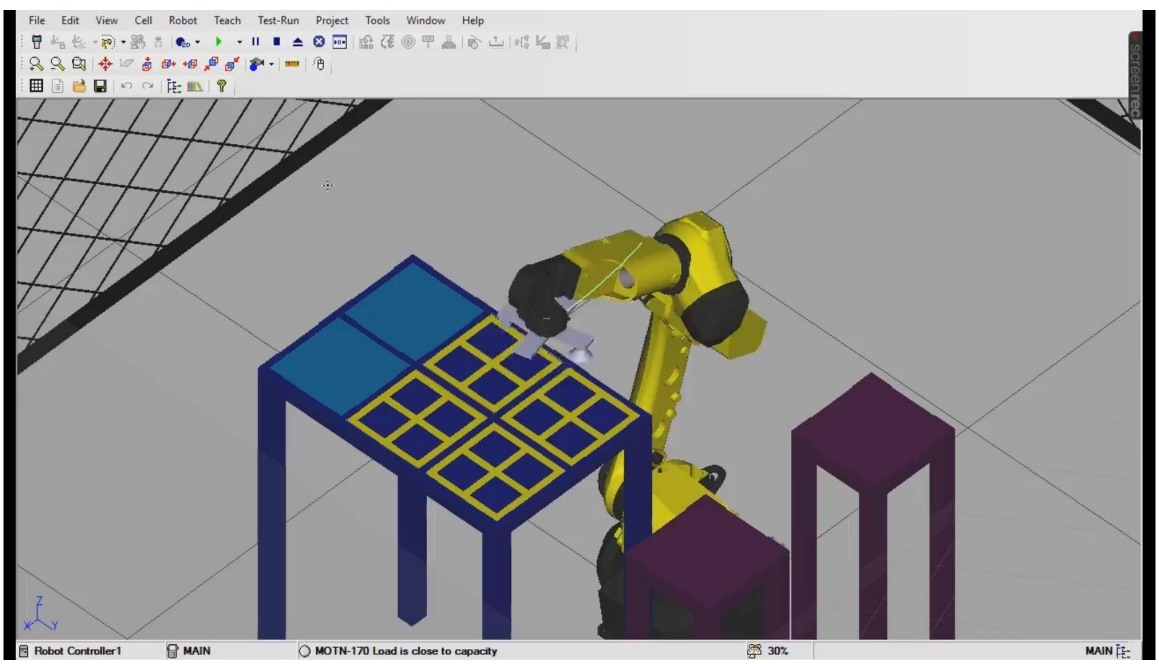

Figure 6.25: Start of Simulation

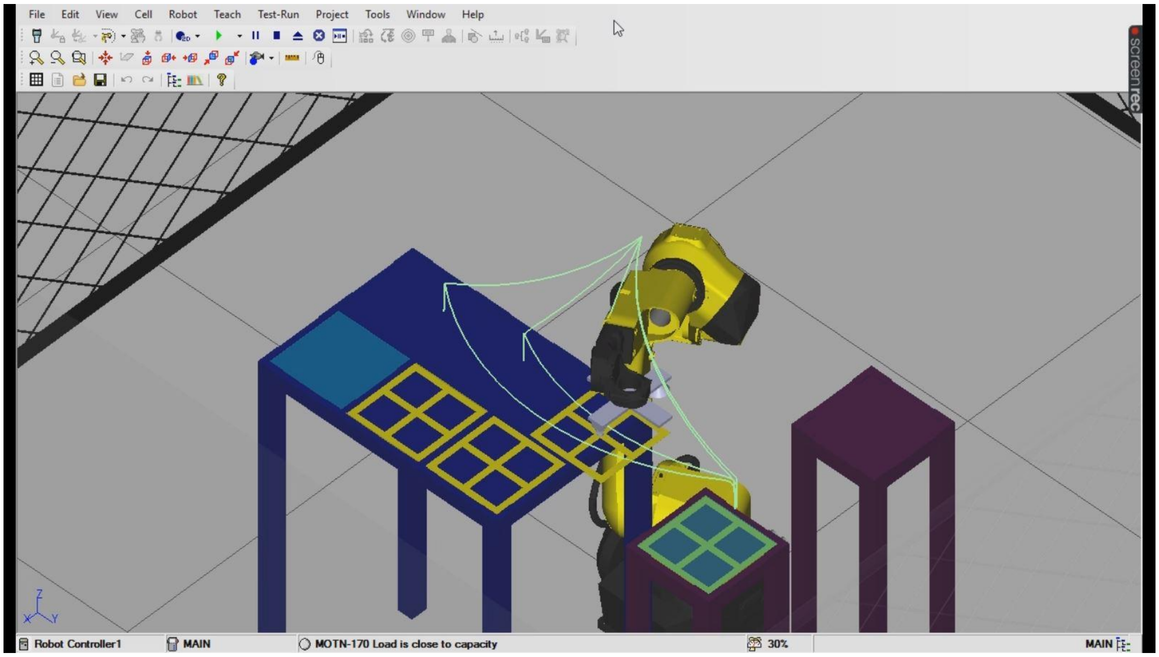

Figure 6.26: Assembly of First Frame

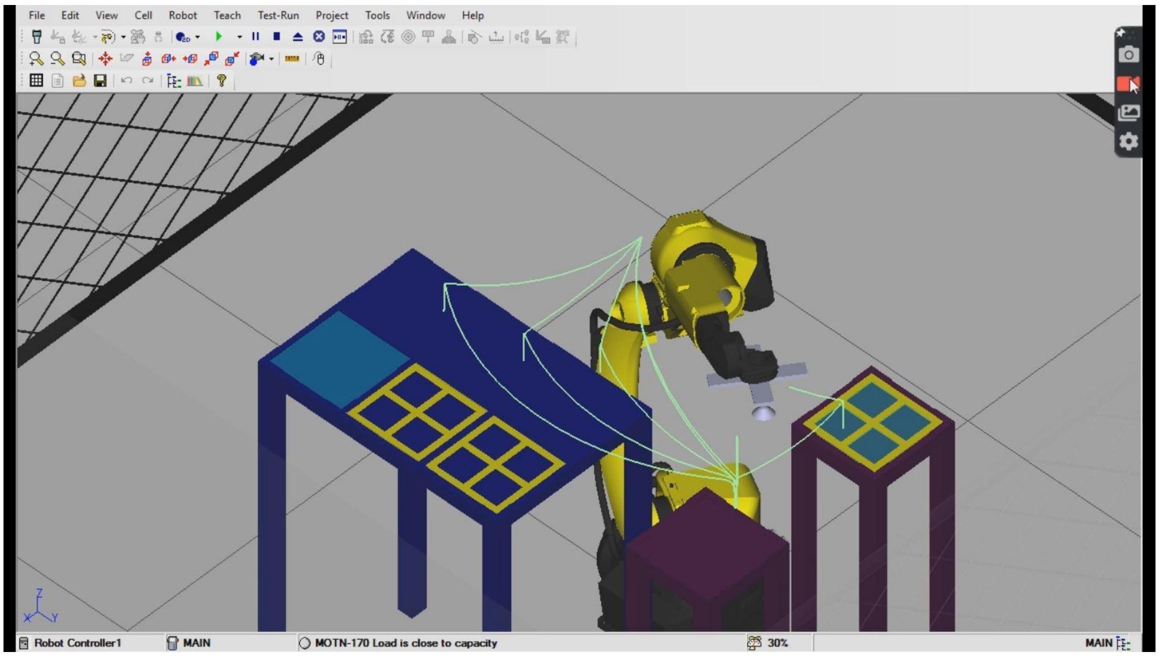

Figure 6.27: Stacking of First Frame

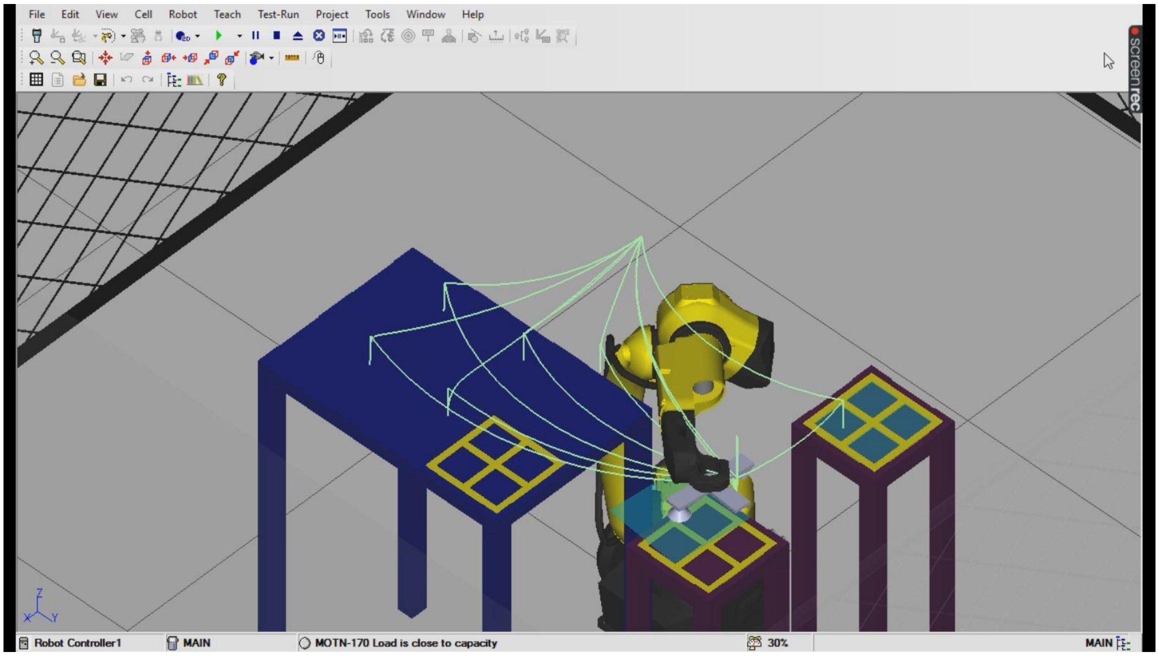

Figure 6.28: Assembly of Second Frame

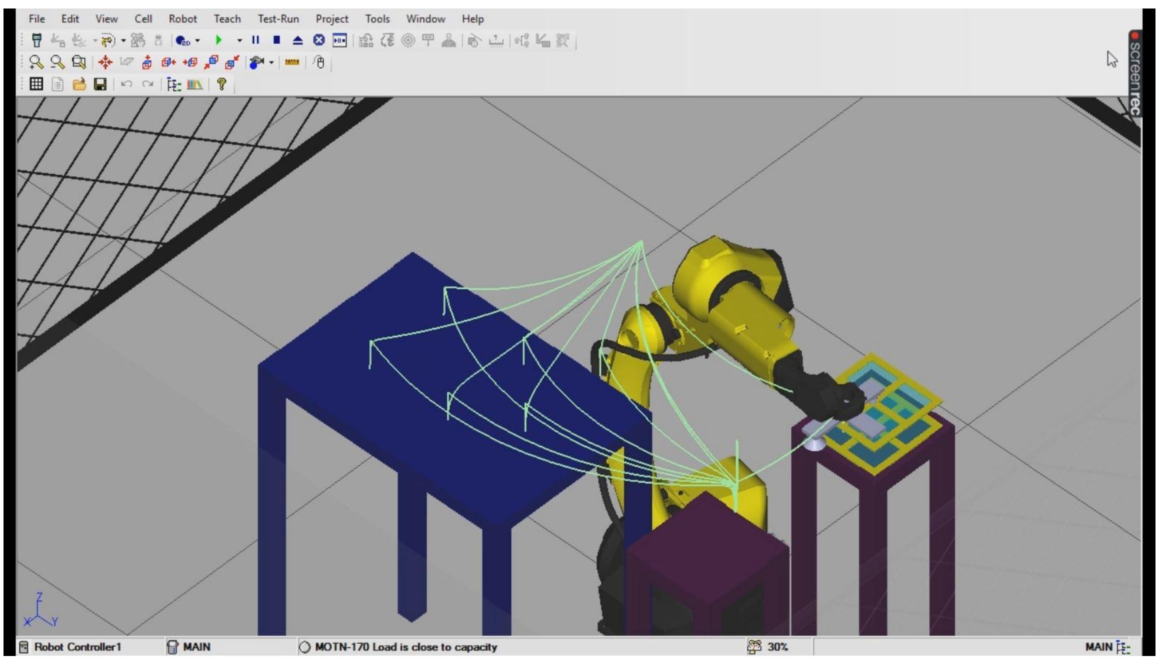

Figure 6.29: Stacking of Second Frame

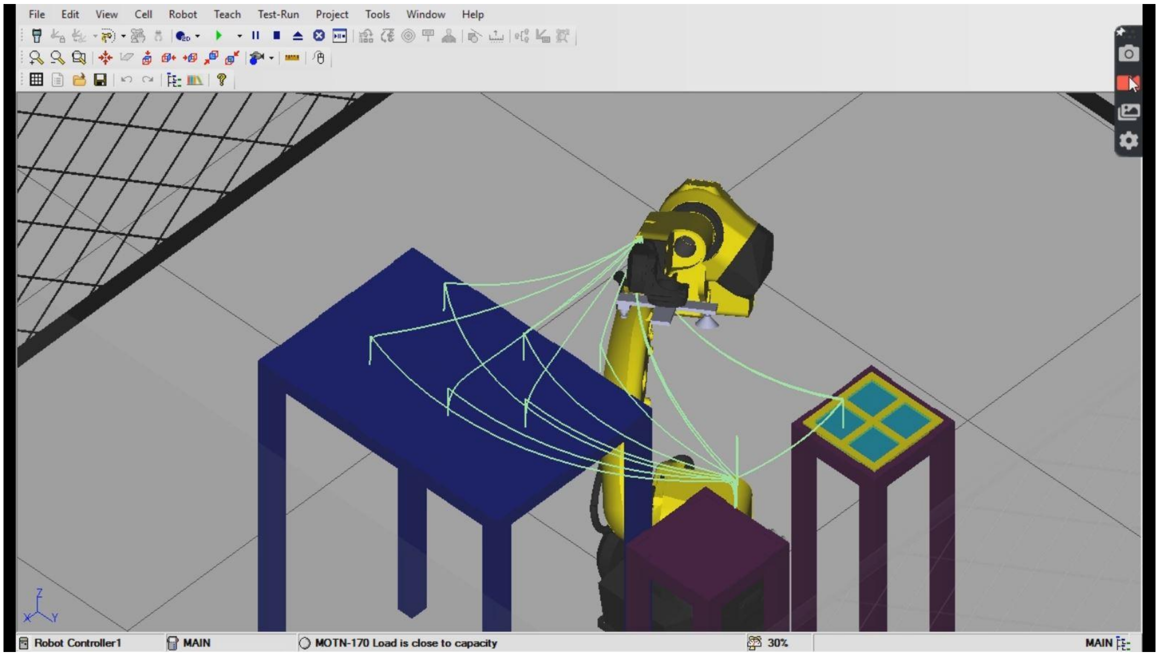

Figure 6.30: End of Simulation

7 Result

It can be inferred from the success of the process that the objectives the project started out with were satisfied. Each of the criteria considered was met. The primary mission of automating the process was clearly fruitful. The additional adaptability and variability objectives were just as successfully met. The process can be adapted for more than two frames by, among other means, having a conveyor belt feeding the parts to the robot instead of static tables in an industrial environment. Other operations like adding permanent joints (welds, rivets, adhesives, etc) or mechanical locks can be achieved by using suitable grippers, which are both available in the market for purchase as well as on the software for simulation.

On the basis of this, it was concluded that the project could be proclaimed a success.

8 Conclusions and Scope for Future Work

The need for automation in many areas of industry is obvious. There is little doubt that it is the way forward. The challenges in taking this path come in the form of acclimatization of the technology and its widespread knowledge and technical know-how. It is the belief of the project team members that the preparation for such a future begins at the undergraduate level. To that end, this project serves as a first attempt at understanding the working of robots and their manipulation for purposes of industry. It is by no means a grasp at complex systems and networks, but only a first step in that direction. Even so, the objectives set out at the beginning were lofty in the eyes of the beginner team members, and as such, delivered great satisfaction and motivation upon completion. The objectives laid out, as mentioned, were successfully completed, and that begs the question of what lays ahead.

The obvious answer to that question would be autonomous systems. Artificial intelligence fuelled systems that take care of the process at all levels, beginning with design, and including fabrication, assembly, storage, error correction, analysis of process outcomes, feedback and improvement. This would minimize human role in industry.

Apart from strictly technical aspects of what lays ahead, there are other concerns. The automation should be done smoothly and carefully so as to not displace workers and cause suffering. After all, the economy must serve the people. Resources must be set aside for retraining workers for the new skilled jobs produced by automation. Safety and convenience of everybody involved must be prioritized. Sustainable development must be aimed for.

This project was the team’s best foot forward in the direction of exploring the territory of automation and getting a grip of the fundamentals. It will serve as a stepping stone for future related endeavours.

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