TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

FACULTY OF INDUSTRIAL ENGINEERING, ROBOTICS AND MANAGEMENT OF PRODUCTION

DEPARTMENT OF DESIGN ENGINEERING AND ROBOTICS

ROBOTICS

MSc THESIS

STUDENT

ONCIOIU ADRIAN DUMITRU

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DESIGN AND IMPLEMENTATION OF A ROBOTIC CELL FOR VIET SANDING MACHINE CALIBRATION

Scientific coordinator

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Student's statement of originality

The undersigned Oncioiu Adrian Dumitru

Graduate of the MSc degree in Robotics:

I declare that my MSc thesis with the title:

DESIGN AND IMPLEMENTATION OF A ROBOTIC CELL FOR VIET SANDING MACHINE CALIBRATION

Represents my original contribution and it was not plagiarized.

The MSc thesis was developed by myself under the coordination of Sl. PhD. Eng, CHIS Ionuţ Adrian and I received the contest of the consultants listed below.

Consultant: ………………………………………………..

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Date: 05.07.2025

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(Student's signature)

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MSc THESIS ABSTRACT

The purpose of the proposed theme

This paper is motivated by a real-world need identified in a wood staircase manufacturing facility, where panel calibration and sanding are performed entirely manually. The topic was selected based on direct industry observations, highlighting a significant lack of automation in woodworking processes. The sector faces multiple challenges, including inefficient manual handling and inconsistencies in product quality.

General

A complete solution was successfully delivered to automate the calibration and sanding process of wood panels.

Specific objectives

To achieve this goal, the work focused on the following: Process Analysis and Requirements Definition, Robotic Integration, PLC Programming, Design of Custom Mechanical Components such as grippers and centering system, 3D CAD Modelling and Simulation, Human-Machine Interface (HMI).

Methodology/Approach/Design

To achieve the objectives of automating the calibration and sanding process of wood panels, I applied the following: Automation and Control Concepts: PLC, Industrial Robotics: Fanuc M-410iC/185 & Fanuc R-2000iC/125L, Mechanical and Pneumatic Design: CATIA, pneumatic actuators and vacuum generators, Human-Machine Interface (HMI): Siemens KTP900 Basic Panel, Recipe Management System, Simulation and Validation: RoboGuide, TIA Portal's Watch Tables and Trace Tools, Project Development Methodology, Scientific and Technical Theories: Pneumatic force, cycle time optimization theory.

Main results

Main results achieved are complete automation of the calibrating and sanding process, integration of Industrial Robotics and PLC Control, functional CAS Model and Simulation, operational HMI. This work brought several contributions to knowledge and industrial revolution: design of vacuum gripping and centering system, application of robotics in the field of woodwork, automation for non-standardized products.
The project successfully changed the traditional ways of handling wood into achievable and helpful behaviours, improving process speed and consistency. The thesis shows that the integration of robotics, pneumatic systems and digital ways is not limited to large scale manufacturing, and it can be adapted to dedicated, great quality production environments.

Results limitations

Certain limitations of the thesis are present and should be noted: limited scope to only one process and limited handling to only one product (panels), simulated environment and not

physical implementation. Proposals for future developments include implementation in real factory environments, integration of Autonomous Guided Vehicles, integration of IoT Monitoring.

Practical implications

The main implications are increased process efficiency, improved precision, increased operator safety and ergonomics. From an economic and commercial point of view, proposed solution could have substantial returns: significant labour costs, increased productivity, improved output, fewer defects.

Other implications

Environmental sustainability could be impacted by the following: energy effectiveness through optimization, decrease of material waste. Social responsibility might include improved workplace safety, support for aging workforce, enhanced product quality and customer satisfaction.

Originality/value

This thesis brings a practical contribution to the field of industrial automation, including sectors like woodworking. Key contributions include development of a scalable automation model, combination of mechanical, electrical and software engineering norms.

Chapters abstract

The Introduction chapter presents the context of industrial automation, outlining the motivation behind the paper and defines the main objectives. It also presents the research and methodology used throughout the project, including field study in the work environment, simulations and technical requirements.
The second chapter is Industrial Context and Initial Analysis. This chapter presents the initial state of the traditional production process. It includes details about the industry, observations from the field and a throughout presentation about the existing calibration and sanding process. Moreover, the chapter outlines the need for automation.
The third chapter is Theoretical and Technical fundamentals, presenting the necessary concepts for understanding the automation solution. It includes a review of the industrial automation technologies used in the project, such as PLCs, industrial robots, conveyors, grippers, HMI interface and sensors.
Chapter four is named Technical Analysis of the Handled Parts, presenting the challenges of handling solid raw wood panels. This chapter defines its characteristics and requirements for reliable automation handling.
The fifth chapter covers the Proposed Solution and General Architecture of the automation system, including workflow logic and safety measures. It presents specific details of the two industrial robots used and the pneumatic vacuum grippers.
Chapter six, CAD Design and 3D Simulation, gives insight into the design of the automated cell, equipment layout and safety zone organization.
The seventh chapter, Control and Programming Logic, describes the control system architecture, including the PLC logic and robot programming, it also explains the gripper controls and the full cycle execution.

This chapter provides a comprehensive user guide for operating the robotic cell, detailing the necessary steps for system startup and transition into automatic mode. It outlines the sequence of actions required by the operator, including switching the robots to AUTO mode, initializing the HMI, and ensuring safe and correct system activation. The focus is on ease of use, operational safety, and clear guidance for daily operation.

The ninth chapter, Comparative Analysis of the Current and Automated Systems, conducts a comparative study between the two systems, using performance indicators such as full cycle time, labour costs and production capacity.

This final chapter summarizes the outcomes of the implemented automation solution, emphasizing the improvements achieved in terms of reliability, operational efficiency, and productivity. Furthermore, it outlines potential directions for future system enhancements, such as the integration of AGVs or AMRs, full process automation, IIoT connectivity, and advanced HMI functionalities. These suggestions aim to further optimize system performance and align it with the evolving needs of modern smart factories.

GENERAL OBJECTIVE AND SPECIFIC OBJECTIVES

The general objective of this thesis is to design, simulate and indorse an automated system for feeding wooden panels into a calibrating sanding machine to improve efficiency and consistency in a woodworking factory. This objective is addressed to solve a specific problem identified during professional experience at DIPPANELS CONCEPT SRL, where the feeding, calibrating and sanding process is human made, therefore it is time-consuming and prone to errors.

The proposed automation solution involves Fanuc industrial robots, Siemens PLC, custom designed pneumatic grippers, and an HMI. The solution is developed such as it handles wood panels of various dimensions and weights.

This objective is relevant to an industrial challenge observed in personal practice, targeting a real problem in production. The objective is also realistic, as it uses real components, programming environments, such as TIA Portal and RoboGuide, and validated mechanical designs, such as CATIA.

The goal of the thesis would benefit medium to large organizations that are part of the woodworking industry, aiming to digitalize and optimize human processes.

For the project to meet its general objective, the thesis was structured with specific objectives:

- Analyse the current workflow and identify automation requirements: Understand the current work ineptitudes at DIPPANELS CONCEPT SRL and set the specification for the automated solution, documenting what are the technical and functional problems encountered.
- Design a robotic cell layout with a gripper suitable for handling wood panels: Deaign a CAD model of the cell that includes the robot, conveyors, pneumatic gripper in CATIA. As a final indicator, the complete 3D model should validate the automated project using RoboGuide.
- Implement PLC logic: Develop and coordinate operations between the robots, conveyors and grippers using Siemens TIA Portal V19. The result should consist of a validated simulation of the control logic with input/output signals.
- Simulate the robot cell for feeding, calibrating and sanding of the panels. This step involves the layout with the two Fanuc robots in RoboGuide for achieving efficient robotic motion paths compatible with the requirements present in the first objective. The result is a validated simulation.
- Create the HMI interface: Implement a user-friendly HMI interface that allow control in manual and automatic modes using Siemens KTP900 and TIA Portal. The result will consist of an HMI whose functionality simplifies the process.
- Confirm the performance of the simulation and estimate efficiency returns: validate the automated process and coordinate process simulation, ergonomic analysis and time efficiency studies, resulting in clear answers.

Part I: General aspects in the context of the project theme

1. INTRODUCTION

1.1. The general context of automation

Automation of industrial processes plays a crucial role in modern manufacturing, essential for quality and efficiency. Nowadays, the demand for high quality products, delivered as soon as possible at the lowest possible cost, is constantly increasing, companies are forced to adapt and search for innovative technologies that support or even replace human labour.

Systems such as industrial robots, programmable logic controllers (PLCs), automatic roll conveyors and HMI interfaces are basic components in modern factories. The wood industry is usually associated with intensive human labour and has great potential to benefit from the technologies listed above. Automating the processes in such a factory can lead to better end-product quality and operational efficiency.

1.2. Motivation for the choice of topic

The motivation of this paper comes from a real need identified in a wood staircase factory, where the panel calibrating and sanding operations are carried out entirely manually. The choice of topic also relates to practical and personal experience working in the woodworking industry, where an impactful lack of automation was observed. Several challenges are present in this field, including inefficient manual handling and quality difference between the products.

Even though the technical process of handling the wood is clear and well put together, it involves significant efforts, such as substantial downtime during implementation and a strong reliance on the human operators. The process involves limitations for scalability and performance in production, such as human errors resulting in quality variations and labour costs. The workers are usually faced with only 2 options in the traditional way of working. The first one is to work as quickly as possible, but that often leads to poor recovery rates and a decrease in the work quality. The second option is to focus on precision and accuracy, which results in reduced performance and slower output of the products delivered. Unfortunately, the challenge remains with no current ideal solution. (Fischer, 1986)

This thesis aims to create a feasible solution to automate the handling, calibration and sanding of the panels in industrial conditions.

1.3. Objectives

The general objective of the thesis is to design a robotic cell focused to automate the calibration and sanding processes of raw wood panels, specifically regarding a VIET industrial calibrating and sanding machine. The main goal is to replace hard labour operations with a reliable and efficient automated system that also ensures productivity increase and consistent surface quality of the wood panels.

The specific objectives set to achieve the general purpose of the paper are the following:

1. Analysing the current manual labour and define the automation requirements for the process of sanding and calibrating. This objective involves a thorough examination of the existing workflow, in which the employees manually handle the raw wood panels during the calibration and sanding process. It includes observing the whole process and examine each operation performed, while evaluating the safety

measurements present in the work environment. This first step ensures a customized solution to the real operational needs of the production.

2. Designing the robotic cell and selecting the required equipment to achieve the perfect layout, such as robots, grippers, conveyors, sensors. The layout was designed as a CAD model to mimic the real-world setup as precisely as possible. This step used professional tools such as CATIA for precise 3D modelling of the required components, and RoboGuide for simulating the factory environment for the robotic integration.
3. Implement and develop the PLC logic for synchronizing ang optimisation of the desired process. This specific objective includes the creation of a control architecture that coordinated the operation of the automated components within the cell, the two Fanuc robots, pneumatic grippers, the centering system and the robotic conveyors. All subsystems will interact in a logical manner to provide a safe, time efficient and entirely synchronized behaviour. The logic is implemented using Siemens TIA Portal V19, which enables clear visualization of the process and accelerates the scalability of the control logic for the industrial automation. Specific details were executed such as interlocks, startup conditions, emergency stop implementations, guaranteeing safety standards. Recipe-based parameterization was developed to adapt the control sequence based on the sizing of the wood panels and palletizing strategies present in the HMI and defined by the operators.
4. Simulating and designing the robot cell and programs for feeding, calibrating and sanding machine. This step focuses on developing the robot motion paths necessary to automate the handling of the wood panels. The two Fanuc robots are crucial for this phase, ensuring the required tasks are performed. To guarantee smooth and safe movements, the robot trajectories are carefully executed, coordinated with the external components, grippers and conveyors. The robot programs were implemented and tested using RoboGuide, a Fanuc software. This specialized environment replicates the real environment needed for the automation requirements to be met. The software enabled virtual layout cell and troubleshooting to avoid any errors before real world implementations. Errors avoided include collision between the components of the system.
5. Design an HMI interface. This step involves designing and implementing a Human Machine Interface (HMI) that shows a user-friendly interface, enabling an efficient interaction between the automated system and the operators. The interface enables the control of the entire cell in manual and automatic modes, granting access to real time data, process status and system diagnostics. The HMI is created using Siemens TIA Portal V19 and downloaded to KTP900 Basic touch panel, making sure the PLC logic is well delivered for industrial environments. The design offers multilingual support for Romanian and English, access hierarchy that avoids operator errors and a clear and well-structured layout.
6. Simulate and validate the system performance. The final step is reserved for simulating the proposed automation system with a focus on evaluating the improvements in productivity and repeatability. The objective was set to ensure the robotic cell and final automated system brings value compared to the previous traditional way of handling raw wood. The validation was performed with the help of time and measurement studies, observing the manual and automated operations, and comparing the time for handling the raw wood in both cases. Automation simulation is also a crucial step to finalize the validation, using virtual tools such as RoboGuide and TIA Portal. The system’s behaviour was tested in realistic conditions to endure the synchronization and error handling.

1.4. Methodology

The thesis work follows interdisciplinary methodology, structured in several stages. The first phase includes a technical documentation of the existing process that was carried out in the factory, with field visits and careful observation of the manual procedure. This step was followed by analysing the specific problems of the traditional process, such as physical effort, low productivity and staff exhaustion.

With all the information gathered, the design phase stared: definition of the technical requirements, selection of the equipment, modelling the cell in CAD and simulating the final process in a virtual environment. The next phase involves the development on the PLC and robots, closely followed by the implementation of the HMI interface used by the operators.

Lastly, a comparation can be analysed between the existing and the proposed process. The analysis will include time estimations, cost and efficiency factor investigations, as well as economic benefits. The results are reinforced by data, models and visual representations included in the appendices, providing a complete picture of the proposed solution.

2. Industrial context and initial analysis

2.1. Description of the factory and current process

The factory analysed in this thesis is in Brasov region and is specialized in the production of solid wood staircases, mainly oak and beech. The factory is one of the few Romanian factories that delivers high standard products, with international collaborations and design awards. The activity involves both mass production and custom orders with high precision components. The raw material used for its orders is made out parts of hard wood, which are joined together with glue to form panels. Because of the raw wood material used in the process, it may result in panels that vary in flatness and thickness. The wood is also affected by the pressing process. For the panels to be usable in the milling, shaping and cutting stages of the process, a sizing operation is necessary. This operation brings the panels to a persistent thickness and a flat, smooth surface.

Figure 2.1. Wood panel sample

The current calibrating process uses a VIET Calibrating-Sanding Machine S3 331TM, an Italian-made machine that is known for its performance in wood processing. The machine is equipped with two sections: the first one is for calibrating with rotating sharp motions, and the second one is for sanding with hard abrasive rollers. Despite the VIET Machine being a modern tool, the handling process is carried out manually. Therefore, the infeed, turning and outfeed operations require manual handling of three operators.

Figure 2.2. VIET Calibrating-Sanding Machine S3 331TM

Figure 2.3. Close-up of VIET Calibrating-Sanding Machine S3 331TM

Figure 2.4. VIET Calibrating-Sanding Machine S3 331TM Specifications

2.2. Field observations

Several observations and recurrent problems were identified in the factory.

Extensive monitoring was done, and several notes were made regarding the raw panels' dimensions. The raw panels reach dimensions of 1220 mm in length, 420 mm in width and thickness of approximately 45 mm. These dimensions depend on the wood types and its density. *(Toolbox, 2006)*

$$oak: \sim 700 kg/m^3$$
$$beech: \sim 640 kg/m^3$$

The weight of the wood part varies between 14 and 17 kg. However, there are custom pieces that can exceed 25-30 kg, and a complete pallet, handled by hand can reach over 500kg each.

These observations were complemented by verbal confirmations with the operators and workers present in the factory. The internal working documentation was analysed, revealing lack of standardization in handling, risk of accidents and unproductive intervals between the staff absence.

2.3. Actual calibration process

The current process involves an operator loading the panels onto the VIET machine's infeed table. The panel is collected up by the inner belt and passed through the calibrating and sanding process. At the end of the machine, two operators must pick up the panel, turn it manually and place it on a pallet. After all the panels on the pallet have been processed on one side, the entire pallet is picked up again and the process repeats for the other side.

This method of handling the wood involves double effort, to process the panel on both sides. This process is putting a strain on the operators' spine, shoulders and wrists, being prone to health conditions and various accidents. The weight of the wood and the lack of any mechanical support for handling it, therefore the process is tiring, and it leads to a lack of productivity. The deficiency of automation in the turning process might lead to an increased risk of faulty positioning or uneven grinding.

2.4. Identifies issues

Based on field observations and process investigation, the following conclusions can be drawn:

- Extreme physical effort: the manual handling of heavy wood panels enforces recurrent mechanical tasks on workers.
- Dependency on trained workers: the handling process requires experienced workers to place the panels accordingly and avoid errors.
- Employee costs: the handling process involves minimum of three skilled workers per shift, causing significant costs.
- Poor functional design: the handling workstations are not set to handle large and heavy components.
- Downtime between cycles: the lack of automation between the steps of the process leads to unproductive gaps.
- Inconsistent quality: the lack of precise handling and operator fatigue can negatively impact the product quality.

All the issues stated above highlight the opportunity to realize an automated solution to modernise the process, protect the employees' health, increase the productivity and quality of the products delivered.

3. Theoretical and Technical Fundamentals

3.1. Industrial Process Automation

Industrial process automation is the application of technologies that facilitate systems and equipment to operate without direct human intervention, using control systems, actuators, sensors and software algorithms. The main goal of automation is to improve process efficiency, product quality, operational safety and overall cost-effectiveness.

According to Mikell P. Groover in his paper "Automation, Production Systems, and Computer-Integrated Manufacturing" *(Groover, 2015)*, automation can be categorized into three main types:

- Fixed automation - used for high production volumes with dedicated equipment.
- Programmable automation - suitable for variable volumes by reprogramming equipment (e.g. industrial robots).
- Flexible automation - allows real-time adaptation to product or process changes.

In the wood industry, where parts are large, heavy and vary in size, customized automation offers a great advantage. It helps reduce labour costs, minimize human error and increase accuracy.

Automation also allows integration with higher-level IT systems (ERP, MES) and the possibility to gather operational data for analysis.

3.2. Industrial robotics

Industrial robots are programmed to perform defined tasks such as parts handling, welding, painting or assembly. They consist of an articulated mechanical structure (with 4-6 axes), electric motors (servomotors), feedback sensors and a command controller.

ISO 8373:2012 defines an industrial robot as "a reprogrammable, multifunctional, automatic manipulator capable of moving materials, parts, tools or special devices through varied, programmed motions to accomplish various tasks." (ISO, 2014)

According to Craig J. in "Introduction to Robotics: Mechanics and Control", the major advantages of industrial robots include (Craig, 2005):

- High repeatability (less than ±0.05 mm for precise applications).
- Flexibility - can be adapted to a variety of tasks.
- Ability to work in hazardous or uncomfortable environments for humans.
- Continuous working time, without breaks or performance variations.

In a general context, industrial robots can be classified according to their kinematic configuration (Cartesian, cylindrical, spherical, SCARA, articulated) and according to the applications targeted (handling, assembly, welding, palletizing, etc.). International standards (e.g. ANSI/RIA R15.06) set requirements for the design, integration and safe use of industrial robots. (Balkan, 2006)

Modern robots can integrate force sensors, vision systems and artificial intelligence software, helping to increase adaptability and accuracy in varied tasks. They can work in synchronization with other automated systems through industrial networks such as ProfiNet, EtherCAT or DeviceNet, becoming part of an integrated Industry 4.0 architecture. (MANIRAJ, 2022)

3.3. Programmable Logic Controller (PLC)

The Programmable Logic Controller (PLC) is the central control unit in most industrial automated systems. Its role is to take input signals from sensors, process them according to the logic program, and control the equipment present in the system (motors, valves, cylinders, grippers, etc.).

According to author Frank D. Petruzella in the book “Programmable Logic Controllers”, a PLC is a device designed to operate in critical industrial environments, capable of running logic sequences. *(Petruzella, 2016)*

The basic structure of a PLC includes:

- Central Processing Unit (CPU) - interprets and executes program instructions
- Input/Output (I/O) modules - connects sensors and actuators
- Memory - storing programming logic (ladder logic, FBD, SCL, etc.)
- Communication interfaces - for the integration of industrial networks.

The advantages of using a PLC are:

- High reliability over time
- Scalability
- Flexible programming
- System diagnostics and troubleshooting. *(Mallikarjun G. Hudedmani*, 2017)*

In modern systems, PLCs can communicate in distributed networks with other equipment such as industrial robots, HMIs or SCADA systems. Common protocols include ProfiNet, EtherNet/IP, Modbus-TCP or OPC UA.

By using a PLC, the automated process is designed to be precise and fast, with the possibility to update the recipe and make dynamic changes to the system requirements.

3.4. Conveyors and Conveyor Systems

Industrial conveyor systems, also known as conveyors, are a key part of an automated system. The conveyors ensure the continuous transfer of products between different workstations, removing manual handling and ensuring a constant flow.

Conveyors can be categorized according to the following principles:

- By drive mode: electric, pneumatic, gravity
- By type of conveying surface: belt, roller, chain, vibrating
- By direction of travel: linear, curved, vertical. *(Deka, 2024)*

According to “Material Handling Equipment” by Rudenko & Myshkin, the choice of conveyor type is based on:

- Weight and dimensions of the handled part
- Chosen transportation speed
- Environmental properties (dust, humidity)
- Integration requirements with other equipment. *(Myshkin, 2018)*

In modern systems, conveyors can successfully synchronize with industrial robots, and are equipped with encoders, sensors and emergency stop components in accordance with ISO 14120 and ISO 13849 standards for the safety of the industrial equipment and operators. *(SICK, 2014)*

3.5. Pneumatic grippers

Pneumatic grippers are devices used to manipulate objects in automated industrial processes. The grippers are operated on compressed air and are used in systems where fast, repeatable component handling is required.

According to "Pneumatic Handbook" *(Barber, 1997)*, a pneumatic gripper is an assembly consisting of:

- Fixed body
- Flexible elements such as gripper fingers
- Pressure chamber
- Seals and guides
- Optional feedback devices.

There are several types of pneumatic grippers:

- Parallel: the fingers of the gripper move linearly and simultaneously inward or outward
- Angular: fingers rotate around a point
- Adaptive: for components that require complex geometries

Special grippers for special cases can also be present, such as pneumatic suction cup grippers, which are designed to generate controlled vacuum to adhere to the component surface. These grippers re useful for handling components with flat surfaces such as a solid panel of wood.

According to "Vacuum Technology: Practice for Scientific Instruments", the essential components of a vacuum suction gripper system are the following *(Wutz, 2013)*:

- Suction cup made from rubber, silicone or polyurethane
- Vacuum generator from either ejector or pump
- Switching valves
- Dust protection filters
- Feedback vacuum sensors.

The suction cups can be flat, for smooth surfaces and concave, for slight curves.

The advantages of a suction cup system include gentle contact and no mechanical harsh interaction, adaptability to numerous surfaces, multiple gripping, easy integration into modular robot end effector. However, the quality of a suction cup gripper system depends on multiple factors including, the effectiveness of the seal between the suction cup and the component handled, the ability to maintain the vacuum created and the resistance to moisture and dust.

Modern solution includes vacuum systems from manufacturers such as Schunk, SMC or Festo. These systems offer adaptability to intelligent modules, monitoring sensors, feedback and self-refining features.

In conclusion, pneumatic grippers, especially the suction cup grippers, are essential in panel handling automated systems. They are efficient because of their adaptability, vacuum force and fast integration with automated systems controlled with PLCs.

3.6. HMI Interface (Human-Machine Interface)

The Human-Machine Interface (HMI) is a visual and functional component that facilitates the interaction between the human operators and the automated system. HMI enables monitoring, controlling, diagnosing and modification of operating parameters of industrial equipment used in an automated system.

According to the paper "Human-Machine Interface Design for Process Control Applications", an effective HMI must fulfil the following requirements *(Fiset, 2009)*:

- Provide a clear and logical presentation of the technological processes
- Provide user friendly operator interaction
- Allow fast access to important information and alarms
- Adapt to various users, such as operators, engineers, technicians

Typical components of an HMI include:

- Touchscreen display
- Pages with diagrams and operating states
- Pages with setting menus that include recipe and parameters configuration
- Pages that display error messages and event logs
- Safety functions such as login, access hierarchy, emergency stop

According to Siemens "HMI Design Guide", best practices in designing an HMI interface include:

- Usage of standardized colour for various states (green = active, red = error)
- Avoid visual clutter by using theme screens
- Implement visual and auditory feedback in case an error occurs
- Quick access: dedicated buttons leading to basic function

In modern industrial systems, HMIs are deployed on local operator panels such as Siemens KTP, Weintek, industrial terminals with Windows/Linux and SCADA platforms.

The HMI is directly connected to the PLC through industrial communications protocols such as ProfiNet, EtherNet/IP. This connection allows the operator to initiate the start and stop commands, modify parameters, select or modify certain recipes and visualize the operation of each subsystem in real time.

3.7. Sensors and detection elements

Sensors are elementary components in the architecture of an automated system, ensuring access to essential information about the status, position of components and the presence of materials and objects.

Sensor transmit data to the PLCs, robots or other control components, allowing real-time decision making.

According to "Sensors and Actuators in Mechatronics: Design and Applications", industrial sensors are essential for (Pawlak, 2007):

- Precise monitoring of the position and movement of objects
- Detecting the presence or absence of objects and materials
- Measuring physical quantities, such as temperature, pressure or distance
- Ensuring safe operation.

Common types of sensors used in automated systems include inductive sensors, optical sensors, pressure and vacuum sensors, capacitive proximity sensors, ultrasonic sensors, encoders.

The inductive sensors can detect metal objects with no direct contact. They are ideal for positioning on conveyors.

The optical sensors can detect the presence of objects by detection interruptions in a light beam. It can be configured as reflective, through-beam or fibre optic types.

The pressure and vacuum sensors are used to monitor the state of pneumatic grippers or vacuum cup systems.

The capacitive proximity sensors can detect non-metallic objects, such as wood, plastic or liquids.

The ultrasonic sensors can measure the distance to a component using the sound waves. They are useful for detecting very large or unusual objects.

The encoders can provide position and speed parameters for various motors or conveyors.

In modern applications, sensors can be integrated into industrial networks (IO-Link, AS-Interface) and can offer additional data such as internal status, operating temperature.

Integration of sensors into an automated system can result in a safe, efficient and adaptable operation of the entire production line. This also allows precise control and quick responsiveness to changes in the operating environment.

4. Technical Analysis of Handled Parts

4.1. Characteristics of solid wood panels

Recent studies in the literature confirm that the density and mechanical properties of hard wood vary based on their type, moisture and fibre content. According to the research paper "Mechanical Properties of Oak and Beech Wood in Relation to Moisture Content", moisture variations can lead to significant fluctuations in density and stiffness. This can moreover result in affecting the automation of the handled parts. These features impose strict requirements while automating the process of handling wood. The applied forces on the components may vary, grip points can be altered. Furthermore, stability can be impacted while the robot is applying certain operations on the parts. (Kasal et al., 2016)

4.2. Problems encountered with raw panels

According to a technical analysis presented in the paper "Wood Handbook: Wood as an Engineering Material", deformations encountered in raw panels are related directly to the gluing technology. They result from uneven adhesive distribution and internal strains in the wood that develop during the drying process. These imperfections affect both further processing of the wood and the performance of robotic operations. The automation would be forced to accommodate wider tolerances, which would impact the design of the centering and positioning operations. (Laboratory, 2010)

Due to the gluing process and the natural variations of wood, raw panels may present the following:

- Deformations occurring during pressing or drying
- Thickness variations through the panel
- Adhesive residues on the surface of the panel

These imperfections demand an accurate calibration to ensure a uniform, smooth panel surface, allowing processing on 3 and 5 axis CNC machines.

4.3. Requirements for automated handling

According to a study by the Centre for Advanced Wood Processing, automated handling of the wood components requires the integration of gripping systems that can adjust to frequent size changes and correct various deformations. The research suggests using active or passive systems in grippers and force sensors to handle parts accurately and protect finished surfaces. (Columbia, 2020)

Wood panels present multiple challenges for automated handling. The panels are heavy, which demands strong actuators and robust mechanical structures. The surface of the panel is difficult to handle and sensitive, therefore it requires the use of gentle gripper systems. An example of this type of system is suction cups, leaving the surface mark free. The wood comes in many dimensions, so the system must be adjustable and adaptable. Moreover, the precise positioning is essential for further calibration in the sanding machine.

Additionally, if the system is properly positioned, the wood's rigidity and strength allow it to be handled at a single gripping point. However, for longer and larger wood pieces, it is recommended to use multiple gripping point simultaneously during moving operations.

4.4. Technical requirements for the automation system

The literature emphasizes that automated systems must adapt to the properties of the handled object. In the study “Design of Automated Handling Systems for Irregular Wooden Parts”, it is shown that any robotic project must begin from a clear analysis of the shape, size, structure and geometry of the certain object. Therefore, equipment is chosen according to several factors: mechanical variations, motion and software control. (Processing, 2019)

To properly handle the wood panels, the automated solution must take into consideration several aspects. The grippers must support heavy weights and must ensure safety and adaptability to different lengths. The robots must have the right accuracy and right reach. The centering system is essential for the pieces alignment to the calibration machine. The positioning system requires mechanical adjustment for each recipe. The HMI needs to be flexible enough to allow quick adjustments, as each type of wood panel requires its own specific settings.

In conclusion, the design of the automated system must start from a clear understanding of the objects used: how they need to be positioned, transported and processed. The next chapter will present a complete architecture and main system components.

Part II: Personal contributions

5. Proposed solution and general architecture

As the demand for standardization in the production of solid wood increases, the automation of the traditional processes has become a priority for many companies in the industry. The present work proposes a complete automation solution for the process of calibrating and sanding the wood panels in a Romanian factory specialized in the production of hard wood stairs. The solution addresses an industrial need by optimizing a process that is time-consuming and physically demanding for workers. It is based on professional experience gained in the integration of industrial robots in numerous environments, as well as on the knowledge and skills acquired during the master's degree in industrial robotics.

The proposed solution is based on the integration of two Fanuc robots, a PLC controlled conveyor system, a centering and turning system of the panels, and a user-friendly HMI interface for recipe selection and process monitoring. The overall solution is controlled through an automation system designed to provide reliability, safety and long-term efficiency.

5.1. Description of the proposed workflow with diagrams and scenarios

The proposed automation solution aims to replace a traditional process that previously involved three operators. The solution presents an automated robotic cell, which performs the feeding and unloading of a calibrating and sanding machine, with automating panel turning and palletizing. The cell structure is presented below.

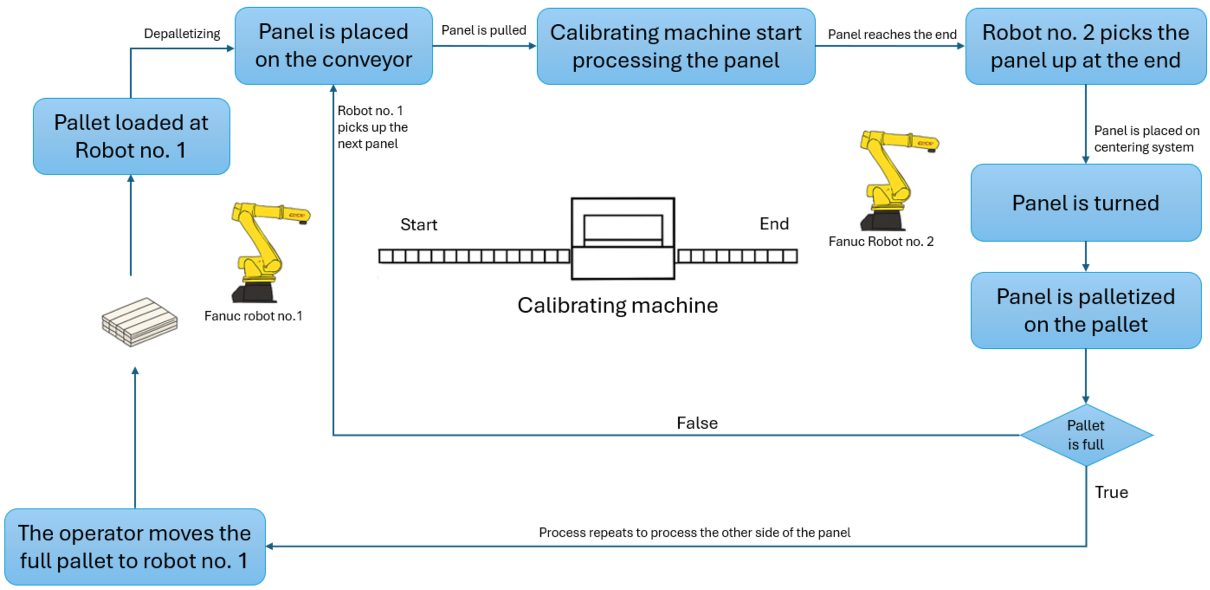


Figure 5.1. Diagram of the workflow

The loading of the raw panels is done manually by the worker. The operator places an entire pallet into the cell using a pallet truck. The access area is delimited by Sick safety light curtain, namely model C40E. Entering the cell automatically disarms the safety system (Euchner relay), stopping all robotic movements and motorizations in automatic mode.

The depalletizing of the panels is performed with the Fanuc 410iC/185 robot, a robot specialized for palletizing operations. It is positioned to the south of the infeed conveyor. It picks up the panel from the pallet, using a pneumatic gripper, and then place them on the infeed conveyor.

The input conveyor is made of joint belt-driven rollers, powered by a 1.1 kW three - phase motor with gearbox (torque 100Nm, output speed 30 rpm). This gear is controlled by a Mitsubishi E800 frequency converter and the ON/OFF commands come directly from the PLC, based on the panel's presence within the detection area of the SICK optical sensor positioned diagonally above the rollers. This sensor checks if the part has been placed and prevents accidental placements of two overlapping panels.

Once the panel reaches the calibrating and sanding machine, it is automatically pulled by the machine, and during processing, the infeed conveyor is stopped. After the first side of the panel is finished sanding, the panel is automatically discharged to the outfeed conveyor. The outfeed conveyor is made of low friction rollers, to prevent mechanical blockages caused by the machine speed.

At the end of the output conveyor stands the Fanuc R-2000iC/125L, a 6-axis extended-reach robot that picks up the panel using a vacuum gripper and then positions it on a specific designed centering system. The system allows the panel to be precisely positioned to be turned to the other side.

After the panel is turned, the robot palletizes it onto an empty pallet, positioned by the operator in the unloading area. At this step, the robot follows a stacking logic defined by the panels size and the maximum height allowed by the pallet.

When a pallet is full, the operator pulls it out with a pallet truck and returns it to the infeed area. Therefore, the flow resumes, and the sanding starts again for the second side. The whole process repeats to obtain perfectly calibrated and sanded on both sides.

5.1.1. Control and synchronization logic

The system is asynchronous; it does not require the synchronization of the robots. Each of the robots operates with the help of the SICK sensors mounted on the ends of the conveyors. The input conveyor activates when the panel is gone and is stopped after the panel is placed, while the output conveyor is passive and only allows the panel to slide. The PLC controls all the “entry permissions” and “pick ready” conditions based on the occurrence of the panel and the position of the equipment involved in the operation.

5.1.2. Flexibility and ergonomics

The HMI interface allows the selection of recipes according to the panel type; therefore, the system is configured to accept certain sizes. This operation is done in the settings menu and is done by the operator before the automated system starts. Operator ergonomics are improved, as the physical effort of handling hard wood panels is no longer present. The operator becomes a cell supervisor, intervening only when the pallets are full or when selecting certain recipes.

5.1.3. Industrial safety

The access to the cell is controlled by optical barriers and fail-safe "mushroom-type" emergency stop switches. The switches cut power off to the robots and motors, regardless of the system, automatic or manual. There is a "teach" mode present in the system, which can be accessed through the control panel, with additional validation through the key switch and local authorization.

5.2. Robots: specifications, models and functionalities

The integration of industrial robots, specifically in a process for handling heavy parts, such as raw wood panels, requires a careful selection of models according to payload, reach, accuracy and flexibility. The paper uses the two following models: the M-410iC/185 and the R-2000iC/125L. These models are recognized as being reliable, performant and easy to integrate.

Both robots were simulated in a virtual environment, RoboGuide, where their compatibility with the functional requirements of the proposed solutions were met. This was done to ensure that any possible future physical implementation would be flawless.

5.2.1. Robot number 1: Fanuc M-410iC/185

The Fanuc M-410iC/185 is a 4-axis palletizing robot, designed for fast tasks, with a solid design and extended reach. It is ideal for applications that require fast cycles of picking up and placing objects, without the need of complex part orientations.

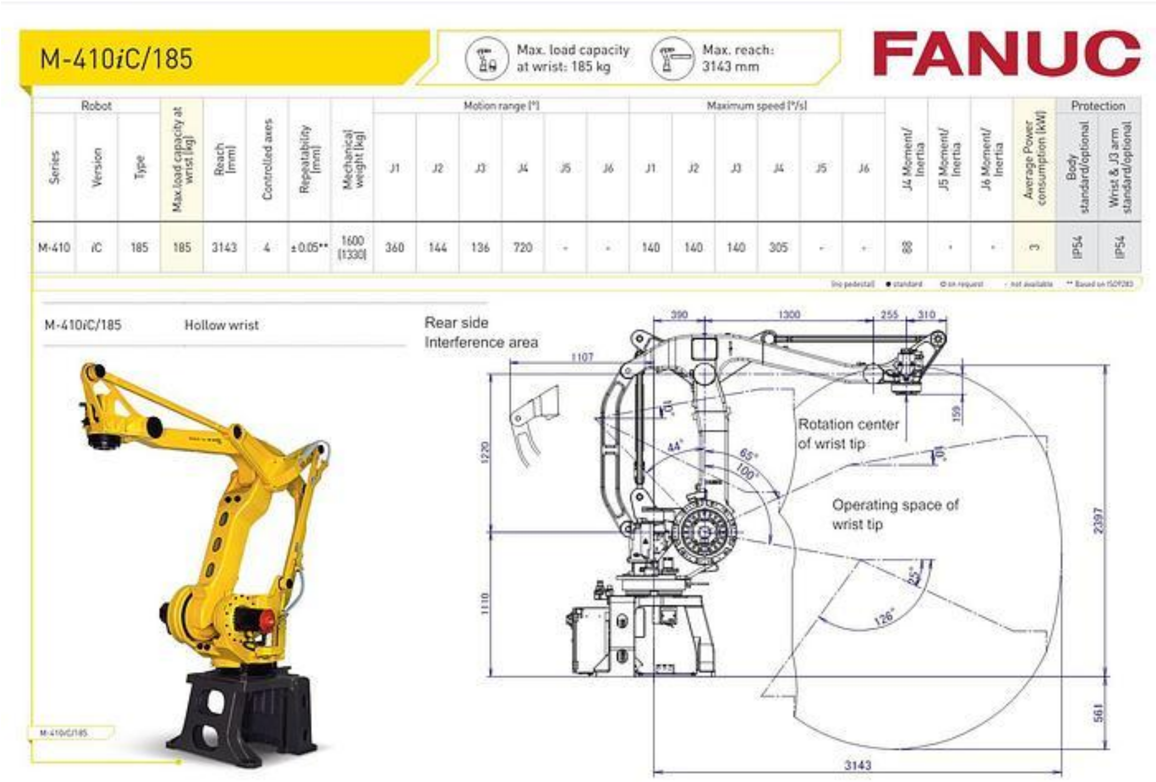


Figure 5.2. Specifications of Fanuc M-410iC/185

Technical specifications include the following:

- Number of axes: 4
- Maximum payload: 185 kg
- Reach: 3143 mm
- Maximum lifting height: 2890 mm
- Positioning accuracy: ± 0.5 mm
- Mounting: floor
- Weight: ~ 1550 kg
- Compatibility with environments: IP67 on axis 1, IP65 res

For the operations required in this automated system, such as depalletizing of oak and beech panels, with common dimensions of 45x420x1220 mm, it was important to select a robot with a high payload and long reach. The robot must be able to cover the pallet area and the infeed conveyor. The M-410iC/185 Fanuc robot has clear advantages for this specific operation due to its compact vertical design, allowing its installation in tight and small places. It has fast cycle times with under 2 second on short paths, ideal for the system. It has strong mechanics, being designed to endure hard industrial environments and function 24/7. Compared to other alternatives such as ABB IRB 660 or KUKA KR 180 PA, the chosen model offers the right balance between its properties, speed, reach, software support with RoboGuide and integration with other Fanuc tools, such as HandlingTool.

5.2.2. Robot number 2: Fanuc R-2000iC/125L

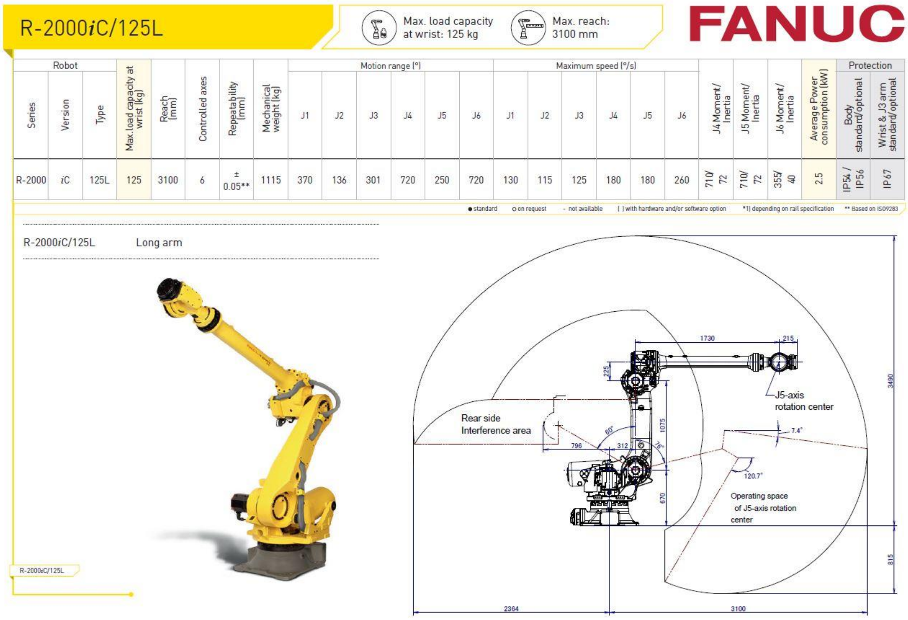
The second robot used in the automated system is the Fanuc R-2000iC/125. It is an adaptable, long-reach, accurate, 6-axis robot. It was chosen to handle the picking, turning and palletization of the parts due to its excellent properties of manoeuvring.

Technical specifications include the following:

- Number of axes: 6
- Maximum payload: 125 kg
- Reach: 3095 mm
- Positioning accuracy: ± 0.2 mm
- Mounting: floor
- Weight: ~ 1550 kg
- Compatibility with environments: IP67 on wrist 4-6, IP54 on anything else

This Fanuc robot has the most complex role in the project. It must pick up the panel as it exits the calibrating machine, position it on a centering system, turn it around to sand the other side of the panel and then palletizing it.

This Fanuc robot was chosen because of its large radius required to cover the conveyor exit, the centering system and the palletizing area. It has the flexibility of the 6 axes, which allow complex manipulations without repositioning. It has high accuracy required to perform exact alignment during panel placement and turning. Lastly, compared to other Fanuc robots like M-900iB or R-1000iA, the R-2000iC/125L was preferred due to it being one of the most stable Fanuc models, optimizing the cost per performance.



R-2000*i*C/125L

Max. load capacity at wrist: 125 kg

Max. reach: 3100 mm

FANUC

Robot								Motion range [°]						Maximum speed [°/s]										Protection	
Series	Version	Type	Max. load capacity at wrist [kg]	Reach [mm]	Controlled axes	Repeatability [mm]	Mechanical weight [kg]	J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6	J4 Moment/ Inertia	J5 Moment/ Inertia	J6 Moment/ Inertia	Average Power consumption [kW]	Body standard/optional	Wrist & J3 arm standard/optional
R-2000	iC	125L	125	3100	6	± 0.05**	1115	370	136	301	720	250	720	130	115	125	180	180	260	710/ 72	710/ 72	355/ 40	2.5	IP54 / IP56	IP67

● standard ○ on request - not available ( ) with hardware and/or software option *1) depending on rail specification ** Based on ISO9283

Figure 5.3. Specifications of Fanuc R-2000iC/125L

5.3. RoboGuide simulation

The entire automated system was simulated in Fanuc RoboGuide environment, where all the operation were analysed:

- Complete coverage of the working areas by all robots
- Analysis cycle times for a single panel, including turning it
- Detect collisions and validate the trajectories
- Integration with HMI and PLC logic
- Space ergonomics and analysing the distance between components and safety zones

This simulation part was essential to confirm the possibility of implementing a cell in a real environment. It also facilitated the optimization of the robot positioning and avoiding future placement problems.

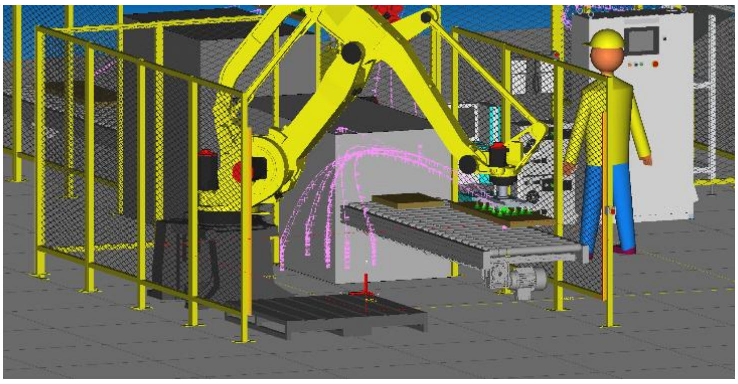


Figure 5.4. Trajectories for first robot Fanuc M-410iC/185

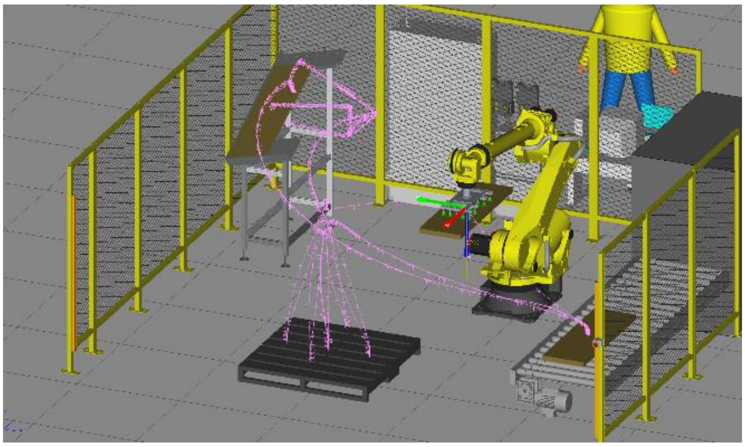


Figure 5.5. Trajectories of second robot Fanuc R-2000iC/125L

5.3.1. Robot integration and programming

The programming of the robots was done in Teach Pendant (TP), using the Fanuc HandlingTool interface. The program is modular, with subroutines for each operation.

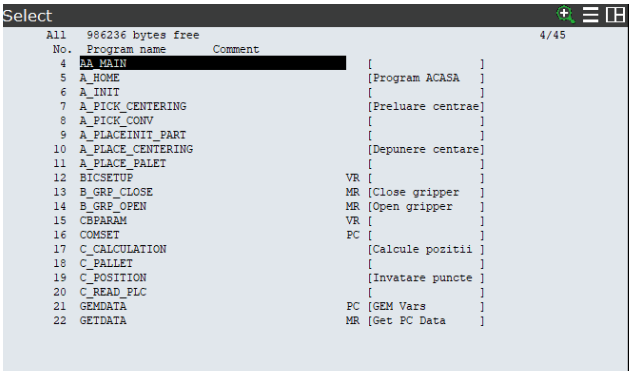


Figure 5.6. First set of subroutines

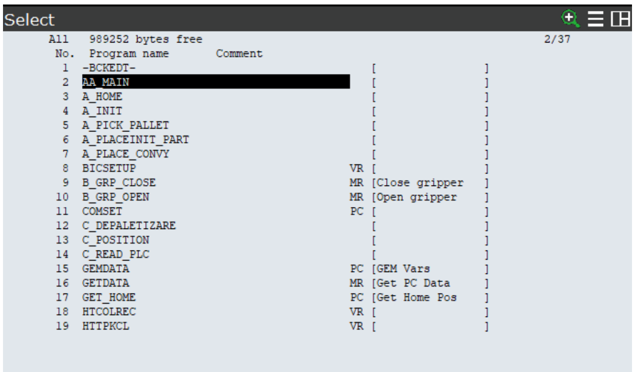


Figure 5.7. Second set of subroutines

Robot movement is controlled by jogging in both the User and Tool frames, with positions saved based on the layout of the work cell. Each robot uses its own uframe, making it easier to move and orient the robot correctly in space. The setup was also tested in RoboGuide, where cycle times, positions, and safety areas were simulated and checked.

5.4 HMI - proposed interface

In any modern automated system, the Human-Machine Interface (HMI) is the main interlocutor between operator and cell. Its purpose is to provide control over automatic and manual modes. It also facilitates recipes updates, system status monitoring and quick faulty diagnostics.

For this automated system, the HMI interface was done in TIA Portal v19 environment and implemented on a Siemens KTP900 Basic terminal. The terminal has a 9-inch touch panel, compatible with the Siemens S7-1200 range of PLCs. It is strong and suitable for mid to high level industrial applications.

Figure 5.8. Siemens KTP900 Basic

The interface is structured with dedicated pages for each essential function, as follows:

1. Main page

The main page gives an overview of the current system status:

- START and STOP buttons for starting or ending a cycle in Automatic mode
- Switch button for automatic or manual mode selection
- Initialization button for starting initialization before Automatic mode is selected
- Activ Recipe displays the corresponding recipe uploaded in the PLC
- Reset errors button is responsible for resetting all alarms present in the system. All errors must be deleted after they are resolved.

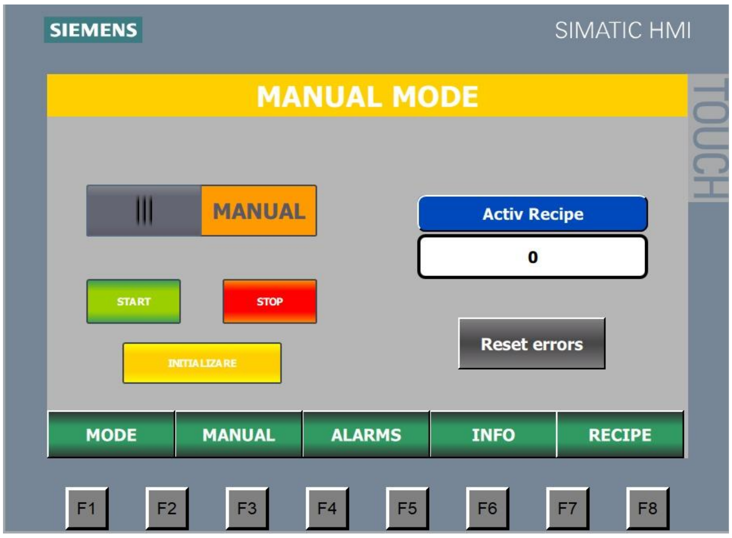


Figure 5.9. Main page of the HMI

2. Manual page

This page can only be activated from the "Manual" button and allows individual control of the infeed and outfeed conveyors. It is also useful for troubleshooting, testing and maintenance.

The buttons present enable the following operations:

- Drop down list enables the selection of the desired conveyor, infeed or outfeed
- START and STOP buttons start or stop the selected conveyor
- The input "Target velocity (rpm)" allows the operator to choose a desired velocity for the conveyors. The initial speed is programmed in the PLC, but for testing purposes, the HMI allows it to be tailored to specific needs.

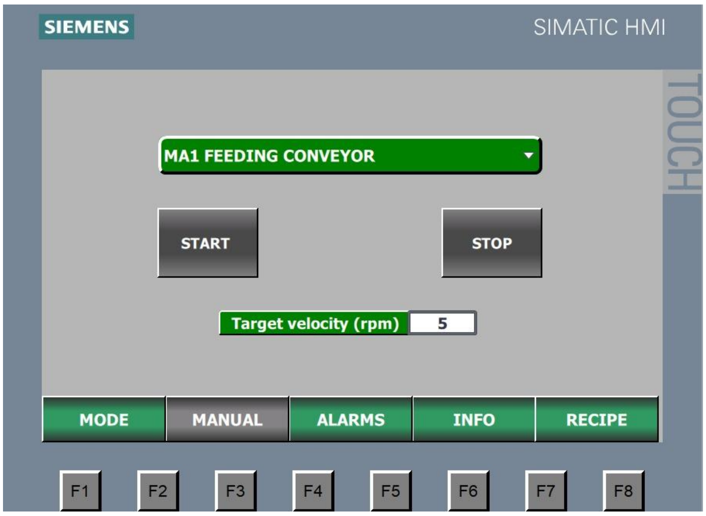


Figure 5.10. Manual page

3. Alarms page

The alarms page displays real-time active alarms and recent alarm history. Alarms are categorized by severity (informational, warning, critical) and can include:

- missing part in any of the robots
- missing vacuum confirmation
- calibration cycle overtime
- PLC errors
- full stack of panels.

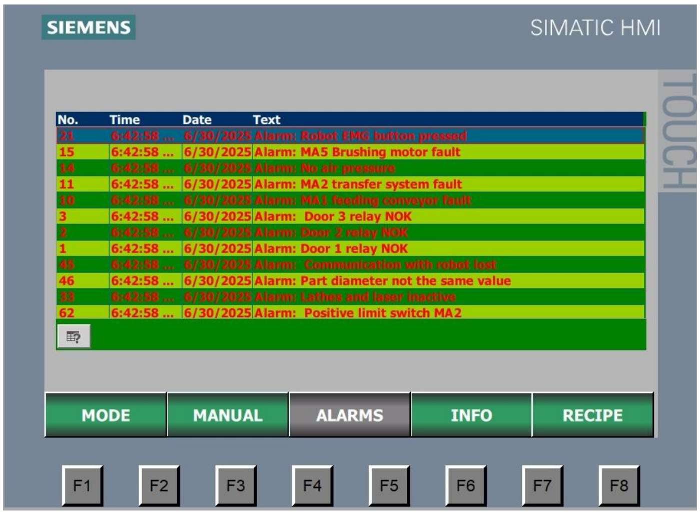


Figure 5.11. Alarms page

The messages are available in Romanian and English and are accessible through a switch on the interface.

4. Information page

The information page displays graphs and states of the system. Real time parameters are present, and graph steps can be monitored.

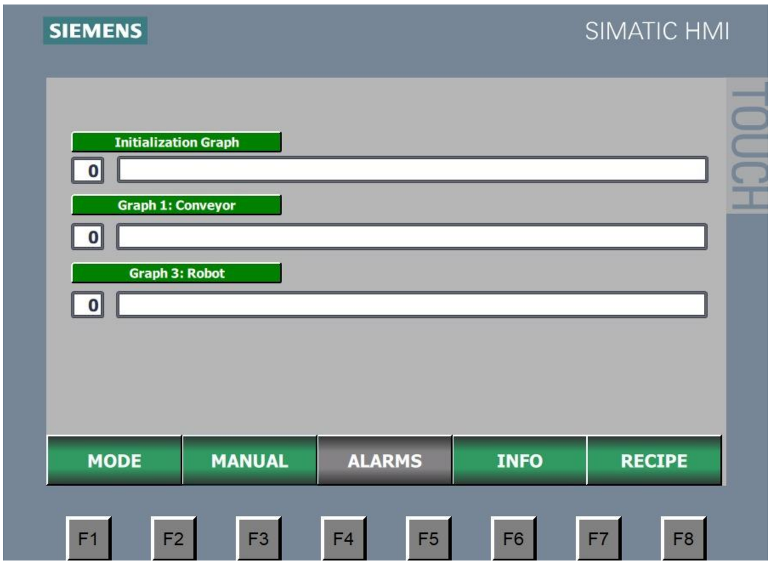


Figure 5.12. Information page

5. Recipe page

Operator manually enters parameters for each wood panel type:

- Length, width, thickness, weight
- Number of pieces
- Palletization index, which represents a binary value (0 or 1) indicating how the last row on the pallet is completed (left to right or top to bottom).

The recipes entered can be saved in the HMI system. They are assigned a unique code so they can be selected from a predefined list, therefore optimizing working times.

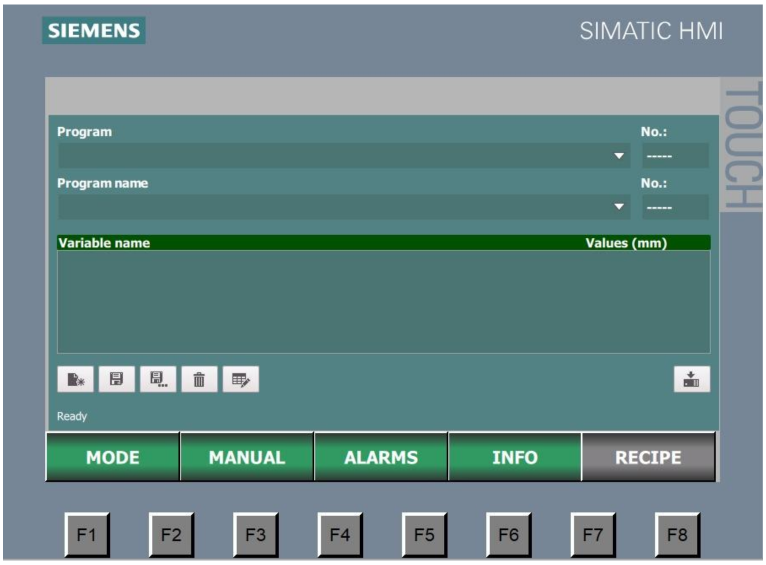


Figure 5.11. Recipe page

All screens are designed for fast and user-friendly navigation, with large, correct labelled buttons and color-coded status (green for active, red for fault, grey for inactive). Vulnerable areas are protected with passwords or access levels according to the organization's hierarchy. These areas include editing the recipes, resetting the alarms and manual entries.

6. CAD Design and cell layout

6.1. Cell layout

The physical and functional validation of the proposed solution was done through the 3D modelling of the automated cell. The cell layout was performed using CATIA V5 and STEP libraries. The CATIA software was responsible for modelling the custom components such as grippers, centering system and support system. The STEP libraries are used for the two Fanuc robots and the VIET S3 331TM calibration and sanding machine.

The model required integration of the infeed conveyor, the calibrating and sanding machine, the outfeed conveyor, the centering system and the two palletizing stations, the one at the start and the one at the end of the process. In addition to the equipment listed, other non-functional components are present, such as protective fences, light barriers, operator access spaces and intervention buffer zones The entire cell layout was built to be modular. It easily adaptable to numerous and specific industrial requirements.

The cell layout has an east to west process orientation. It has a structured flow of the wood panel from infeed to outfeed, to allow efficient integration and of the robots. This approach prevents robots from crossing paths and avoids mechanical collisions.

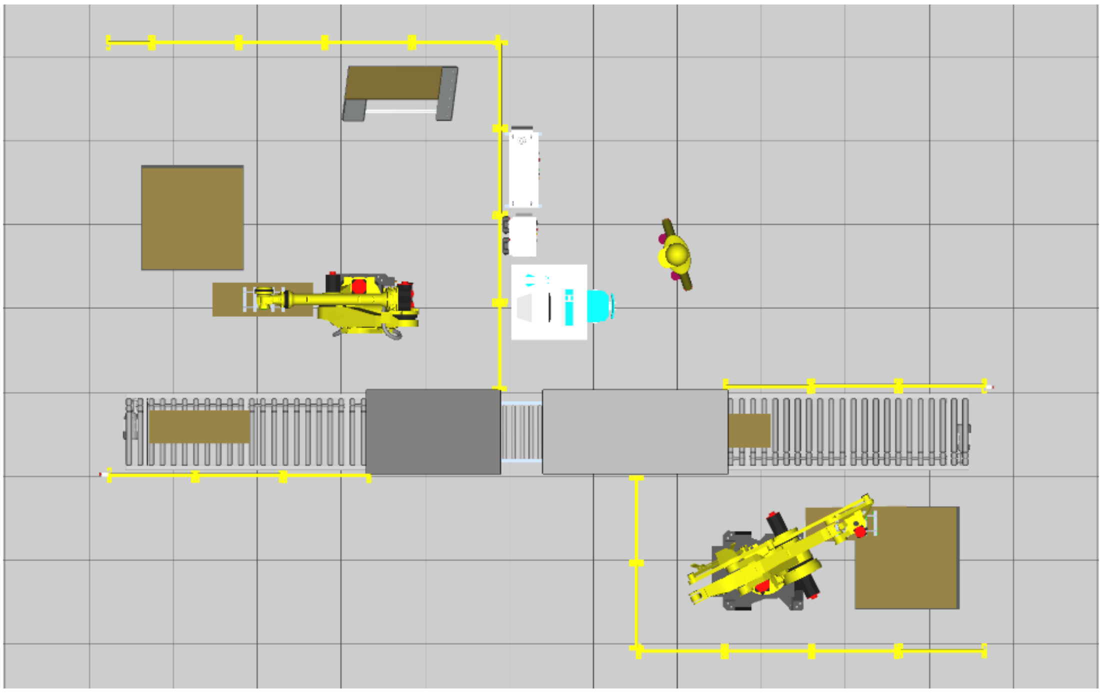


Figure 6.1. Cell layout

6.2. Equipment positioning in the 3D simulation

The positioning of the equipment in the 3D cell layout was done according to the logic of the process and the need for safety, maintenance and ergonomics. The calibration machine was placed in the center as the core of all the equipment. The other components were evenly distributed around the machine, according to their east to west process orientation.

The Fanuc M-410iC/185 robot was placed on the side of the loading area. This positioning facilitates easy access to the pallet and the infeed conveyor. Moreover, because to its large radius and compact design, the Fanuc robot can handle parts without the risk of collisions with other equipment in the cell.

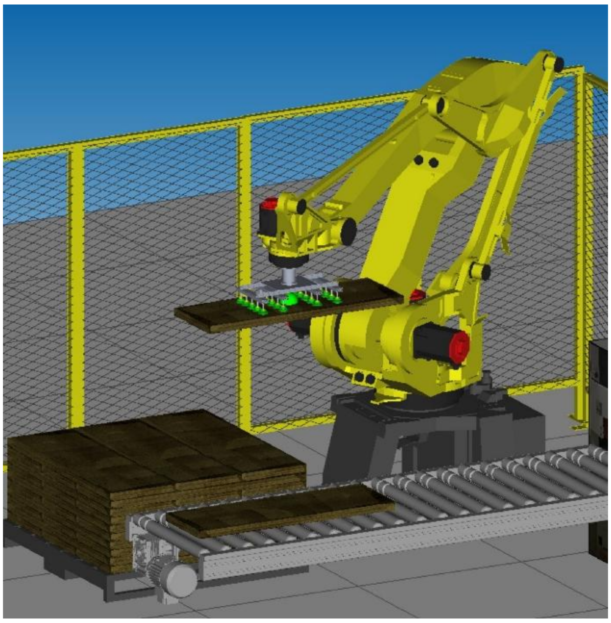


Figure 6.2. Fanuc M-410iC/185

At the end of the process, on the west side of the cell, is the Fanuc R-2000iC/125L robot. It was positioned to cover three critical operations: panel pick-up from the conveyor, placement of the panel on the centering system and lastly, palletizing the panels. The robot features a long reach and six-axis flexibility, and it is set up with multiple distinct uframes corresponding to key zones: the centering station, the exit conveyor, and the final pallet area.

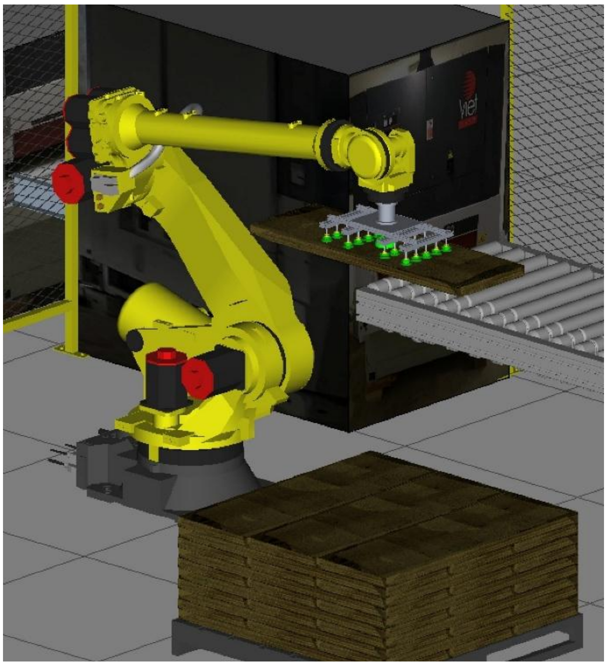


Figure 6.3. Fanuc R-2000iC/125L

The positioning of the conveyors, fences and HMI panel has been optimized for quick operator intervention and pallet truck access with maximum visibility and safety.

This robot is responsible for turning the wood panel; therefore the centering system is placed next to it for easy reach.

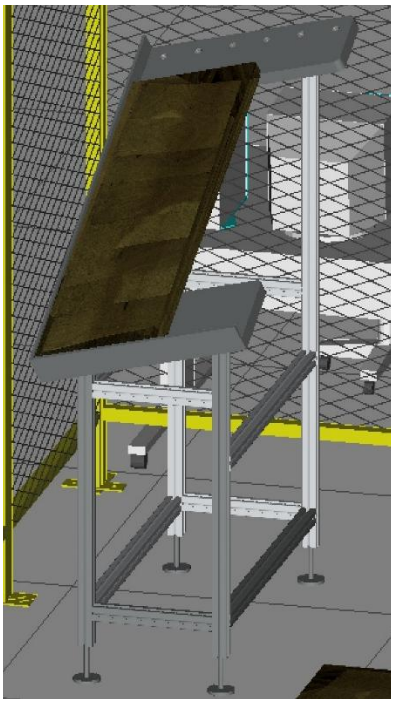


Figure 6.4. Centering system in the 3D simulation

Lastly, next to the VIET calibrating and sanding machine, stands the electrical panel of the VIET machine, the controllers R30-iA Mate of the robots, the integrated electrical panel of the automated cell, and the operators desk zone.

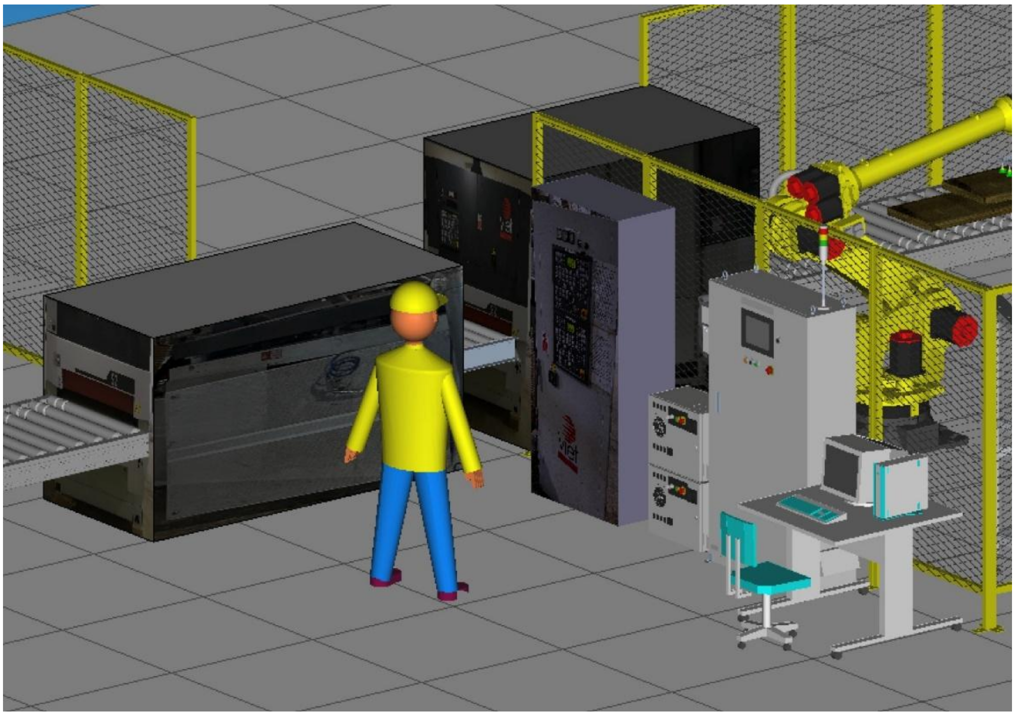


Figure 6.5. Operating zone

6.3. Grippers

Each robot is equipped with its own gripper system, with vacuum suction cups sized accordingly to properly handle the panels dimensions, taking into consideration that pieces can weight over 30kg per piece and have a length of 1200 mm. The design was realized in CAD and includes:

- Bosch profiles with lightweight aluminium structure
- 20 large suction cups with a diameter of 30 mm
- Adjustable supports
- Quick coupling
- Electrical vacuum system Festo OVEM or similar
- ON/OFF control
- 3/2 valves controlled from PLC and input/outputs from the robot
- Feedback from pressure sensors for clamping confirmation (Vacuum_OK)
- Control via digital outputs and integration into the program

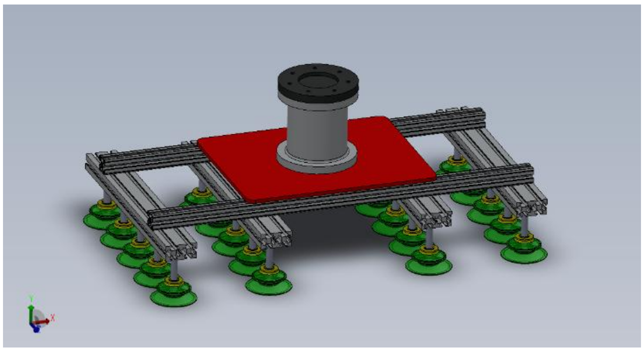


Figure 6.6. CAD Design of the pneumatic vacuum grippers system

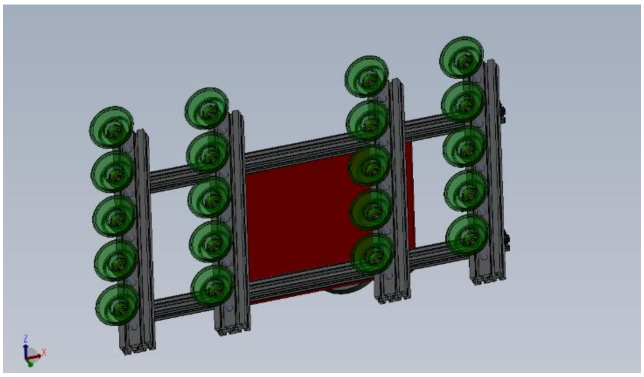


Figure 6.7. Close-up of the suction cups

The modular configuration of the gripper allows adaptability to different panel sizes. This can be done through mechanical repositioning of the suction cups. For future improvements, the gripper system can be equipped with optical feedback or force sensors for adaptive gripping.

This integrated system of robot selection, gripper design, logic programming and simulation, creates a scalable system ready to be implemented in a real industrial environment.

The integration of pneumatic grippers in a robotic cell requires a careful mechanical, control and interfacing approach. The grippers used in this system have been customized to provide a secure, reliable grip on raw wood panels without damaging its surface.

Each gripper is composed of an aluminium support body with 4 industrial suction cups with a diameter of 125 mm, connected by vacuum hoses to a vacuum generation system. For the gripper to allow different panel sizes, the suction cups are distributed on a "U" shaped frame with adaptable distances, for example 420x1220 mm, 400x1000 mm, etc.

The pneumatic solution consists of 3 position solenoid valves, electronically controlled by the PLC, an electric vacuum ejector (Festo OVEM), vacuum circuit connected to the vacuum cups through spiral hoses and a blow-off port for safe part separation at the end of the operation.

The three solenoid valve positions have the following controls:

- Position 1: opens vacuum circuit - suction cups pull the panel
- Position 2 (centre): all channels closed - pressure is kept
- Position 3: directs compressed air to the suction cups - blow-off for detachment + hose cleaning.

This logic guarantees a secure grip and elimination of any remains of wood or wood dust that could affect the long-term performance of the system.

The gripper is controlled through the robot system using standard digital outputs, which connect to the PLC that operates the solenoid valve.

The signals are managed by the robot controller but are also monitored by the PLC for safety feedback. The solenoid valve is powered by a 6-bar compressed air supply, having its own filter and regulator mounted in the pneumatic panel of the cell.

Advantages of the proposed gripper system:

- Reliability: simple system without no unnecessary moving parts
- Adaptability: compatible with multiple panels dimensions
- Safety: active feedback for operations in the system
- Low maintenance: blow-off function avoids circuit debris
- Lower cost: compared to servo-electric gripping systems.

6.3.1 Evaluation of payload dynamics and moment of inertia

The gripper selection went beyond simply ensuring reliable panel handling. It involved a detailed analysis of payload capacity, inertia forces, vacuum force distribution, dynamic stability, and mechanical integration with the robot. The two robots deployed in the cell are FANUC M-410iC/185 and FANUC R-2000iC/125L, each equipped with identical, modular grippers constructed from Bosch aluminium profiles. These grippers feature an oversized mounting flange, offering both structural rigidity and a high degree of adaptability to various fixture dimensions. The physical dimensions of the gripper were determined by analysing the most common types of panels handled. The overall length of the gripper is 500 mm, the width is 300 mm, and the height (from the flange of the robot to the surface of the suction cups) is approximately 280 mm. On this structure are mounted 20 suction cups distributed in four rows of five, allowing a balanced distribution of gripping forces and adaptability to panels with weights ranging from 15 to 30 kg.

One of the primary objectives of this analysis was to validate the total payload handled by each robot by calculating the combined mass of the gripper (estimated at 7.5 kg) and the panel in the analysis scenario (30 kg). The resulting total load of approximately 37.5 kg remains well within the permissible limits of both robots, 185 kg for the M-410iC/185 and 125 kg for the R-2000iC/125L ensuring a generous safety margin. Additionally, the analysis assessed whether the gripper's mounting position on the robot arm introduces moments of inertia that could negatively impact the system's dynamic stability or kinematic performance.

The moment of inertia of the gripper was calculated by modelling it as a rectangular plate, using the classical relation:

$$I = \frac{1}{12} \cdot m \cdot (l^2 + h^2)$$

where l and h are the lateral dimensions, and m is the mass of the components. Applying this formula to the gripper itself (without payload), results in a moment of inertia about the central axis of about 0.2 kg-m². This was added to the moment of inertia generated by the manipulated panel, considering a uniform mass distribution and a centre of gravity positioned at mid-length. The values obtained were compared with the moment limits admitted by each axis of the two robots, according to the datasheets provided by the manufacturer, confirming that the moments introduced in the system are manageable without loss of accuracy or safety.

The suction cups used are 30 mm in diameter, and the gripping force per suction cup was calculated assuming a depression of approximately -0.6 bar. The formula applied was

$$F = A \cdot \Delta P$$

where A is the suction cup area and ΔP is the pressure difference with the atmosphere. The result is an average force of about 42.4 N per suction cup, which leads to a total gripping force of about 848 N in the standard 20-suction cup configuration. This force is significantly higher than the maximum weight of the panel handled (approx. 294 N for a 30 kg panel), giving a safety factor of almost 3, which is suitable for dynamic operations in industrial environments.

Panel stability during handling depends not only on the total gripping force but also on how that force is distributed. To ensure the panel remains securely positioned during the accelerations and decelerations typical of robotic arm movement, simulations and calculations were carried out to compare the stabilizing moments generated by the outer suction cups with the destabilizing moments caused by the panel's centre of gravity. The results confirmed that the suction cup layout provides sufficient stabilizing torque across all analysed scenarios.

Finally, the kinematic analysis involved estimating the inertial forces generated within the system at acceleration values up to 3 m/s², which are typical for industrial applications. Under these conditions, a 30 kg panel generates an inertial force of 90 N, in addition to its own weight. As a result, the total force required to securely hold the panel with the gripper is approximately 384 N which is below 50% of the vacuum system's theoretical maximum holding capacity.

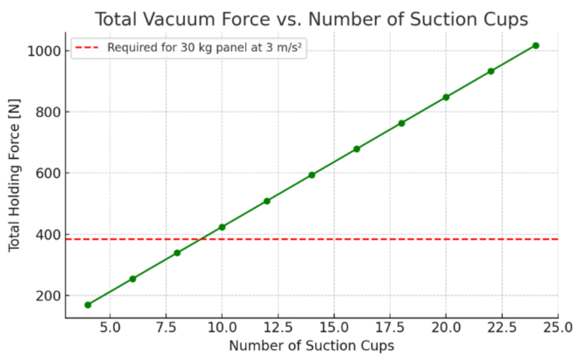


Figure 6.8 Vacuum force and no. of suction cups

The above graph illustrates the total vacuum holding force as a function of the number of suction cups. With a constant holding force of approximately 42.4 N per suction cup (based on a 30 mm diameter and a vacuum level of -0.6 bar), the total force increases linearly with the number of cups. A red dashed line indicates the minimum required force to hold a 30 kg panel under an acceleration of 3 m/s², approximately 384 N. As shown, a configuration with 20 suction cups delivers over 840 N of holding force, more than double the requirement, confirming the system's margin of safety.

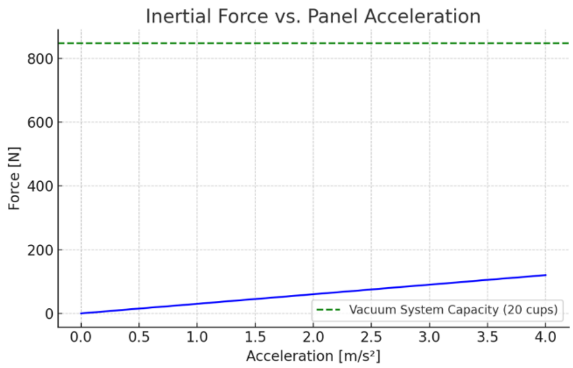


Figure 6.9 Inertial force and Part acc.

The figure 6.9 presents how the inertial force generated by the panel varies with acceleration. For a 30 kg wooden panel, the inertial force is determined using Newton's second law :

$$F = m \cdot a$$

The blue line indicates a linear increase in force, reaching up to 120 N at an acceleration of 4 m/s². In contrast, the green dashed line represents the gripper's maximum theoretical holding force. This comparison demonstrates that even under rapid acceleration, the vacuum system provides a substantial safety margin, ensuring dependable performance in high-speed operations.

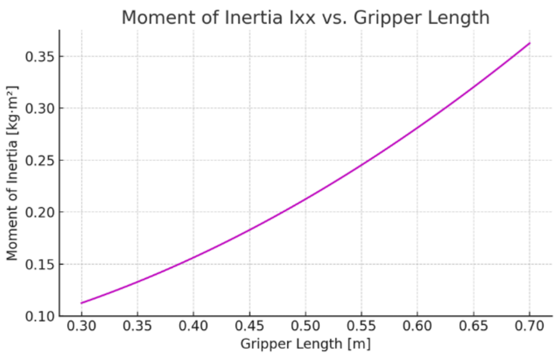


Figure 6.10 Moment of inertia vs gripper length

The 6.10 figure show the variation of the moment of inertia (Ixx) as a function of the gripper's length. Based on the standard formula for a rectangular plate, Ixx increases quadratically with length when the width (0.3 m) and mass (7.5 kg) remain constant. This analysis highlights the impact of dimensional changes on the mechanical load transmitted to the robot's joints. At a current length of 0.5 m, the gripper remains within a range of moderate inertial demand, achieving a balance between structural reach and dynamic performance. Beyond Ixx, the moments of inertia about the Y-axis (Iyy) and Z-axis (Izz) are essential for a full understanding of the gripper's rotational behaviour. These moments describe resistance to rotation about axes perpendicular to the X-axis. While Ixx often dominates in typical gripping motions, considering Iyy and Izz is important for ensuring stability and controlling vibrations in multi-directional movements. Together, these values provide a comprehensive inertial profile for optimizing gripper design and robotic arm dynamics.

In the figure 6.11, a stability parabola, showing the stabilizing moment generated by the outer suction cups as a function of the displacement of the panel's centre of gravity (CG) from the geometric centre. This model assumes symmetrical suction placement and calculates the restoring moment provided by one suction cup arm. When the CG is cantered, the stabilizing moment is maximized; as the CG shifts left or right, the moment decreases and eventually becomes destabilizing (negative), indicating a tipping risk. This analysis reinforces the importance of panel alignment and gripper symmetry to maintain safe handling under various load distributions.

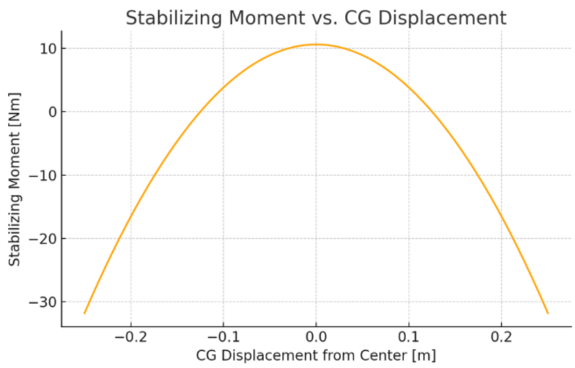


Figure 6.11 Stabilizing moment and centre of gravity

Together, these graphical analyses confirm that the gripper was not only appropriately designed for the target application but also offers ample mechanical resilience and functional flexibility. The results validate its use across a wide range of panel sizes and operating conditions, while also providing a foundation for further optimization or adaptation in future robotic implementations.

6.4. Panel centering system

To ensure correct panel handling between the two calibration phases, the solution integrates a mechanically ingenious passive system that uses gravity and tilted geometry to automatically position each panel to a fixed reference point. This system eliminates the need for additional drivers and optimizes handling times

The system consists of a double tilted plane on which robot 2 (Fanuc R-2000iC/125L) deposits the panel coming out of the calibration and sanding machine. This plane is made of a stiff metal frame. It is covered with non-stick material to allow smooth sliding of the solid wood panels. This material can be technical Teflon or high-density polyethylene.

The plane has two inclinations:

- 23.580° to the horizontal, in the transverse direction (X-axis), for horizontal guidance
- 17.43° to the horizontal, in the longitudinal direction (Y-axis), for guiding the workpiece to an automated stop.

This configuration makes the panel, once deposited, slide by the force of gravity into a fixed corner, determined by two solid stops. By using this method, each panel is cantered without pneumatic forces or sensors.

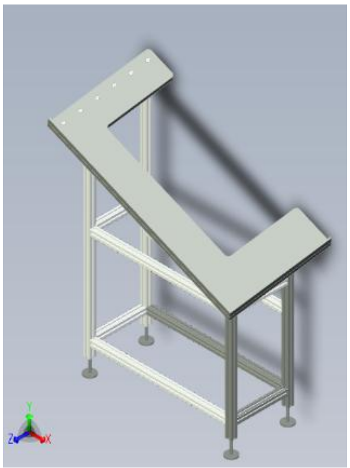


Figure 6.8. Visual representation of the centering system in CAD model

The systems functionalities include the following statements. The panel depositing is executed by the robot. It positions the panel above the plane and by releasing, it results in sliding. The centering is done by the planes tilted configuration, allowing it to slide to a fixed corner. The clamping is done naturally since the panel stops at the same point each time, tilted on the fixed corner. The pick-up is realized by the robot by grabbing the panel from the opposite side, so that the unprocessed side of the wood becomes face up and can be palletized. The system is 100% passive, relying on geometry and gravity. There are no pneumatic drives involved, no sensors or programmed operations other than those executed by the robot.

To allow the handling of several types of panels and wood pieces, with variations in length, width or thickness, the system is mechanically adjustable. The end stops can be moved according to the panel's dimensions. Tilt angles can be adjusted on their screws or exchangeable plates. The base is provided with portable mounting areas for adaptability to standards from 800 mm to 1300 mm. This flexibility makes the system ideal for a wide production line where pallets of panels may differ from day to day.

Advantages of the solution include zero active components with no maintenance; therefore, the reliability is increased. The automatic centering of the panels is done with no sensors, so it is simple and quick. The pick-up is efficient; robots can pick-up the perfectly aligned panel with no additional effort. The cost is low compared to other systems with powered guiding. There is no interface for electrical or pneumatic systems, therefore the mounting is simple.

6.5. Safety zones

Operator safety was a strict requirement in the cell layout configuration. All necessary precautions required by 10218 and ISO 13849 were respected in the CAD model and RoboGuide simulation. The cell is only accessible to authorized operators. Once the operator enters the cell, all movements and operations are stopped to prevent accidents. The working area of the robots are physically delimited by metal fencing.

There are E-STOP buttons present in the cell, visibly accessible and well positioned for easy reach. They are placed in each access corner. The distance between them, minimum of 500 mm, complying with emergency intervention regulations. Virtual collision zones have also been defined in the RoboGuide simulation to prevent overlaps in robot trajectories.

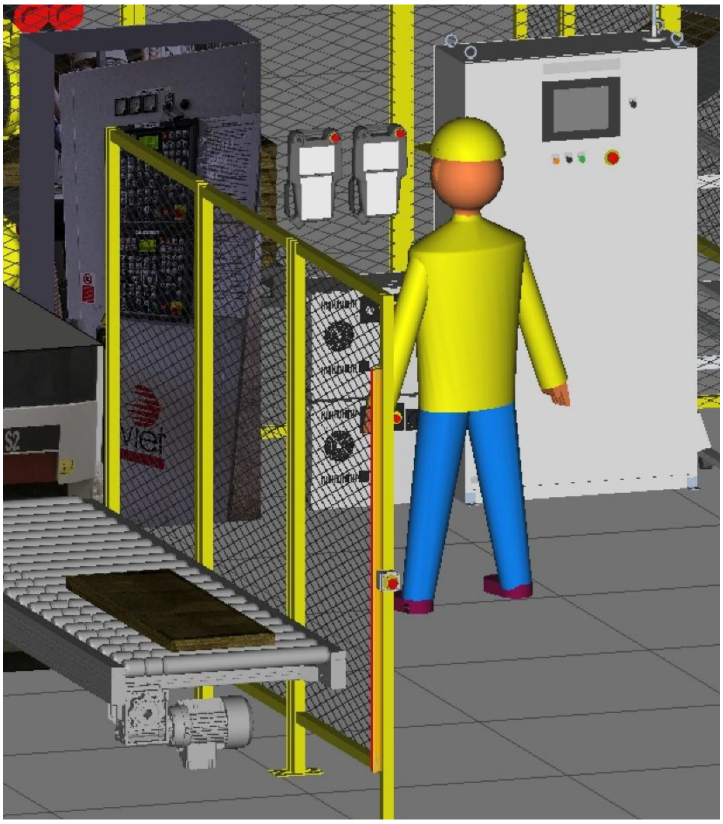


Figure 6.9. Safety zone representation

The figure 6.9. presents multiple safety points near the operator's station. The safety zones are near each robot on the end of the fence, represented by buttons, easily reachable in case an emergency occurs during pallet pick-up or drop-off. There are also emergency stop buttons on both robots teach pendants and controllers that immediately shut down the robots, a safety button on the VIET machine that stops only the machine, and another safety button located on the electrical panel. The optical barrier is present in plain sight of Figure 6.9., at the end of the fence.

7. Control and programming logic

The proposed solution is based on a well-structured control architecture, where the communication between the PLC, robots, sensors, actuators and other equipment is designed to ensure a safe and efficient process. This chapter describes the control architecture, the programming logic on the PLCs and robots, the code structure and the essential steps of the automated system.

7.1. Control architecture

The system is operated on a Siemens S7-1214 DC/DC/RLY programmable logic controller. This PLC is a strong model suitable for medium to large sized applications. It integrates both input and output digital modules and ProfiNet communication. Through the ProfiNet interaction, communication between all equipment is possible.

The network includes the following equipment:

- two ProfiNet splitters, one for each Fanuc robot
- two Mitsubishi E800 frequency converters, used to control the motorized infeed and outfeed conveyors
- two SMC EX260 solenoid valve islands, used to control the vacuum for grippers
- two Turck TBEN LL-4dxp allocators for the digital inputs and outputs

Connected to the digital inputs of the PLC are the following safety components:

- emergency stop buttons
- Euchner relays, used for monitoring the light curtains and interlock doors, signalling any unauthorized access to the cell
- the SICK sensors for panel presence on each of the conveyors

Connected to the digital outputs of the PLC are the following components:

- one light poles with three digital outputs
- Euchner safety relay for emergency buttons
- three light curtains.

Additionally, the optical sensors present on the conveyors detect the occurrence of the panel and notifies the PLC when then panel is correctly positioned for picking-up or placing on the infeed conveyor. This integrated architecture with dedicated inputs and outputs for safety and ProfiNet for flexible control, ensure fast response times, smooth diagnosis process and flexibility for further system improvements.

7.2. PLC code structure

The source code of the PLC was developed in TIA Portal, using a clear structure into Function Blocks (FB) and Functions (FC). Therefore, the program is modular, easy to maintain and customizable for future modifications or debugging.

FCs are used for the implementation of automation and initialization graphs. In the current program they are used to fully automate the cell.

FBs include reusable functions such monitoring the vacuum feedback, controlling the solenoid valves, filtering detection signals or resetting alarm states.

The majority of the logic was implemented in LAD, or ladder logic, for increased ease of debugging and diagnostics. However, the control of the two Mitsubishi E800 converters, the logic was written in SCL. It consists of a specific function adjusted from the official Mitsubishi documentation, allowing the ProfiNet to control the speed and the commands for start and stop operations.

Additionally, timers and binary flags are present to ensure synchronization between the cycle states, making sure the correct sequence is maintained.

The hardware configuration of the automated system includes the following components: the PLC, the HMI, the two SMC EX260 solenoid valve islands, the VIET calibrating and sanding machine, the two Turck TBEN LL-4dxp allocators and two Mitsubishi E800 frequency converters.

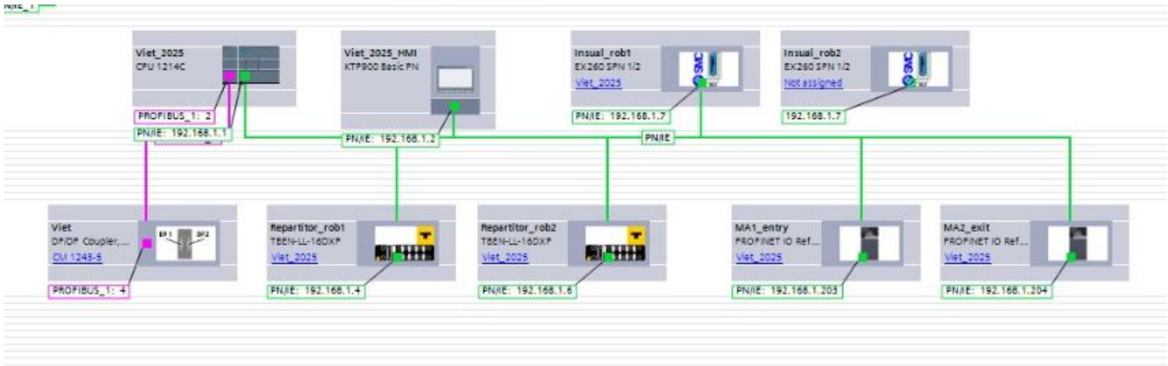


Figure 7.1. Hardware configuration

In Figure 7.1. we have two types of connections. The colour pink represents the Profibus protocol and green represents the ProfiNet connection. It is also observed that each of the components have an individual IP address and name assigned. These components have been imported from the manufacturer's libraries.

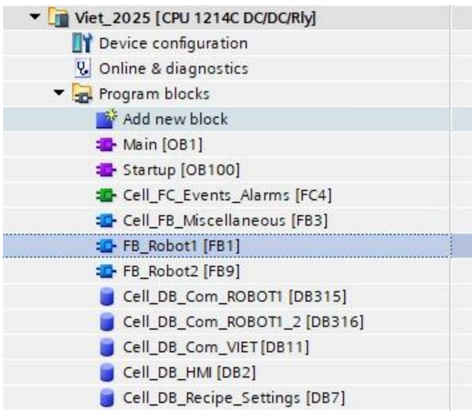


Figure 7.2. Code structure of the PLC

Figure 7.2. presents the code structure of the PLC with all the program blocks, functions and data block used for its programming.

Each hardware component has its own database, except for the components handling the digital inputs and outputs, which use tags to transmit data. Tags are names used to represent locations, variables, or inputs and outputs in a PLC program, making the code easier to understand.

The data blocks store essential data, mapping input and output signals to their corresponding hardware components, ensuring accurate communication within the automated system.

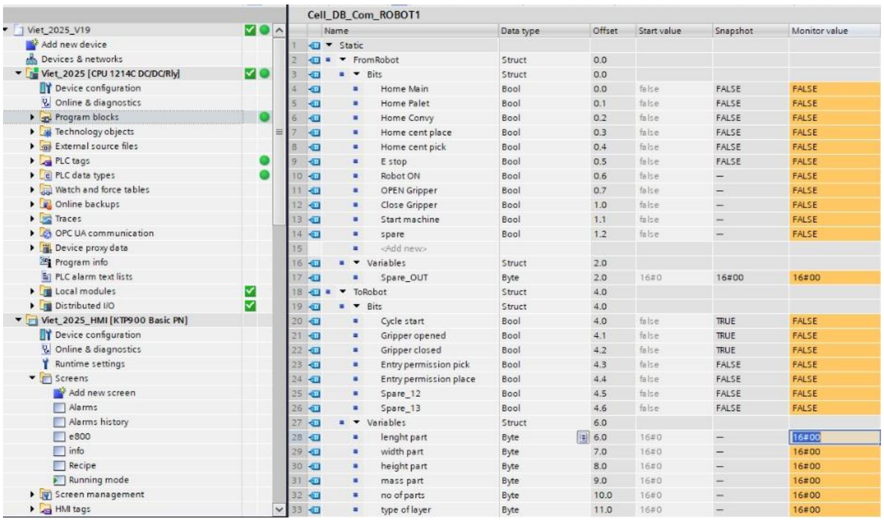


Figure 7.3. Data block structure

Figure 7.3. represents the structured layout of a communication data block (CELL_DB_Com_ROBOT) within Siemens TIA Portal. This DB, or data block, plays a crucial role in managing data, status and control exchange between the PLC and the robotic systems.

The current data block example contains two main components. First one, FromRobot, contains the status bits received from the robot to the PLC, of type Bool. These status bits are used to signal the robot's state. For example, the Home Main is used to see if the robot is in the main home position, the Home Pallet is used to see is the robot is in pallet home position, and so on. The second section, ToRobot, includes the signals sent from the PLC to the robot, again using the Bool data type. For example, the Cycle start is used to start the robot cycle, the Gripper opened is used to detect if the gripper is opened.

All the data blocks in the project are using the same structure presented. This modular approach of the data block facilitates the bidirectional communication between PLC and the robot.

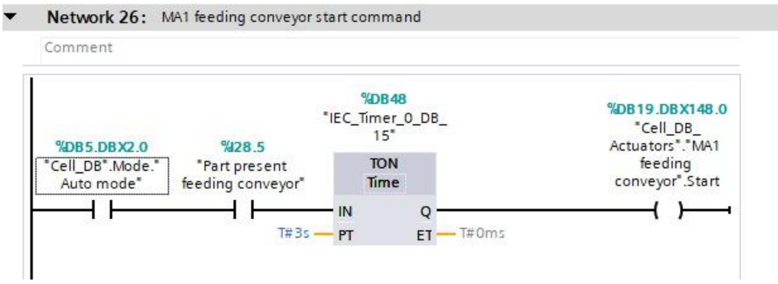


Figure 7.4. Feeding conveyor start command

In the proposed automation system, LAD, or Ladder Logic, is extensively used. The networks programmed serve as logic description of the equipment's operations.

Figure 7.4 represents the infeed conveyor start command. The conveyor is started using this LAD network that need to make sure three essential conditions are met before the process starts. First condition, "Cell_DB"."Mode"."Auto mode", is that the automatic mode is activated. This is done by switching the system in automatic mode, indicating the PLC that the process is ready for automation. The second condition, "Part present feeding conveyor" checks if the panel is detected by the corresponding sensor. This is done through photoelectronic sensor that detects the presence of the panel on the conveyor, preventing the conveyor from running empty. The third condition checks for a three second timer. A TON "IEC_Timer_0_DB_15", or on-delay, timer is used to establish a three second delay after the panel is detected by the sensor. This ensures the panel is correctly positioned before starting the infeed conveyor.

The three conditions are placed in series, using logical AND, in the ladder diagram. The output command is only activated when all three contacts are closed, implying they are set to true. The timer, TON, is triggered when the panel is detected, and after three seconds, the output becomes true. This allows the final execution step to activate the infeed conveyor. Once all conditions are met, the PLC sets the "Cell_DB"."Actuators"."MA1 feeding conveyor"."Start" output, being able to start the conveyor.

7.3. Fanuc robot code

The programs for the robots were developed in the Fanuc RoboGuide environment, using the Tech Pendant interface and the HandlingTool package. A main program was created for each robot, split into subroutines according to the corresponding performed operations.

The work areas are defined in several local UFRAMEs, each one corresponding to a zone: pallet zone, conveyor zone, centering zone. This system provides flexibility for easy modifications.

Programs such as “B_GRP _CLOSE” and “B_GRP_OPEN” from Annex 11 and Annex 12 are in charge of opening and closing the gripper.

The M-410iC/185 robot is responsible for the following operations: picking up the wood panel from the pallet and placing the panel on the infeed conveyor of the calibration and sanding machine. The main program represents the main loop that controls the robot’s logic. It checks whether the robot is initialized, reads information from the PLC, handles the panel operations mentioned and loops the subroutines if the pallet is not full. The “A_PICK_PALLET” and “A_PLACE_CONVY” are computed after the depalletization is complete, making sure the robot will have available panels to process.

```
1: IF (!DO[33:Home Main]) THEN ;
 2: CALL A_INIT ;
 3: ENDIF ;
 4: ;
 5: CALL C_READ_PLC ;
 6: ;
 7: LBL[1] ;
 8: IF (R[16:NO_PARTS]<>0) THEN ;
 9: ;
 10: OVERRIDE=70% ;
 11: CALL C_DEPALETIZARE ;
 12: CALL C_POSITION ;
 13: CALL A_PICK_PALLET ;
 14: CALL A_PLACE_CONVY ;
 15: ELSE ;
 16: WAIT R[80]=1 ;
 17: ;
 18: ENDIF ;
 19: JMP LBL[1] ;
```

The program “A_PICK_PALET” is responsible for picking up the panel from the pallet. Firs two lines set the reference coordinate system through “UTOOL_FRAME” and “UTOOL_NUM”. The robot moves to a home position above the pallet through “PR[2:Home_palet]”, then to the calculated pick-up point “PR[21:PICK_PALET_CAL] “ using an offset in Z “PR[100:Z_OFFSET-]”. The robot lowers to the pick-up location with a linear movement. The gripper closes “CALL B_GRP_CLOSE” and the panel is elevated. The tracking of remaining panel left is done through decrement of the counter “R[16:NO_PARTS]”. Finally, the robot returns to the home pallet position and if the cycle end flag is set “F[2:Sfarsit ciclu]” and all the panels are picked up “R[21:NO_OF_PICK] = 0”, it resets both cycle flags “F[1]” and “F[2]”.

```
1: UFRAME_NUM=1 ;
2: UTOOL_NUM=4 ;
3: ;
4:J PR[2:Home_palet] 100% CNT100 ;
5:J PR[21:PICK_PALET_CAL] 80% CNT50 Tool_Offset,PR[100:Z_OFFSET-] ;
6:L PR[21:PICK_PALET_CAL] 100mm/sec FINE ;
7: ;
8: CALL B_GRP_CLOSE ;
9: CALL PICK_PALET_SIM ;
10: ;
11:L PR[21:PICK_PALET_CAL] 1500mm/sec CNT50 Tool_Offset,PR[100:Z_OFFSET-] ;
12: ;
13: R[16:NO_PARTS]=R[16:NO_PARTS]-1 ;
14: ;
15:J PR[2:Home_palet] 80% CNT100 ;
16: IF (F[2:Sfarsit ciclu]) THEN ;
17: IF (R[21:NO_OF_PICK]=0 AND F[1:Inceput ciclu]=ON) THEN ;
18: ;
19: F[1:Inceput ciclu]=(OFF) ;
20: F[2:Sfarsit ciclu]=(OFF) ;
21: ENDIF ;
22: ENDIF ;
```

The program “A _PLACE_CONVY” is controls the panel placement on the infeed conveyor. Similar to the picking up program, the first two lines set the coordinate system. The robot is moved to a home position above the conveyor, through “PR[3:Home_conveyor]”, then waits for permission to place the part, therefore “DI[80:Place_convy_permission]” must be ON. The robot moves to a calculated position, PR[20:PLACED_CONVY_CAL], using Z offset, then executes a linear movement to set the panel down on the conveyor. Then the gripper is opened, “CALL B_GRP_OPEN”, discharging the panel. The end of the program the robot backs off from placement position and returns to the conveyor’s home position. The last line represents the ON signalling to start the calibrating and sanding machine “DO[108:START machine]”.

```
1: UFRAME_NUM=2 ;
2: UTOOL_NUM=4 ;
3: ;
4:J PR[3:Home_conveyor] 80% CNT100 ;
5: WAIT (DI[80:Place_convy_permission]) ;
6:L PR[20:PLACED_CONVY_CAL] 1500mm/sec CNT50
Tool_Offset,PR[100:Z_OFFSET-] ;
7:L PR[20:PLACED_CONVY_CAL] 100mm/sec FINE ;
8: DO[108:START machine]=OFF ;
9: CALL B_GRP_OPEN ;
10: CALL PLACE_CONVY_SIM ;
11: ;
12: //WAIT (!DI[80:Place_convy_permission]) ;
13: ;
14:L PR[20:PLACED_CONVY_CAL] 1500mm/sec CNT50
Tool_Offset,PR[100:Z_OFFSET-] ;
15:J PR[3:Home_conveyor] 80% CNT100 ;
16: DO[108:START machine]=ON ;
```

The R-2000iC/125L robot has complex tasks to execute: picking up the panel from conveyor after the processing is done for one side of the panel, positioning the panel on the inclined centering system, picking up the panel from the centering system, using a robot arm rotation so the gripper is oriented to the unprocessed side of the panel, and finally, dropping off the panel on the final pallet. The main program, present in Annex 1, is similar to the M-410iC/185 robot, with processing operation stored in a FOR Loop, until the pallet is full.

The “A_PICK_CONVEYOR” program is used to pick up the panel from the conveyor after the first side is processed. Firstly, reference frames are set for the conveyor, then the robot moves to home position above the conveyor “PR[3:Home_conveyor]”. It waits for a digital input signal “DI[80:Pick_convy_permission]”, ensuring the wood panel is ready to be picked up. Afterwards, it moved down to the pickup position with Z offset “PR[99:Z_-100]”, then lowers down to the conveyor, closing the gripper through “CALL B_GRP_CLOSE”. To avoid the movement of the conveyor, it is set to OFF using “DO[108:START machine]”. The panel is now picked up and the robot return to the home position.

```
1: UFRAME_NUM=3 ;
2: UTOOL_NUM=3 ;
3: ;
4:J PR[3:Home_conveyor] 100% CNT100 ;
5: WAIT (DI[80:Pick_convy_permission]) ;
6:L PR[20:PICK_CONVY_CALC] 3000mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
7:L PR[20:PICK_CONVY_CALC] 300mm/sec FINE ;
8: ;
9: CALL B_GRP_CLOSE ;
10: CALL PICK_CONVY_SIM ;
11: DO[108:START machine]=OFF ;
12: ;
13:L PR[20:PICK_CONVY_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
14: //WAIT (!DI[80:Pick_convy_permission]) ;
15:J PR[3:Home_conveyor] 100% CNT100 ;
```

The program "A_PLACE_CENTERING" places the panel on the centering system. After setting the centering frames, the robot moves to the system's home position "PR[4:Home_cent_place]", then moves to a calculated point "PR[22:PLACE_CENT_CALC]" with Z offset, lowering to system. The command "CALL B_GRP_OPEN" opens the gripper, therefore releasing the part. The "DO[108:START machine]" signalling to ON means the conveyor is allowed to continue the transporting of the next panels. The robot then moves to a calculated position "PR[22:PLACE_CENT_CALC]", preparing for the flip of the panel.

```
1: UFRAME_NUM=2 ;
2: UTOOL_NUM=3 ;
3: ;
4:J PR[4:Home_cent_place] 100% CNT100 ;
5:L PR[22:PLACE_CENT_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
6:L PR[22:PLACE_CENT_CALC] 250mm/sec FINE ;
7: ;
8: CALL B_GRP_OPEN ;
9: CALL PLACE_CENT_SIM ;
10: DO[108:START machine]=ON ;
11: ;
12:L PR[22:PLACE_CENT_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
13:J PR[4:Home_cent_place] 100% CNT40 ;
14: ;
15:L P[1] 2500mm/sec CNT70 ;
```

The "A_PICK_CENTERING" picks the panel from the centering system, flips it and prepares it for palletizing. It uses the same frames for centering. The robot moves above the centering system "PR[5:Home_cent_pick]", then positions to the pick-up location "PR[23:PICK_CENT_CALC]" with Z offset, slowly approaching for the gripper to act. "CALL B_GRP_CLOSE" closes the gripper and the robot collects the panel, then retracts linear from the pick-up position. "PR[98:-800Y]" represents the robot moving linear on the Y-axis of the userframe, flipping the panel, and returning to home position.

```
1: UFRAME_NUM=2 ;
2: UTOOL_NUM=3 ;
3: ;
4:J PR[5:Home_cent_pick] 100% CNT50 ;
5:L P[1] 2500mm/sec CNT50 ;
6: ;
7:L PR[23:PICK_CENT_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
8:L PR[23:PICK_CENT_CALC] 250mm/sec FINE ;
9: ;
10: CALL B_GRP_CLOSE ;
11: CALL PICK_CENT_SIM ;
12: ;
13:L PR[23:PICK_CENT_CALC] 2500mm/sec CNT100 Tool_Offset,PR[100:Z_100] ;
14:L PR[23:PICK_CENT_CALC] 700mm/sec FINE Offset,PR[98:-800Y] ;
15:L P[1] 2500mm/sec CNT50 ;
16: ;
17:J PR[5:Home_cent_pick] 100% CNT100 ;
```

The program “A_PLACE_PALET” places the flipped panel onto the final pallet. The program starts by setting the pallet reference frame, then moves the robot to the pallet home position “PR[2:Home_palet]”. After that, the robot moves to the pallet calculated location “PR[21:PLACE_PALET_CALC]” with Z offset, slowly lowering for the drop off. “CALL B_GRP_OPEN” opens the gripper to release the panel onto the pallet. The robot retracts vertically and returns to the home position of the pallet. Finally, the part counter “R[16:NO_PARTS]” decreases by 1, tracking precisely how many panels can fit in the current pallet.

```
1: UFRAME_NUM=1 ;
2: UTOOL_NUM=3 ;
3: ;
4:J PR[2:Home_palet] 100% CNT100 ;
5:L PR[21:PLACE_PALET_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
6:L PR[21:PLACE_PALET_CALC] 250mm/sec FINE ;
7: ;
8: CALL B_GRP_OPEN ;
9: CALL PLACE_PALET_SIM ;
10: ;
11:L PR[21:PLACE_PALET_CALC] 2500mm/sec CNT100 Tool_Offset,PR[99:Z_-100] ;
12:J PR[2:Home_palet] 100% CNT100 ;
13: ;
14: R[16:NO_PARTS]=R[16:NO_PARTS]-1 ;
```

The initialization programs for both robots are present in the annexes 3 and 4. They are both very similar, preparing the robot system for the required operations. This includes checking home positions, handling a possible gripped panel, safely placing the panel if required and returning the robot to the home position. The safely placing of a panel is in Annexes 5, for R-2000iC/125L and 6 for M-410iC/185.

The annexes 8 and 10 present the Learning Points of the automated system. The subroutines consist of two parts. First part is purpose to learn the reference points at the initial rendering of the cell but can be easily refactored in case of losing calibration. The second part presents adjusting the reference points, depending on the parameters received form the PLC, in order to generate the robot’s computed positions.

The annexes 7 and 9 are subroutines for depalletization and palletization of the panels.

In the annex 7, the depalletization for the M-410iC/185 robot is described. The subroutine calculates the number of layers and placement logic for picking up the panel. It is based on the total number of pallets and the placement pattern of the last layer.

The logic of the subroutine is as follows:

- The subroutine divides total panels into groups of 3 per layer
- It tracks the leftover panels, the layer height and X/Y positions
- Joggles between right-to-left and top-to-bottom placement configurations
- Uses modulus and arithmetic to calculate the position offsets dynamically for panel picking

The same logic applies to Annex 9, which is responsible for the palletizing of robot R2000iC/125L.

The code is clear and carefully structured, with labels (LBL), conditions, jumps and discrete signals. Each action is validated with binary signals received from the PLC. Additionally, the trajectories have been tested in the RoboGuide Simulation to prevent collisions.

8. Operator user guide

This chapter describes in detail the steps required to initialize and start the robotic cell equipped with two industrial robots in automatic mode. The instructions are designed for the technical operator who needs to interact directly with the HMI interface, robot controllers and the PLC.

1. Enabling the Automatic Mode

For optimal functionality of the system in automatic mode, each robot must be switched to AUTO mode. The operation involves the following steps:

- Turn the key on the controller of each robot to the AUTO position
- Ensure the TP, or Teach Pendant, interface is set to the OFF position to allow full control from the PLC

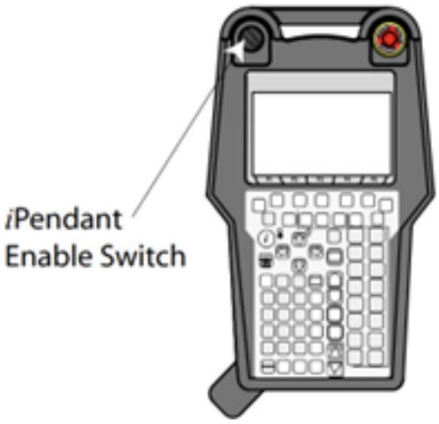


Figure 8.1. Teach Pendant pointing to the Enable Switch

Figure 8.2. Controller key

These steps are essential to fully give control of the work cycle to the automated system and prevent unauthorised personnel to access the manual mode.

2. Checking the Running Condition

After activating the AUTO mode on the robots, the operator must enter the HMI and confirm that the running conditions are met. This is a crucial condition for initiating the automatic processes and ensures the entire system is safe to operate.

If the running condition is not active, it is suggested to check the alarms page. Common causes of this issue can include:

- Emergency stop buttons are active
- Active or not reseted light curtains
- Robots present faulty conditions such as safety, lack of communication

It is mandatory to remediate these alarms before continuing the process.

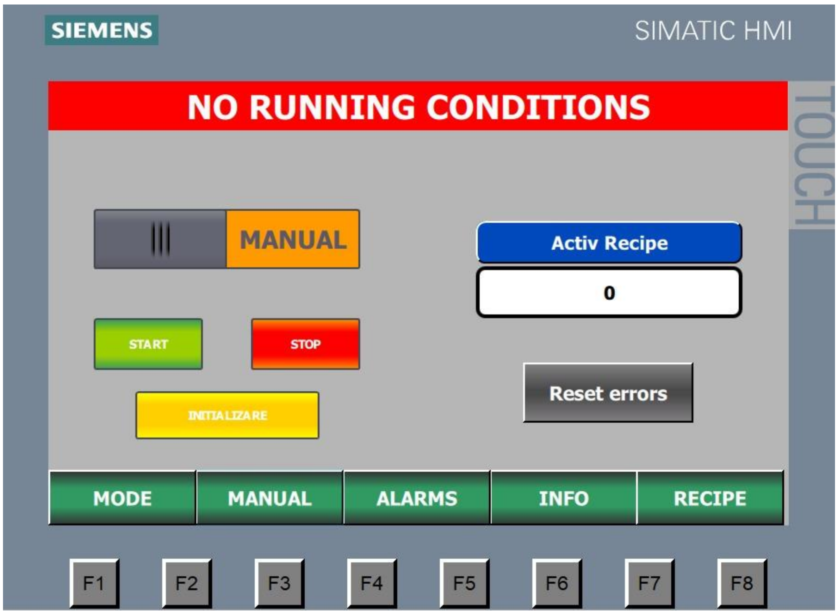


Figure 8.3. No running condition

3. Production recipe configuration

Once the run condition is active, the system allows a temporary switch to the manual mode, necessary for entering the parameters of the product that needs processing.

For creating the recipe, the operator must enter the specific technical parameters in the HMI. These parameters will define the process recipe, including the following:

- Panel dimensions (mm), such as length, width, height, used to adapt the pick-up position
- Weight of the panel (kg), used to configure the grippers vacuum suction parameters
- Number of panels on the pallet
- Orientation of the last layer, representing a logical variable, 0 or 1, that indicates the direction of the last layer, influencing the palletization and depalletization logic.

There is a list of important actions the operator must take before saving the recipe. Firstly, he must bring a pallet with panels to robot position 1, intended to depalletize. Lastly, he must place an empty pallet at robot position 2, intended to palletize.

This order is essential for the consistency of the production line.

4. Cell Initialization

Once the recipe has been saved, they are loaded into the PLC and the cell initialization process is ready to start. This can be done using the dedicated button INT.

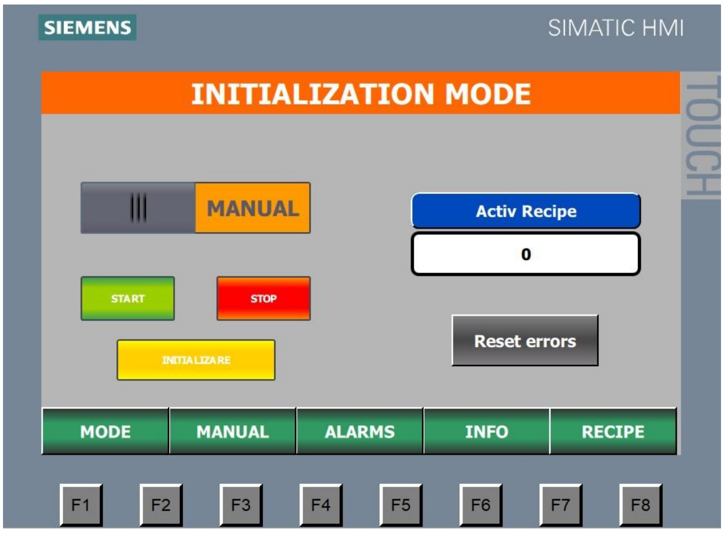


Figure 8.4. Initialization mode

Initialization mode has the following impacts:

- Resetting all internal variables both in the PLC and the robot controllers
- Writing the last saved recipe parameters to the PLC registers.

Safe robot positioning is essential. If the robots are not in the home position, they generate an automatic and safe motion trajectory to reach this position.

If the robot has a panel in the gripper at the time of the initialization, it is automatically released to a defined point near the pallet. Code snippets from Annexes 3 and 4 are responsible for this operation

5. Starting the Automatic Cycle

After the initialization, the cell waits for the Start Cycle command.

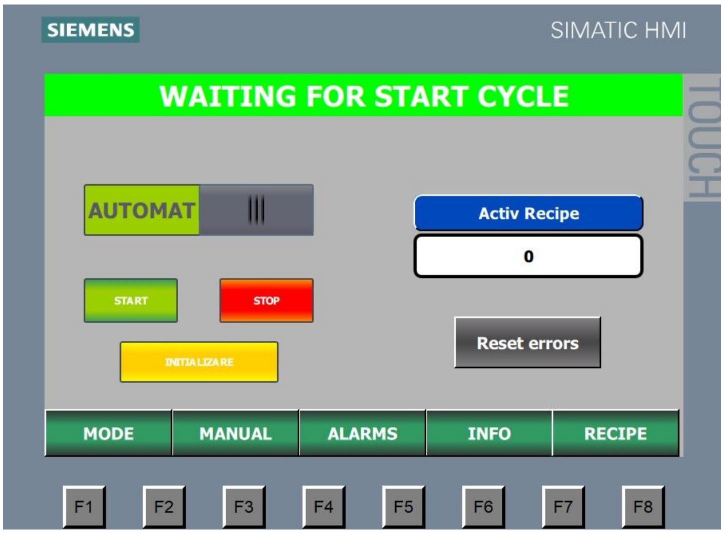


Figure 8.5. Waiting for Start Cycle

When activating this command the following happens: the system enters fully automatic mode and the PLC starts executing the automation graph, coordinating the infeed and outfeed conveyors. This action also triggers the robot's main programs.

The sequence of operations is crucially important. Robot 1 picks up the panels from the pallet and places them on the infeed conveyor. The parts are being fed into the calibrating and sanding machine. When exiting the machine, Robot 2 picks up the panels and orients them through a centering system, centers them and then palletises them onto the empty pallet. This specific cycle continues until all the panels are processed on the first side.

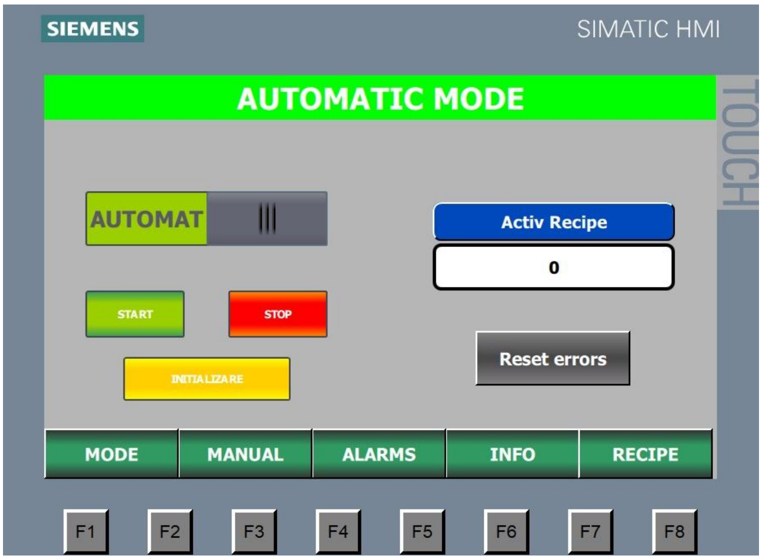


Figure 8.6. Automatic Mode

6. Pallet Change and Repeat Cycle

The operator needs to move the palletized pallet from Robot position 2 to Robot Position 1. He also needs to bring a new empty pallet to the Robot position 2. Therefore, this procedure allows the restarting of the cycle and start the processing of the other side of the panel.

7. System Monitoring and Diagnostics

The HMI provides an Information page, which allows real-time monitoring of the steps executed in the automatic graph. This provides a clear representation of the cycle progress.

If alarms occur during operation, they are displayed on the Alarm page. Firstly, the operator must determine the cause of the issue, fix the problem, then resume the cycle by pressing the "START CYCLE" button. The system is designed to automatically resume the cycle from the point it was interrupted.

In the situation of a complete reset, the current pallet must be completely removed and the operator must resume the entire process from the beginning: recipe creation, initialization, automatic start.

9. Comparative Analysis of the Current and Automated Systems

To evaluate the impact of the proposed automated solution, a comparative analysis was conducted between the current operational model and the planned improved system. This evaluation is based on real field data and direct observations of the full simulation in a virtual environment, taking into consideration four representative requirements: cycle times, operational costs, labour and production output. Lastly, a return on investment, or ROI, is also estimated to confirm the feasibility of the investment into the automated system.

9.1. Comparison of cycle times

In the current system, the handling of a wood panel involves a minimum of three human operations: picking up the panel from the pallet, feeding the panel into the machine, turning the panel and stacking it on the pallet. Each of these operations is performed out manually.
According to factory observations, the average time per part is:

- Pick + Feed: ~30 seconds
- Evacuate + Return: ~40 seconds
- Palletizing: ~20 seconds
- Total: ~90 seconds/panel.

In the automated system, the operations including all robotic movements are estimated at:

- Depalletizing: 10 seconds
- Feeding: 8 seconds
- Pick + Return: 20 second
- Palletizing: 6 seconds
- Total: ~44 seconds/panel.

The results show a decrease of 50% in handling time per operation. This results into faster production timing and increased daily product output without compromising the quality.

9.2. Workforce involved

In the current work environment, three operators are needed during operational for the following tasks:

- One operator for feeding the panel into the conveyor
- Two operators for discharge, returning the panel and for palletizing.

During an 8-hour shift, these employees undertake hard physical labour, with regular work breaks.

After the implementation of the automated cell, the system only needs one operator present. This operator performs the role of a supervisor for the cell, required to do the following tasks:

- placing and discharging of pallets
- recipe selection and cell supervision
- intervention in case of error or alarm.

This change results in a 66% staff reduction, reducing payroll costs. Moreover, available employees that were dismissed from this activity can be redirected to more valuable tasks.

9.3. Operational and maintenance costs

Most of the costs in the manual system present are primarily represented by labour. The estimation for an 8-hour shift, 40-hour weeks, with 2 shifts per day, the average cost for a processing line that require 3 operators results of an average gross wage of 4500 lei per month per operator. The monthly wage costs are resulting in approximately 27000 lei per month. The annual cost including contributions is 340000 lei per year.

In the automated system, these costs can be reduced to one employee in 2 shifts, resulting in an estimated annual cost of approximately 115000 lei per year.

In terms of maintenance, the manual system requires minimal maintenance but involves physical effort of the staff.

An automated system involves periodic maintenance, mainly for parts like grippers, sensors. It estimates to approximately 15000 lei per year.

In comparison, the annual savings are around 210000 lei, excluding the other benefits such as reduced number of accidents, increased production quality.

9.4. Daily production capacity

The daily production rate is also a strong indicator of the current system's efficiency. The current system performs in 80 seconds per panel and 2 shifts/day, the capacity resulting in ~720 parts/day. The automated system performs in 33 seconds per panel, the capacity resulting in ~1750 parts/day. Both systems complete overall the same operations.

The increase in daily production capacity is ~2.4x. This result allows the production to expand and accommodate more orders without additional labour costs.

9.5 Estimated return on investment

The estimated cost for the entire automated system, specifically the robotic cell including equipment, integration, components design and installation, is approximately 180000 euros. This cost includes the two Fanuc robots with grippers, the conveyor system, the sensors, wiring and electrical panels, the programming and simulation.

While saving an annual amount of roughly 42000 euros by only reducing salaries and maintenance, the return on investment, or ROI, is estimated at less than 4.3 years.

If we take into consideration the additional benefits such as doubled production capacity, reduced errors and increased safety of the employees, the payback could drop below three years.

10. Conclusions

The implementation of a robotic cell for handling, calibrating, sanding, and palletizing wood panels proved to be an effective technological solution addressing key industrial needs, including improved efficiency, enhanced safety and increase process reliability. The project applied solid concepts of automation, programming and 3D simulation, facilitated by a strong architecture and a clear structured human-machine interface.

10.1. Overview of implementation benefits

The proposed solution has the following benefits:

- Reduction in processing time by more than 50%, through complete automation of panel handling
- The removal of physical labour, through the use of industrial robots and vacuum systems
- Reduction in labour costs, from 3 operators per shift to one
- Increase in daily production capacity by more than 140%, without affecting other resources
- Increased reliability and safety in operation, through protection systems: fences, sensors, interlocks
- Flexibility to multiple wood types, due to the recipe settings available
- Monitoring and user-friendly control, through the structured HMI that presents clear commands and alarms.

The benefits clearly prove the solution is effective and justify a possible investment in terms of costs and efficiency.

10.2. The impact on productivity and reliability

By reducing the physical labour and keeping all operations synchronized, the automated system makes the industrial process more predictable, scalable and efficient. It removes delays between the steps, lowers the risk of human error and proves consistency in terms of product quality.

Over time, the benefits could be more impactful, automation also bringing the following:

- better process tracking
- improved product quality through consistent processes
- less wear on the robots and machines due to controlled cycles
- easier integration with digital systems, such as MES.

Therefore, the system becomes a flexible platform that can grow and adapt to various production changes.

10.3. Suggestions for future improvements

The proposed automated system meets most of the existing needs of a modern process of handling, calibrating, sanding and palletizing of panels. However, for a complete integration to Industry 4.0 requirements, the following are necessary: autonomous mobility, full system automation, digitalization through IIoT and control interface optimization. These four key improvements will also maximize efficiency in the long term.

10.3.1 Integration of AGV/AMR robots for pallet transportation

In the current proposed system, the loading and unloading of the pallets in the automated cell is done manually. This way, it still requires one operator present. Moreover, potential downtime in the continuous process might occur. A modern solution involves integration of autonomous mobile robots, such as AGV, Automated Guided Vehicle, or AMR, Autonomous Mobile Robot.

The robots given as an example can transport pallets from the warehouse area to the automated cell area, without any guidance. They operate with proximity sensors, LiDAR maps and cameras, in order to navigate in the work area without any collisions. In an ideal operations flow, the AGV robot could bring a full pallet to the entrance of the cell, wait for its complete unloading and then pick it up emptied and take it back to the warehouse area.

The integration of these robots into the PLC's ProfiNet network can allow automatic commands from the central system without any operator present. They can also send feedback status, position or load signals. This way, the PLC is always informed whether a pallet is full or not. The implementation of this kind of equipment can completely reduce the need of human intervention, therefore increase autonomy and reduce labour costs.

10.3.2. Full system automation

The proposed solution automates panel handlining, but the rest of the system remains mainly manual. This part includes dropping of pallets at the entrance of the cell, picking up the pallet at the end, sorting the pallet.

To turn the system into a fully autonomous system, a closed-loop automated flow can be implemented, ensuring synchronization across all steps of the process. This approach would require extra equipment. It requires the use of smart independent driven conveyors, with integrated sensors, in order to transport the pallets. It would also demand the use of automated buffer stations, where the pallets can be stored temporarily. The usage of automated loading stations is necessary for the panels to be automatically placed on conveyors and pickup up from the pallets. Lastly, the fully automated system would require the integration of a secondary robot, or additional interactive robot arm to either sort the final panels or label them.

This modern automated system would be able to operate 24/7 with minimal downtime, ideal for high production lines. Manual handling breaks for operators are completely eliminated. Moreover, the system evolves into a complete loop of reliable and standardized operations.

10.3.3. IIoT connection (Industrial Internet of Things)

Industrial Internet of Things connectivity is another potential step in the evolution of the proposed automated system. By integrating IIoT, the system would become a digitalized automation system with remote access to data. In the current form, the information is only visible locally on the HMI, limiting the visibility for operators and other technical departments involved.

Connecting the PLC, robots and equipment to an IIoT platform enables access to the following:

- online monitoring of cell status, including alarms and RUN and STOP cycles
- data logging and analysis
- automatic notifications to operators, using different communication channels, such as e-mail, SMS or mobile application
- web-based access to dashboards.

Compatible platforms include Siemens MindSphere, Ignition, Kepware. This platform allows simultaneous supervision of multiple cells in different locations.

10.3.4. Possible HMI upgrade

The proposed HMI is operational and user-friendly but has clear potential for improvement. This can be done by upgrading to a more advanced version of the Siemens Comfort or Unified Panels. An upgrade from KTP900 Basic panel to a KTP1200 Comfort panel would result in the following benefits:

- larger and higher resolution screen
- detailed graphics with smoother animations
- connection to external networks and integrated web server

The interface can also be enhanced with role-based authentication. Each of the users, operators, technicians, engineers, would have its own account with tailored access to the HMI. This addition could avoid unauthorized employees to access restricted pages.

Other improvements include the integration of the HMI with mobile phones or tablets through web portals or mobile applications. The operator could receive notifications in case of errors and the supervisors could view the status of the processing line without physical presence.

By implementing these ideas, the automated cell proposed could go from a local automation to a fully autonomous system. This means a more scalable system, capable of more advanced operations with data monitoring and fast adjustment to production requirements.

Annexes

Annex 1. Main Program of Robot R2000-iC/125L

```
1: IF (!DO[33:Home Main]) THEN ;
 2: CALL A_INIT ;
 3: ENDIF ;
 4: ;
 5: CALL C_READ_PLC ;
 6: ;
 7: LBL[1] ;
 8: IF (R[16:NO_PARTS]<>0) THEN ;
 9: ;
 10: OVERRIDE=70% ;
 11: CALL C_DEPALETIZARE ;
 12: CALL C_POSITION ;
 13: CALL A_PICK_PALLET ;
 14: CALL A_PLACE_CONVY ;
 15: ELSE ;
 16: WAIT R[80]=1 ;
 17: ;
 18: ENDIF ;
 19: JMP LBL[1] ;
```

Annex 2. Main Program of M410-iC/185

```
1: IF (!DO[33:Home Main]) THEN ;
 2: CALL A_INIT ;
 3: ENDIF ;
 4: WAIT 22.00(sec) ;
 5: DO[108:START machine]=ON ;
 6: WAIT 12.00(sec) ;
 7: OVERRIDE=100% ;
 8: CALL C_READ_PLC ;
 9: CALL C_POSITION ;
 10: ;
 11: FOR R[17:increment]=1 TO R[9] ;
 12: R[18]=R[17:increment]-1 ;
 13: CALL C_PALLET ;
 14: CALL C_CALCULATION ;
 15: ;
 16: CALL A_PICK_CONV ;
 17: CALL A_PLACE_CENTERING ;
 18: CALL A_PICK_CENTERING ;
 19: CALL A_PLACE_PALET ;
 20: ;
 21: ENDFOR ;
 22: WAIT R[80]=1 ;
 23: ;
 24: JMP LBL[1] ;
```

Annex 3. Initialization Program of Robot R2000-iC/125L

```
 1: CALL C_POSITION ;
 2: IF (DO[33:Home Main] OR DO[34:Home Palet] OR DO[35:Home Convy] OR
DO[36:Home cent place] OR DO[37:Home cent pick]) THEN ;
 3: ;
 4: CALL A_HOME ;
 5: IF (DI[62:GRP closed]) THEN ;
 6: CALL A_PLACEINIT_PART ;
 7: ENDIF ;
 8: ;
 9: ELSE ;
 10: UFRAME_NUM=0 ;
 11: UTOOL_NUM=3 ;
 12: PR[6]=LPOS ;
 13: IF (PR[6,2]<100) THEN ;
 14:L PR[6] 100mm/sec FINE Tool_Offset,PR[99:Z_-100] ;
 15: UFRAME_NUM=1 ;
 16: ;
 17:L PR[2:Home_palet] 200mm/sec FINE ;
 18: CALL A_HOME ;
 19: IF (DI[62:GRP closed]) THEN ;
 20: CALL A_PLACEINIT_PART ;
 21: ENDIF ;
 22: ;
 23: ;
 24: ELSE ;
 25: IF (PR[6,2]>630) THEN ;
 26:L PR[6] 100mm/sec FINE Tool_Offset,PR[99:Z_-100] ;
 27: UFRAME_NUM=3 ;
 28:L PR[3:Home_conveyor] 200mm/sec FINE ;
 29: CALL A_HOME ;
 30: IF (DI[62:GRP closed]) THEN ;
 31: CALL A_PLACEINIT_PART ;
 32: ENDIF ;
 33: ;
 34: ELSE ;
 35: IF (PR[2,4:Home_palet]<0) THEN ;
 36:L PR[6] 100mm/sec FINE Tool_Offset,PR[99:Z_-100] ;
 37: UFRAME_NUM=2 ;
 38:L PR[5:Home_cent_pick] 200mm/sec FINE ;
 39: CALL A_HOME ;
 40: IF (DI[62:GRP closed]) THEN ;
 41: CALL A_PLACEINIT_PART ;
 42: ENDIF ;
 43: ;
 44: ;
 45: ;
 46: ELSE ;
 47:L PR[6] 100mm/sec FINE Tool_Offset,PR[99:Z_-100] ;
```

```
48: UFRAME_NUM=2 ;
49:L PR[4:Home_cent_place] 200mm/sec FINE ;
50: CALL A_HOME ;
51: IF (DI[62:GRP closed]) THEN ;
52: CALL A_PLACEINIT_PART ;
53: ENDIF ;
54: ;
55: ;
56: ENDIF ;
57: ENDIF ;
58: ENDIF ;
59: ENDIF ;
60: CALL B_GRP_OPEN
```

Annex 4. Initialization Program of Robot M410-iC/185

```
1: CALL C_POSITION ;
2: IF (DO[33:Home Main] OR DO[34:Home Palet] OR DO[35:Home Convy]) THEN ;
3: ;
4: CALL A_HOME ;
5: IF (DI[62:GRP closed]) THEN ;
6: CALL A_PLACEINIT_PART ;
7: ENDIF ;
8: ;
9: ELSE ;
10: UFRAME_NUM=0 ;
11: UTOOL_NUM=4 ;
12: PR[5]=LPOS ;
13: IF (PR[5,2]<900) THEN ;
14:L PR[5] 100mm/sec FINE Tool_Offset,PR[100:Z_OFFSET-] ;
15: UFRAME_NUM=1 ;
16: ;
17:L PR[2:Home_palet] 200mm/sec FINE ;
18: CALL A_HOME ;
19: IF (DI[62:GRP closed]) THEN ;
20: CALL A_PLACEINIT_PART ;
21: ENDIF ;
22: ;
23: ELSE ;
24:L PR[5] 100mm/sec FINE Tool_Offset,PR[100:Z_OFFSET-] ;
25: UFRAME_NUM=2 ;
26:L PR[3:Home_conveyor] 200mm/sec FINE ;
27: CALL A_HOME ;
28: IF (DI[62:GRP closed]) THEN ;
29: CALL A_PLACEINIT_PART ;
30: ENDIF ;
31: ENDIF ;
32: ENDIF ;
33: CALL B_GRP_OPEN
```

Annex 5. Subroutine for detecting existing panel in gripper for R2000-iC/125L

```
1: UFRAME_NUM=0 ;
2: UTOOL_NUM=3 ;
3: ;
4: ;
5: ;
6:J PR[8:Place init part] 16% FINE Tool_Offset,PR[99:Z_-100] ;
7:L PR[8:Place init part] 100mm/sec FINE ;
8: CALL B_GRP_OPEN ;
9:L PR[8:Place init part] 500mm/sec FINE Tool_Offset,PR[99:Z_-100] ;
10: CALL A_HOME
```

Annex 6. Subroutine for detecting existing panel in gripper for M410-iC/185

```
1: UFRAME_NUM=0 ;
2: UTOOL_NUM=4 ;
3: ;
4: ;
5:J PR[8:Place init part] 15% FINE Offset,PR[99:Z_OFFSET+] ;
6:L PR[8:Place init part] 100mm/sec FINE ;
7: CALL B_GRP_OPEN ;
8:L PR[8:Place init part] 600mm/sec FINE Offset,PR[99:Z_OFFSET+] ;
9: ;
10: CALL A  HOME
```

Annex 7. Subroutine for the depalletizing logic

```
1: R[20:NO_OF_LAYERS]=R[16:NO_PARTS] DIV 3 ;
2: R[21:NO_OF_PICK]=R[16:NO_PARTS] MOD 3 ;
3: ;
4: IF (F[2:Sfarsit ciclu]) THEN ;
5: IF (R[21:NO_OF_PICK]=0 AND F[1:Inceput ciclu]=ON) THEN ;
6: ;
7: F[1:Inceput ciclu]=(OFF) ;
8: F[2:Sfarsit ciclu]=(OFF) ;
9: ENDIF ;
10: ENDIF ;
11: ;
12: IF (R[21:NO_OF_PICK]<>0) THEN ;
13: R[20:NO_OF_LAYERS]=R[20:NO_OF_LAYERS]+1 ;
14: R[19:SAVED LAYERS]=R[19:SAVED LAYERS]+1 ;
15: F[2:Sfarsit ciclu]=(ON) ;
16: ENDIF ;
17: ;
18: IF (!F[1:Inceput ciclu]) THEN ;
19: ;
20: IF (R[22:TYPE_OF_LAYER]=0 AND R[21:NO_OF_PICK]=0) THEN ;
```

```
21: R[22:TYPE_OF_LAYER]=1 ;
22: ELSE ;
23: IF (R[22:TYPE_OF_LAYER]=1 AND R[21:NO_OF_PICK]=0) THEN ;
24: R[22:TYPE_OF_LAYER]=0 ;
25: ENDIF ;
26: ENDIF ;
27: ENDIF ;
28: ;
29: IF (R[30:actual_Z_layer]<>0) THEN ;
30: R[30:actual_Z_layer]=R[12:HEIGHT_PART]*R[20:NO_OF_LAYERS] ;
31: ELSE ;
32: R[30:actual_Z_layer]=R[12:HEIGHT_PART]*1 ;
33: ENDIF ;
34: ;
35: SELECT R[22:TYPE_OF_LAYER]=0,JMP LBL[10] ;
36: =1,JMP LBL[20] ;
37: ;
40: LBL[10:right to left] ;
41: SELECT R[21:NO_OF_PICK]=0,JMP LBL[11] ;
42: =1,JMP LBL[12] ;
43: =2,JMP LBL[13] ;
44: ;
45: LBL[11] ;
46: R[31:actual_Y_layer]=2.5 ;
47: JMP LBL[90] ;
48: LBL[12] ;
49: R[31:actual_Y_layer]=.5 ;
50: JMP LBL[90] ;
51: LBL[13] ;
52: R[31:actual_Y_layer]=1.5 ;
53: JMP LBL[90] ;
54: ;
55: ;
56: LBL[20:up tp down ] ;
57: ;
58: ;
59: SELECT R[21:NO_OF_PICK]=0,JMP LBL[21] ;
60: =1,JMP LBL[22] ;
61: =2,JMP LBL[23] ;
62: ;
63: LBL[21] ;
64: R[32:actual_X_layer]=2.5 ;
65: JMP LBL[90] ;
66: LBL[22] ;
67: R[32:actual_X_layer]=.5 ;
68: JMP LBL[90] ;
69: LBL[23] ;
70: R[32:actual_X_layer]=1.5 ;
71: JMP LBL[90] ;
72: ;
73: LBL[90] ;
74: ;
```

Annex 8. First subroutine for training the reference point and calculate the positions

```
1: !1. INVATARE PUNCTE ;
2: //J P[1:HOME] 100% FINE ;
3: PR[1:Home]=P[1:HOME] ;
4: ;
5: //J P[2:HOME_PALET] 100% FINE ;
6: PR[2:Home_palet]=P[2:HOME_PALET] ;
7: //J P[3:HOME_CONVEYOR] 100% FINE ;
8: PR[3:Home_conveyor]=P[3:HOME_CONVEYOR] ;
9: ;
10: //J P[4:REF_PLACE_CONVY] 100% CNT100 ;
11: PR[10:REF_PLACE_CONVY]=P[4:REF_PLACE_CONVY] ;
12: ;
13: //J P[5:REF_PICK_PALLET] 100% FINE ;
14: PR[11:REF_PICK_PALLET]=P[5:REF_PICK_PALLET] ;
15: ;
16: //L P[6] 100mm/sec FINE ;
17: PR[8:Place init part]=P[6] ;
18: PR[8,1:Place init part]=PR[8,1:Place init part]-600 ;
19: PR[8,2:Place init part]=PR[8,2:Place init part]-200 ;
20: PR[8,3:Place init part]=PR[8,3:Place init part]-45 ;
21: ;
22: !2.CALCULE PUNCTE ;
23: ;
24: !Calcul pct depunere init ;
25: PR[8,1:Place init part]=PR[8,1:Place init part]+R[14:LENGTH/2_PART] ;
26: PR[8,2:Place init part]=PR[8,2:Place init part]+R[15:WIDTH/2_PART] ;
27: PR[8,3:Place init part]=PR[8,3:Place init part]+R[12:HEIGHT_PART] ;
28: ;
33: !punct de depunere pe conveyor ;
34: ;
35: PR[20:PLACED_CONVY_CAL]=PR[10:REF_PLACE_CONVY] ;
36: PR[20,1:PLACED_CONVY_CAL]=PR[20,1:PLACED_CONVY_CAL]-200 ;
37: PR[20,2:PLACED_CONVY_CAL]=PR[20,2:PLACED_CONVY_CAL]-600 ;
38: PR[20,3:PLACED_CONVY_CAL]=PR[20,3:PLACED_CONVY_CAL]+45 ;
40:PR[20,1:PLACED_CONVY_CAL]=PR[20,1:PLACED_CONVY_CAL]+R[15:WIDT
H/2_P ART] ;
41:PR[20,2:PLACED_CONVY_CAL]=PR[20,2:PLACED_CONVY_CAL]+R[14:LENG
TH/2_ PART] ;
42: PR[20,3:PLACED_CONVY_CAL]=PR[20,3:PLACED_CONVY_CAL]-
R[12:HEIGHT_PART] ;
44: ;
45: !punct de preluare palet ;
46: PR[21:PICK_PALET_CAL]=PR[11:REF_PICK_PALLET];
47: ;
48: PR[21,1:PICK_PALET_CAL]=PR[21,1:PICK_PALET_CAL]-600 ;
49: PR[21,2:PICK_PALET_CAL]=PR[21,2:PICK_PALET_CAL]-200 ;
50: PR[21,3:PICK_PALET_CAL]=PR[21,3:PICK_PALET_CAL]-45 ;
```

```
51: ;
52: SELECT R[22:TYPE_OF_LAYER]=0,JMP LBL[11] ;
53: =1,JMP LBL[12] ;
54: ;
55: LBL[11] ;
56: PR[21,3:PICK_PALET_CAL]=R[30:actual_Z_layer] ;
57:
PR[21,1:PICK_PALET_CAL]=PR[21,1:PICK_PALET_CAL]+R[14:LENGTH/2_PART] ;
58:
PR[21,2:PICK_PALET_CAL]=(PR[21,2:PICK_PALET_CAL]+(R[11:WIDTH_PART]*R
[31:actual_Y_layer])) ;
59: JMP LBL[90] ;
60: ;
61: LBL[12] ;
62: PR[21,3:PICK_PALET_CAL]=R[30:actual_Z_layer] ;
63:PR[21,2:PICK_PALET_CAL]=PR[21,2:PICK_PALET_CAL]+R[14:LENGTH/2_PAR
T] ;
64:PR[21,1:PICK_PALET_CAL]=(PR[21,1:PICK_PALET_CAL]+(R[11:WIDTH_PART
]*R[32:actual_X_layer])) ;
65: JMP LBL[90] ;
66: ;
67: ;
68: LBL[90] ;
69: IF (R[22:TYPE_OF_LAYER]=1) THEN ;
70: PR[21,6:PICK_PALET_CAL]=PR[21,6:PICK_PALET_CAL]+90 ;
71: ENDIF ;
```

Annex 9. Subroutine for palletization

```
1: ;
2: R[20:NO_OF_LAYERS]=R[16:NO_PARTS] DIV 3 ;
3: R[21:NO_OF_PLACE]=R[16:NO_PARTS] MOD 3 ;
4: ;
5: IF (R[21:NO_OF_PLACE]<>0 AND F[3:CNC loaded]) THEN ;
6: R[5]=R[21:NO_OF_PLACE] ;
7: R[19:SAVED LAYERS]=R[19:SAVED LAYERS]+1 ;
8: R[21:NO_OF_PLACE]=0 ;
9: ENDIF ;
10: ;
11: IF (R[19:SAVED LAYERS]=R[30:actual_Z_layer]/R[12:HEIGHT_PART]) THEN ;
12: F[1:Inceput ciclu]=(ON) ;
13: ENDIF ;
14: IF (!F[3:CNC loaded]) THEN ;
15: IF (R[18] MOD 3=0) THEN ;
16: R[30:actual_Z_layer]=R[30:actual_Z_layer]+R[12:HEIGHT_PART] ;
17: ENDIF ;
18: ENDIF ;
19: IF (!F[3:CNC loaded]) THEN ;
20: IF (R[18] MOD 3=0 AND R[22:TYPE_OF_LAYER]=0) THEN ;
21: R[22:TYPE_OF_LAYER]=1 ;
```

```
22: ;
23: ELSE ;
24: IF (R[18] MOD 3=0 AND R[22:TYPE_OF_LAYER]=1) THEN ;
25: R[22:TYPE_OF_LAYER]=0 ;
26: ENDIF ;
27: ENDIF ;
28: ENDIF ;
29: R[1]=(R[17:increment] MOD 3) ;
30: ;
31: SELECT R[22:TYPE_OF_LAYER]=0,JMP LBL[10] ;
32: =1,JMP LBL[20] ;
33: ;
34: ;
35: ;
36: LBL[10:right to left] ;
37: SELECT R[1]=0,JMP LBL[11] ;
38: =1,JMP LBL[12] ;
39: =2,JMP LBL[13] ;
40: ;
41: LBL[11] ;
42: R[31:actual_Y_layer]=2.5 ;
43: JMP LBL[90] ;
44: LBL[12] ;
45: R[31:actual_Y_layer]=.5 ;
46: JMP LBL[90] ;
47: LBL[13] ;
48: R[31:actual_Y_layer]=1.5 ;
49: JMP LBL[90] ;
50: ;
51: ;
52: LBL[20:up tp down ] ;
53: ;
54: ;
55: SELECT R[1]=0,JMP LBL[21] ;
56: =1,JMP LBL[22] ;
57: =2,JMP LBL[23] ;
58: ;
59: LBL[21] ;
60: R[32:actual_X_layer]=2.5 ;
61: JMP LBL[90] ;
62: LBL[22] ;
63: R[32:actual_X_layer]=.5 ;
64: JMP LBL[90] ;
65: LBL[23] ;
66: R[32:actual_X_layer]=1.5 ;
67: JMP LBL[90] ;
80: LBL[90] ;
102: IF (F[3:CNC loaded]) THEN ;
103: F[3:CNC loaded]=(OFF) ;
104: ENDIF ;
```

Annex 10. Second subroutine for training the reference point and calculate the positions

```
1: //J P[1:HOME] 100% FINE ;
2: PR[1:Home]=P[1:HOME] ;
3: ;
4: //J P[2:HOME_PALET] 100% FINE ;
5: PR[2:Home_palet]=P[2:HOME_PALET] ;
6: ;
7: //J P[3:HOME_CONVEYOR] 100% FINE ;
8: PR[3:Home_conveyor]=P[3:HOME_CONVEYOR] ;
9: ;
10: //J P[4:HOME_CENT_PLACE] 100% FINE ;
11: PR[4:Home_cent_place]=P[4:HOME_CENT_PLACE] ;
12: ;
13: ;
14: //J P[5:HOME_CENT_PICK] 100% FINE ;
15: PR[5:Home_cent_pick]=P[5:HOME_CENT_PICK] ;
16: ;
17: ;
18: ;
19: //J P[6:REF_CONVY_PICK] 100% FINE ;
20: PR[10:PICK_REF_CONV]=P[6:REF_CONVY_PICK] ;
21: PR[10,1:PICK_REF_CONV]=PR[10,1:PICK_REF_CONV]-600 ;
22: PR[10,2:PICK_REF_CONV]=PR[10,2:PICK_REF_CONV]-200 ;
23: PR[10,3:PICK_REF_CONV]=PR[10,3:PICK_REF_CONV]-45 ;
24: ;
25: //J P[7:CENT_REF_PLACE] 100% FINE ;
26: PR[11:CENT_REF_PLACE]=P[7:CENT_REF_PLACE] ;
27: PR[11,1:CENT_REF_PLACE]=PR[11,1:CENT_REF_PLACE]+600 ;
28: PR[11,2:CENT_REF_PLACE]=PR[11,2:CENT_REF_PLACE]+200 ;
29: PR[11,3:CENT_REF_PLACE]=PR[11,3:CENT_REF_PLACE]-45 ;
30: ;
31: //J P[8:CENT_REF_PICK] 100% FINE ;
32: PR[12:CENT_REF_PICK]=P[8:CENT_REF_PICK] ;
33: PR[12,1:CENT_REF_PICK]=PR[12,1:CENT_REF_PICK]-600 ;
34: PR[12,2:CENT_REF_PICK]=PR[12,2:CENT_REF_PICK]+200 ;
35: PR[12,3:CENT_REF_PICK]=PR[12,3:CENT_REF_PICK]+45+50 ;
36: ;
37: //L P[9:REF_PALET_PLACE] 100mm/sec FINE ;
38: PR[13:REF_PALET_PLACE]=P[9:REF_PALET_PLACE]
39: PR[13,1:REF_PALET_PLACE]=PR[13,1:REF_PALET_PLACE]-600 ;
40: PR[13,2:REF_PALET_PLACE]=PR[13,2:REF_PALET_PLACE]-200 ;
41: PR[13,3:REF_PALET_PLACE]=PR[13,3:REF_PALET_PLACE]-45 ;
42: ;
43: //L P[10:Place init part] 100mm/sec FINE ;
44: PR[8:Place init part]=P[10:Place init part] ;
45: PR[8,1:Place init part]=PR[8,1:Place init part]-600 ;
46: PR[8,2:Place init part]=PR[8,2:Place init part]-200 ;
47: PR[8,3:Place init part]=PR[8,3:Place init part]-45 ;
```

```
 50: !Calc place init part ;
 51: PR[8,1:Place init part]=PR[8,1:Place init part]+R[14:LENGTH/2_PART] ;
 52: PR[8,2:Place init part]=PR[8,2:Place init part]+R[15:WIDTH/2_PART] ;
 53: PR[8,3:Place init part]=PR[8,3:Place init part]+R[12:HEIGHT_PART] ;
 54: ;
 59: ;
 60: !Calc pct prel conv ;
 61: PR[20:PICK_CONVY_CALC]=PR[10:PICK_REF_CONV] ;
62:PR[20,1:PICK_CONVY_CALC]=PR[20,1:PICK_CONVY_CALC]+R[14:LENGTH/2
_PART] ;
 63:PR[20,2:PICK_CONVY_CALC]=PR[20,2:PICK_CONVY_CALC]+R[15:WIDTH/2_
PART] ;
 64: PR[20,3:PICK_CONVY_CALC]=PR[20,3:PICK_CONVY_CALC]+R[12:HEIGHT_
PART] ;
 65: ;
 66: !Calc pct dep cent ;
 67: PR[22:PLACE_CENT_CALC]=PR[11:CENT_REF_PLACE] ;
 68: PR[22,1:PLACE_CENT_CALC]=PR[22,1:PLACE_CENT_CALC]-
R[14:LENGTH/2_PART] ;
 69: PR[22,2:PLACE_CENT_CALC]=PR[22,2:PLACE_CENT_CALC]-
R[15:WIDTH/2_PART] ;
 70: PR[22,3:PLACE_CENT_CALC]=PR[22,3:PLACE_CENT_CALC]+R[12:HEIGHT_
PART] ;
 71: ;
 75: !Calc pct prel cent ;
 76: PR[23:PICK_CENT_CALC]=PR[12:CENT_REF_PICK] ;
 77:PR[23,1:PICK_CENT_CALC]=PR[23,1:PICK_CENT_CALC]+R[14:LENGTH/2_
PART] ;
 78: PR[23,2:PICK_CENT_CALC]=PR[23,2:PICK_CENT_CALC]-
R[15:WIDTH/2_PART] ;
 79:PR[23,3:PICK_CENT_CALC]=PR[23,3:PICK_CENT_CALC]-
R[12:HEIGHT_PART]
```

Annex 11. Close gripper subroutine

```
1: LBL[1] ;
 2: !Close gripper ;
 3: DO[62:CLOSE gripper]=ON ;
 4: //WAIT (!DI[61:GRP opened]) ;
 5: WAIT 1.00(sec) ;
 6: //WAIT (DI[62:GRP closed]) TIMEOUT,LBL[998] ;
 7: ;
 8: JMP LBL[999] ;
 9: LBL[998:error] ;
 10: CALL PROMPTOK(10) ;
 11: DO[61:OPEN gripper]=ON ;
 12: UALM[1] ;
 13: JMP LBL[1] ;
 14: LBL[999:end] ;
```

Annex 12. Open gripper subroutine

```
 1: !Open gripper ;
  2: DO[61:OPEN gripper]=ON ;
  3: //WAIT (!DI[62:GRP closed]) ;
  4: WAIT 1.00(sec) ;
  5: //WAIT (DI[61:GRP opened]) ;
```

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