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MASTER’S DEGREE IN AUTOMATION ENGINEERING

MASTER THESIS

IN

VIRTUAL COMMISIONING OF A PALLITIZING STATION IN ROBOTSTUDIO ENVIRONMENT

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ABSTRACT

This thesis explores the development and implementation of a palletizing robot cell utilizing the ABB IRB 460 robot within the RobotStudio environment, focusing on virtual commissioning to enhance industrial automation efficiency. The study aims to validate the robotic system's performance, thereby reducing commissioning time and costs. By simulating various operational scenarios, the research evaluates the station layout design, interface configuration, and system reliability under diverse conditions. The findings demonstrate that virtual commissioning effectively identifies potential issues prior to physical deployment, leading to improved operational efficiency and cost-effectiveness. This work highlights the significant advantages of employing virtual tools in industrial automation and outlines future prospects for advancing robotic systems in response to evolving manufacturing demands.

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1 INTRODUCTION:

1.1 Company description:

<u>Who is ADS: company presentation</u>

<u>ADS Automation:</u>

ADS Automation srl is a young and dynamic company founded in April 2005 by the will of the founding partner Andrea Zaccherini, who boasts more than ten years of experience in robotics acquired at ABB, a company that is at the top of the world in this sector.

Initially, its activity was based on technical assistance as an intervention on failure.

Subsequently and rapidly, it broadened its horizons towards other activities, thanks also to the collaboration with ABB, such as:

- Study and design
- Software programming
- Training and plant management courses
- Technical assistance
- Preventive maintenance
- Overhaul, reconditioning of systems
- Construction and installation of systems

From March 1, 2010, ADS Automation officially becomes a Partner of ABB.

Currently ADS Automation designs and creates complete robotic systems, also performs upgrades with hardware and software modifications on existing systems, such as replacing the old robot with a new one. It also deals with technical assistance, maintenance and resale of Sapri robotic systems.

All this thanks to a high-profile technical staff, through which ADS Automation is able to respond with competence and transparency to customer requests.

Extremely short intervention times at customers throughout Italy, own spare parts warehouse and availability to support customers even by telephone are the result of an organizational set-up aimed at fully satisfying the production needs of the companies that turn to us.

The future goal, in addition to strengthening and confirming all the activities that are already carried out, is to increasingly establish ourselves as integrators in the creation of innovative and customized robotic systems.

1.2 WHAT IS VIRTUAL COMMISSIONING?

New production equipment and manufacturing plants are not ordered from catalogs, instead the specifications and requirements for new production lines are commissioned—engineered, negotiated, and hopefully accepted between the customer and vendor to define a designed-to-fit production line. However, traditional commissioning exposes vendors and customers to significant "work-at-risk" because in commissioning the equipment is reviewed interactively.

Virtual commissioning is the process of simulating the operation of production systems and devices in a virtual environment. This technology allows for testing and optimization of both the mechanical and software aspects of a system before its physical assembly in a production facility. This technology enables the reduction of actual start-up time for robotic production lines and workstations, early risk analysis, detection of errors, and improvement in the quality of systems at the design stage of the project. A key element of this process is the creation of a "digital twin", which accurately replicates the real functioning of a factory and allows for digital simulation of the entire development of the production facility. This enables us to monitor process parameters, control, and improve the performance of machines and robots, and reveal bottlenecks, production gaps, and processes with low efficiency.

It can be described as, "the act of setting up, testing, and validating a system's design and operation in a virtual environment on a computer." Or in a better explanation is that it requires using software to test and validate control software before the physical machine is built.

Before VC, companies had to physically build the robot and see its functionality and test, in order to do a fault analysis and check and debug the controller program, where nowadays everything has changed.

This is done to guarantee that hardware and software are configured properly and will work as designed when used in real-life situations. Since commissioning work can be completed concurrently with build or even earlier in the project, it can be completed before the machine is built, removing most of it from the critical path.

In the fast-growing industrial world, automation and robotics play an important role in improving efficiency, precision and operational safety across different sectors. Among the numerous applications of robotics, palletizing stands out as a crucial process in manufacturing and logistics.

Growing product complexity and personalization are characteristics of the modern industry. Products develop by incorporating advanced sensing, communication, and situational response capabilities with ever-higher degrees of reasoning. Such a situation is supported by smart manufacturing, which is typically included under the industry 4.0 umbrella and offers a mechanism to respond to constantly changing product specifications while preserving high process efficiency and economic competitiveness. The application of new communication, information, and control technologies made manufacturing systems smarter and more self-sufficient. Advanced sensory equipment, modular controllers, and service-oriented computing platforms are examples of modern assets that integrate cyber-physical systems with high-fidelity simulation prediction models. Specifically, the continuous digitization of factories has necessarily altered not just the production process but also the design and consumption of products.

Development and commissioning processes are frequently very compressed due to the constant demand for adaptable and customized products in current markets. To achieve realism, ease of use, and reliability, simulation and virtual prototyping technologies are combining their roles in transferring testing and optimization operations to virtual environments. Their use includes the associated manufacturing systems and the entire product life cycle.

Reconfigurable automation systems controlled by sophisticated controllers that can comprehend operating scenarios and determine and carry out the best course of action to achieve the highest productivity and manufacturing quality under any circumstance are key to the increased adaptability that modern manufacturing plants demand. As a result, the control logics must incorporate the intelligence and manufacturing knowledge required to analyze the environment and provide the most reliable and effective methods. Such intelligent robotic manufacturing programming has grown more difficult and complicated, taking a long time to validate and verify.

Palletizing is the systematic process of placing and organizing items onto pallets, which enables efficient storage, handling, and transportation. In this kind of process, robotics became the preferred solution for many industries, since it gives us a high speed accurate 24/7 operator, and to not forget that it is reliable solution that only need maintenance.

ABB’s RobotStudio is at the front of virtual commissioning technology. As a powerful simulation software, that provides a comprehensive platform for the offline programming and virtual testing of ABB robots. Enabling engineers to simulate real-world conditions and interactions with great precision, this ability is particularly use in applications like palletizing, where the movements of the robot and the interactions with various products must be carefully directed, that will ensure efficiency and safety.

1.3 OBJECTIVE

This thesis is centered on the virtual commissioning of a palletizing station using the ABB IRB 460 robot. The IRB 460 is specifically designed for high-speed palletizing applications, making it an ideal candidate for this study. Known for its speed and precision, the IRB 460 can significantly enhance the productivity of palletizing operations, especially in industries where large volumes of products need to be processed quickly and accurately. That will involve creating a detailed simulation of a palletizing station in RobotStudio, encircling all aspects of the system, including, the layout of the station, the integration of peripheral devices, the robot's programming. By simulating various operational scenarios, the study aims to validate the system's performance and reliability, ensuring it meets the required specifications before physical deployment.

This thesis seeks to demonstrate the practical benefits of virtual commissioning in reducing the time, cost, and risks associated with robotic system deployment.

1.4 RESOURCES

The resources available to us include:

•PhD students.

• Developers and leaders responsible for production within the company.

• Developers responsible for creating new products within the company.

• Developers specialising in automation at the company.

• Software for creating a virtual representation of a prototype, which includes software for communication "RobotStudio "

1.5 TARGET AUDIENCE

The target audience for this master thesis are production developers, sales manager, automation

team members, production technicians and key decision-makers at ADS Automation.

However, several other departments within the company could use this project as a

base for knowledge for industry 4.0.

1.6 ROBOTSTUDIO

RobotStudio, developed by ABB, is a software used for the modelling, simulation, and offline programming of robot cells. RobotStudio can be utilized either with a real robot controller or with a simulated virtual controller operating on a personal computer. The system consists of two distinct components: the simulation and visualization part, and the controller module. Within the simulation and visualization component, users have the ability to generate basic 3D models or import complex geometries from professional CAD applications. The robot is capable of navigating inside a three-dimensional environment and may be directed to specific locations in space. RobotStudio simplifies geometrical models developed in CAD software, leading to decreased computing requirements for simulation and increased compatibility with various file types of input into the software. The emulation component of RobotStudio primarily focusses on the controller, providing the ability to write and modify actual program code. Additionally, it enables the transfer of the robot code to the physical controller. Additionally, it has the capability to replicate the motions and sequences of various automation devices apart from the Robot, such as conveyors or other handling equipment. One drawback of RobotStudio is its limited compatibility, as it can only be used to program robots provided by ABB. Therefore, the use of robots from providers other than ABB in production systems limits the applicability of RobotStudio.

2 Literature Review

2.1 OVERVIEW OF PALLETIZING TECHNOLOGIES AND THEIR EVOLUTION:

Palletizing technology has transformed significantly over the years, adapting to meet industry demands for efficiency, flexibility, and automation.

2.1.1 Manual and Mechanical Palletizing:

Early palletizing relied on manual labor where workers would load and stack boxes onto pallets by hand. While where this method was effective for smaller operations, but it was not labor friendly where it was inconsistence (that depend only if the worker is able to load and stack) and to not forget the fact of the high risk for the health of the worker, and also if it is heavy load it used to take days to finish. here the mechanical palletizing came as a need, then it has been developed in order to overcome the main issues that we faced, where this method imposed the need of a conveyor belt and a mechanical stackers that could easily arrange the items for a smooth stacking, thus the effective result is having a faster and more efficient way to do palletizing.

eve after achieving the following mechanical stack , we still facing an issue that result in non-flexibility , in other words for varying product shapes or weights.

Figure 1: Development of Palletizers

Figure 2: Robotic Palletizers in early 1980s

2.1.2 Introduction of Robotic Palletizers

In the 1970s and 1980s, the introduction of industrial robots revolutionized palletizing. These robotic palletizers are programmed to pick stack and move the items in a way that allows a faster speed and accurate precision. Although in the beginning programming was complex due to the limitation on the knowledge and humanizing more the programming, these robotic systems showed their value in large scale production environments which provide us a reliable and repeatable stacking with minimal human intervention, that made the investors be interested in such a product due to its high return on investment rate.

Early robotic palletizers were somewhat rigid in their capabilities, which means they had limitations often on handling specific shapes or sizes. But they do still represent a significant increase in reducing labor costs and improving workplace safety, that turned back on more dollars and less risk for the business owners that were interested in this product.

2.2 MODERN ROBOTIC PALLETIZING

2.2.1 Technological Advancements

Modern robotic palletizers have integrated cutting-edge technologies, making them more versatile and efficient. Equipped with sensors, machine vision, and advanced algorithms, these robots can now handle diverse product types, shapes, and orientations. Machine vision systems enable robots to detect product dimensions and packaging types, which is crucial for mixed-case palletizing where item variability is high. These capabilities allow robots to stack products precisely and optimize space on pallets, even when product configurations change frequently.

Figura 3: modern Palletizing Station

2.2.2 Collaborative Robots (Cobots)

The implementation of collaborative robots that are also referred to as COBOTS, has resulted in an increase in the flexibility of palletizing systems since they were intended to work simultaneously with humans , which means that the cobots are ideally suited to be implemented for environments in which space is divided between people and robots. The good ability of Cobots is that they can recognize the presence of humans and to signal their movements in real time to ensure the safety of both humans and robots. The implementation of these safety features includes force sensors and speed control mechanisms that are embedded within the cobots. In applications that require human intervention or monitoring, cobots are frequently utilized because they combine the benefits of automation with the adaptability of humans.

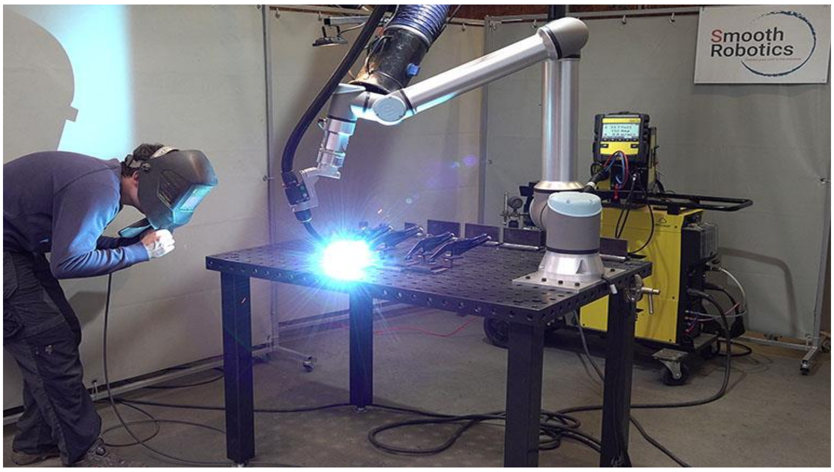


Figura 4: Cobot Welding: Overcoming the Welder Shortage in 2024

2.2.3 Artificial Intelligence and Machine Learning

AI and machine learning have taken robotic palletizing one step ahead by granting the ability to learn from experiences and improve (learn and adapt) with time. The AI-driven robots will self-optimize their stacking patterns independently for various product characteristics, decrease the possibilities of errors, and speed up the process of stacking.

Machine learning algorithms analyze production data to refine robot movements and improve overall operational efficiency. This makes it essential in a high-mix, low-volume production environment where the settings of robots are very frequent for different products or different patterns. Predictive algorithms allow robots to estimate when they might need maintenance, thus helping improve system uptime and reducing unplanned downtime.

The outcome of these converging technologies in modern robotic palletizing systems is exceptionally flexible, safe, continuous improvement-oriented solutions answering the industrial demand for flexible automation of high efficiency.

2.3 Software and Digital Integration

2.3.1 Simulation and Offline Programming

Modern robotic palletizing systems benefit from advanced simulation tools like ABB's RobotStudio, which supports the full cycle of design, programming, and testing within a virtual environment. Using offline programming, engineers can model the robot movements, loading configurations and paths for different products without interrupting the line of production. In this way we can create a simulation that allows for a precise, time-efficient adjustments of the program, that result us as running tests and resolve issues virtually without the need of the existence of the physical machine, ultimately reducing on-site commissioning time and costs, that was always the cause of the creation of such technology. The ability to picture complex tasks digitally also allows for better collaboration and troubleshooting across teams before physical deployment.

Offline programming offers flexibility in iterative design where engineers can modify and optimize programming for specific tasks, such as adjusting speed, angles, or end-effector grip strength, to handle various items safely and efficiently. Having the ability of the virtual testing of the changes suggested, engineers reduced the risks of real-world programming errors, regarding speed angles or the load the end-effector can take, that could otherwise lead to equipment damage, production delays, or increased costs or also unnecessarily losing time that is the most valuable thing for mass production or any type of automation work. Additionally, simulation software can perform stress-testing scenarios, such as assessing robot response under high load or variable conditions, ensuring resilience and reliability in the real-world setup.

2.3.2 Virtual Commissioning and Digital Twins

Manufacturers are investing in increasingly complicated automation to save costs, improve quality, and create innovative products. To boost the reliability of this equipment as well as process control, they aim to use Industry 4.0 technologies like IoT sensors and digital twins. For the companies who develop and implement this automation, the challenge is quite unique. Their objective is to accelerate the end point of final acceptance examination, offering smart automation that generates the most ROI for their clients. Virtual commissioning offers a method for achieving this.

What is the link between a digital twin and virtual commissioning? Both involve the construction of complex simulations of physical systems. There are differences, and it is feasible, if possibly undesirable, to have one without the other.

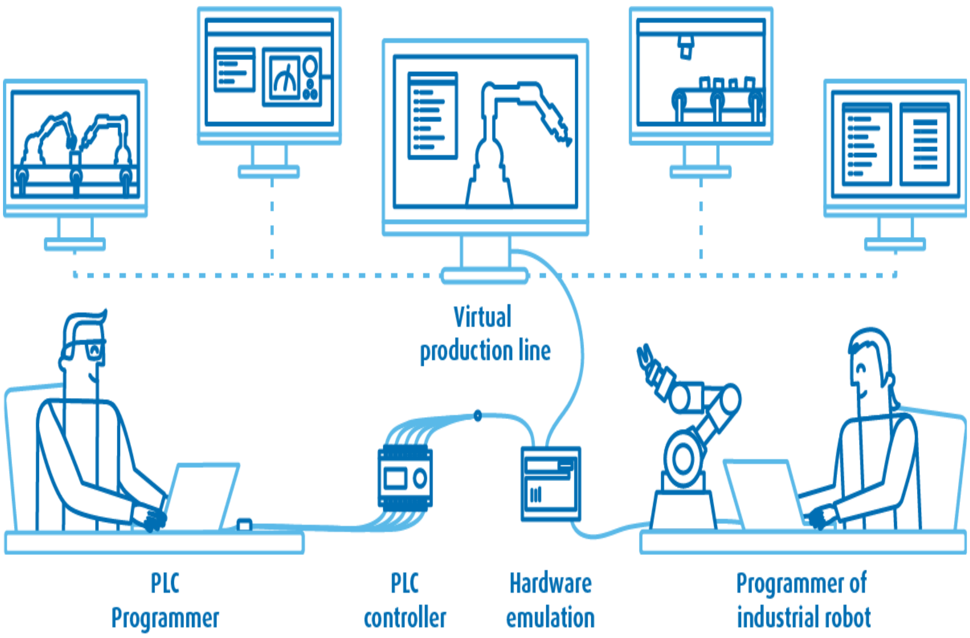


Figura 5:Virtual Commissioning – Software Testing Not Just in IT

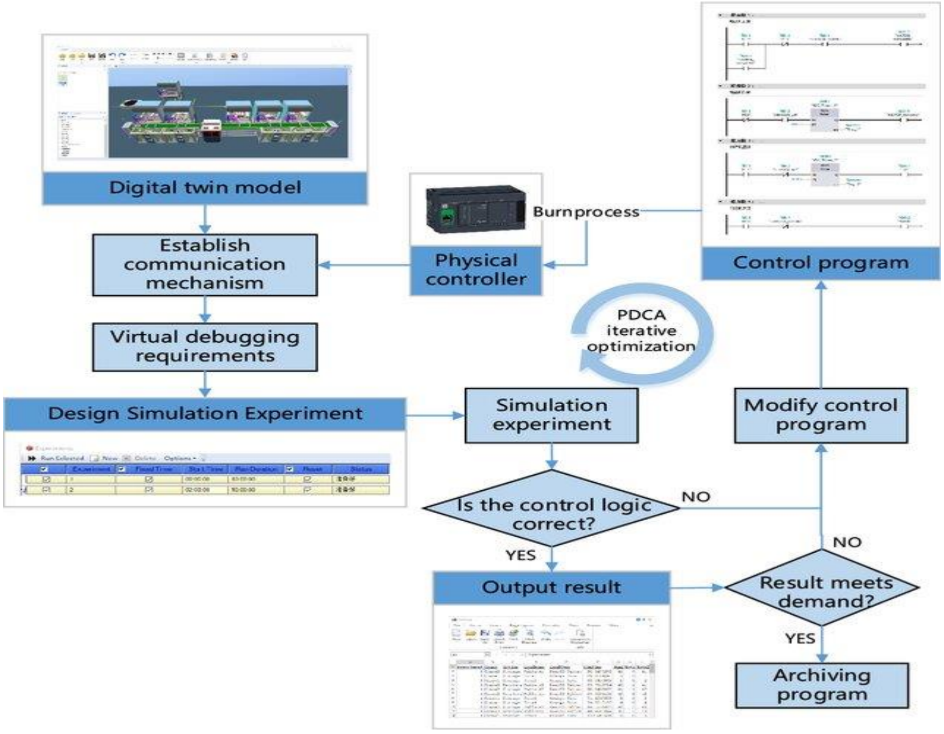


Figura 6:Digital twin-driven virtual commissioning of equipment.

Summarizing Industry 4.0

The term has been utilized for several years; however, a brief introduction will establish the context for a discussion on digital twins and virtual commissions.

Industry 4.0, the fourth industrial revolution, implies the introduction of cyber-physical systems which enable an important enhancement in manufacturing abilities, comparable to the previous revolutions of steam, electricity, and computerization. Industry 4.0 involves the integration of powerful sensor technologies with internet connectivity and artificial intelligence to create "smart" manufacturing systems. These are devices, processes, cells, and lines capable of reporting their status, responding to trends, and optimizing performance with little to no human interaction. The complexity of Industry 4.0 systems requires the development of new processes that facilitate their implementation and management. Two of these procedures are digital twin and virtual commissioning.

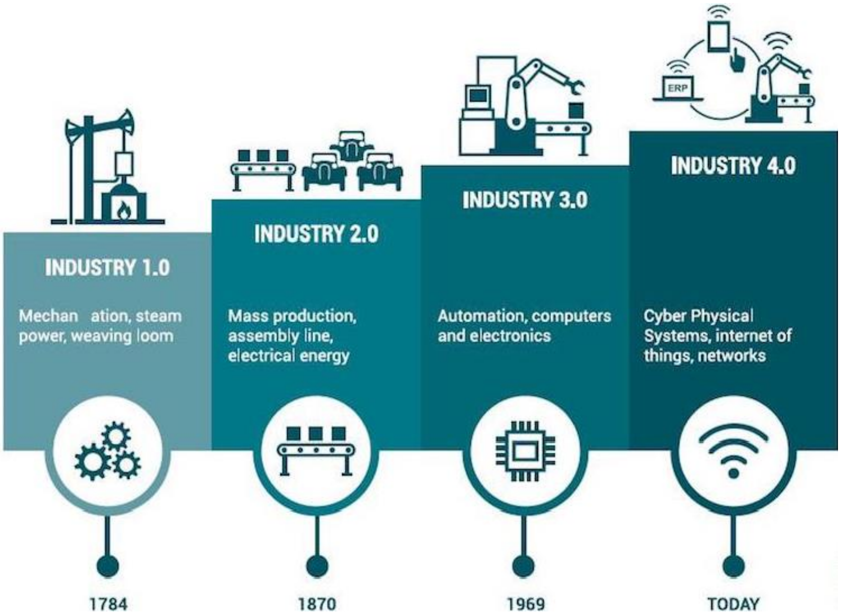


Figura 7:Evolution of Industry: From Mechanization to Cyber-Physical Systems

Virtual commissioning with digital twin technology has revolutionized the development and testing of palletizing systems. The digital twin—a precise, virtual replica of the physical system—mirrors real-world performance and dynamics, providing engineers with a safe and controlled space for testing and optimization. This model is calibrated with real-world parameters such as machine specifications, product dimensions, and task requirements, enabling a high-fidelity representation of the palletizing process.

These include everything from ideal stacking patterns to the most complicated failure cases. Digital twins allow engineers to simulate these scenarios, enhance the processes, alter settings, and debug virtually to minimize errors when commissioning to the physical system is performed. Digital twins allow remote collaboration where experts at different locations can interact and analyze the virtual model, thereby enhancing team-based problem-solving and reducing commissioning times.Beyond just initial deployment, digital twins allow for continuous improvements in that data from the real system feeds into the digital twin for continuous optimization. This sort of feedback loop helps in identifying further areas of process improvement and fine-tunes system performance to promote efficiency and lower operating costs.

2.3.3 Integration with IoT and Industry 4.0

Integration of IoT and Industry 4.0 technologies made the palletizing systems smarter, more autonomous, and data-driven. Embedding IoT devices into robotic palletizers gave us the capability to keep track of real-time data such as speed, torque, temperature, and system load, offering us a continuous track of production. That information allowed the engineers to keep track of machine conditions and predict maintenance needs. Consequently, that gave us the ability to reduce the number of unexpected breakdowns, and the overall productivity improved. For example, using sensor data, palletizers can change stacking pattern or configuration real-time, based on product dimensions or other environmental factors. Therefore, the performance is accurate and reliable in most operating conditions. In other words, IoT integration improved flexibility in the operation. Besides this, a lot of such systems are integrated with management platforms where, from remote points, engineers are allowed to observe several machines and production lines, optimizing resource distribution and reducing manual interventions.

This IoT-enabled adaptability supports higher productivity, as palletizers can respond dynamically to changing demands, such as processing different product batches on the same line or adjusting to supply chain requirements. Through seamless integration with Industry 4.0 technologies, robotic palletizers can align closely with broader production goals, supporting an interconnected, efficient manufacturing ecosystem that adapts to market demands in real-time.

2.4 Research on Palletizing System Efficiency

Studies on palletizing systems have been examined in order to know the effects of different robotic configurations, also the gripper technologies used and the algorithmic optimizations that will allow to maximize efficiency and flexibility.

2.4.1 Robotic Configurations and Mechanical Setups

The configuration aspect is important because it dictates the effectiveness, adaptability, and performance of robotic palletizers. The sets of configurations vary between different advantages and shortcomings, which are determining factors in different industrial uses. In this regard, we consider a closer look into some of the types of arm configuration:

2.4.2 Single-Arm Robots

Single-arm palletizing robots find wide application in industries where the key considerations are cost-effectiveness, simplicity, and easy maintenance. Most of these robots have few moving parts, that leads to less mechanical failure, and we get simpler and easier maintenance. Because of their relatively simple design, they also tend to be more cost-effective in both initial setup and ongoing operational costs. In general, single-arm robots are used in applications with lower requirements or   simpler product handling. Examples of the use of Single Arm robots: applications in which only one kind of product is continuously palletized. To add more about this type of robot, a crucial point is that their programming is also less complex, thus that will enable a quicker setup and a shorter learning curve that the operator must apply.

Figura 8: IRB 460 Palletizing Robot 4 Axis Industrial Robot Arm High Speed Palletizer With Gripper

LIMITATIONS

However, single-arm robots are limited in terms of speed and multitasking. Because they can only handle one item (task) at a time, they are generally slower in high-quantity situation where quick handling of varied products is required. This makes single-arm robots more suitable for small to medium-sized operations where consistent but not extremely high-speed processing is acceptable.

2.4.3 Dual-Arm Robots

In high-demand production lines, dual-arm robotic configurations offer a significant advantage. Using a dual-arm robot configuration, multiple operations are executed in parallel, such as picking up an object with one arm and placing another. Thus, more specifically, multitasking allows higher processing speeds and throughput in the dual-arm configuration that is particularly effective in complicated high-speed palletizing applications, where products must be manipulated in rapid succession. With this ability to perform operations concurrently, dual-arm robots considerably reduce cycle times and increase overall productivity, adding so much value to divisions quite frequently that are suffering from fluctuations in demand, such as food and beverage, automotive, and logistics.

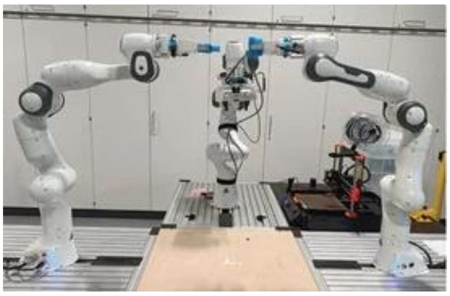


Figura 9:Robotic Dual-Arm Assembly

Moreover, the capability of a dual-arm robot in manipulating complex product shapes and size is also more versatile. With both arms able to work independently or in coordination, these robots are rather fitted for cases of mixed-load palletizing, where various items could differ in weight, shape, or even handling requirements. A good example could be when one arm holds a stabilizing frame or fixture while the other positions the product for high stacking stability and precision. This is a very important feature in enhancing flexibility and adaptability in several environments.

Comparative Studies and Industry Implications:

Productivity and cost-effectiveness differ when comparing single-arm and dual arm robots. While the configuration of the dual arms robot makes them more complicated and expensive, studies show it can be compensated for by an increase in throughput and flexibility in situations of high demand. In applications scenarios with ow demand, single arm robots often perform similarity but a much lower cost, especially in those cases where facilities require simpler and more repetitive palletization tasks.

Also, hybrid approaches are being explored for some industries where more single-arm robots are set up in coordinated configurations-a configuration which provides similar efficiencies as dual-arm robots but with greater flexibility. That opens the possibility of scaling operations according to the production needs of a facility through addition or removal of single-arm robots.

2.4.4 Customization and Modularity:

Lots of robotic configurations can be changed to suit needs, and many are modular, allowing businesses leeway in working out arm configurations, the kind of grippers, and movement patterns needed for their business. For example, some dual-arm robots can be programmed to work independently when the workload has shifted. Modular designs let companies upgrade existing setups with a minimum amount of downtime. In a nutshell, single-arm or dual-arm configurations depend largely upon the type of needs in the production line. From affordable single-arm robots for very basic applications to the more capable and high-throughput, complex palletizing undertaken with a dual-arm robot configuration, speed, versatility, and precision are top-notch. Clearly, knowing these aspects helps industries make informed choices by balancing initial costs with long-term efficiency and adaptability. The palletizing robot comes in different configurations: single-arm and dual-arm. Studies have made comparisons between single-arm and dual-arm robots and found that the latter can provide better speeds and also deal with more items, which is helpful in high-demand environments. Dual-arm robots can perform several activities together, like lifting and placing, and this effectively increases their throughput in production lines involving products of all descriptions at high speed. On the other hand, single-arm robots are usually simpler, cheaper, and easier to maintain; thus, finding applications in low-volume applications or in less complicated palletizing tasks.

2.4.5 Gripper Design and Adaptability

Selection of gripper technology is very important in the handling of various shapes, weights, and levels of product fragility. Various grippers, like vacuum grippers and mechanical grippers, each have different advantages. Vacuum grippers are ideal for lightweight items that are fragile, allowing them to lift items with a minimum level of pressure and decreasing the potential for damage. Mechanical grippers provide a firm hold and are preferred for sturdier items, including boxed goods or even metal parts.

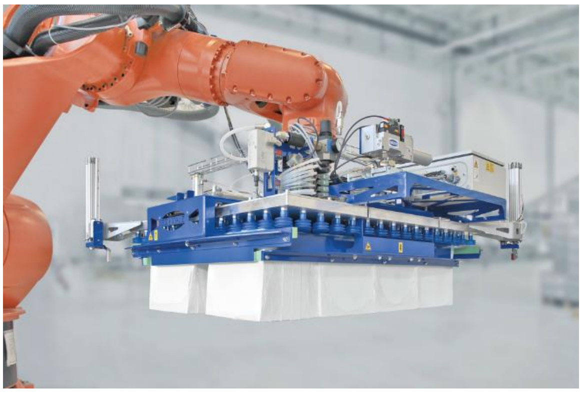


Figura 10: Vacuum Gripping Systems

Figura 11:Pneumatic Mechanical Gripper

More innovative designs-such as multi-functional or adjustable grippers-are far more common, since this enables a single robot to handle several item types without the need for manual changeovers. This can be advantageous in a mixed-product environment where a variety of shapes, weights, and package types must be palletized by the same robot. Multifunctional grippers thus mean less downtime and higher throughputs.

2.4.6 Optimization Techniques for Path Planning and Energy Management

"Path Planning Algorithms" (PPA) is used to improve operational efficiency of palletizing systems, which minimizes unnecessary movements. These algorithms determine the following: what is the optimal path for the robotic arm to take in order to reduce cycle time, lower energy consumption, and that minimize wear on mechanical parts?

Common algorithms, such as "Rapidly-Exploring Random Tree" (RRT) is also a common algorithm that can be considered, and also all hybrid methods that in its role allow robots to quickly navigate complex environments in order to avoid obstacles and optimize movements for speed and accuracy and so on.

In order to reduce the operational cost" Energy Optimization Techniques" (EOT) are good techniques that can be adapted in order to reduce the cost. During idle times, Robots can be programmed to enter low-power states or to follow the energy-efficient motion paths, that require less force. For example, if we controlled acceleration and deceleration rates the energy costs can be lowered without impacting cycle time.

2.4.7 Case Studies on Real-World Applications

Real-world applications demonstrate these advancements in practice. ABB Robotics, for instance, has developed solutions that apply advanced grippers and path optimization in their robotic palletizing systems, providing flexibility for clients in sectors like food and beverage, pharmaceuticals, and logistics. ABB's RobotStudio software is frequently used to simulate and validate robotic setups before implementation, enabling companies to test configurations, refine algorithms, and ensure optimal performance without disrupting production.

The integration of these research insights helps companies improve their palletizing processes, making them faster, more adaptable, and less costly to operate. With advancements in robotic configurations, gripper technologies, and sophisticated optimization techniques, robotic palletizing systems are becoming indispensable for modern, high-efficiency production environments.

Studies on robotic palletizing systems have explored various configurations and mechanical setups to optimize efficiency and adaptability. For instance, comparative studies between single-arm and dual-arm robotic setups indicate that dual-arm configurations can increase speed and allow for simultaneous handling of multiple items, thus improving throughput in high-demand scenarios

Optimization techniques in palletizing systems often involve algorithms for path planning and energy management. Path planning algorithms help minimize unnecessary movements, thus enhancing cycle times and reducing wear on equipment. Techniques such as energy optimization also help reduce operational costs by minimizing power usage during idle states or optimizing the motion profile to require less force. Research shows that these optimization strategies can lead to significant energy savings and more consistent palletizing performance

2.4.8 RobotStudio in Academic and Industrial Research

ABB's RobotStudio has been a valuable tool in both academic and industrial settings for simulating, testing, and optimizing palletizing processes. In academic research, RobotStudio is frequently used to validate robotic movements and operational sequences before implementing them in real-world setups. This simulation capability has proven especially useful for optimizing robotic paths, thus reducing cycle times and energy use. Studies often show that virtual models created in RobotStudio help improve accuracy by allowing engineers to fine-tune settings in a virtual environment first, which reduces errors during actual commissioning

In industrial case studies, RobotStudio has been instrumental in helping companies achieve high levels of productivity while minimizing disruptions to ongoing operations. For example, simulations of complex palletizing tasks in RobotStudio have allowed companies to design customized robotic configurations that address specific production needs, such as handling a diverse range of products or adjusting to fluctuating demands. These applications demonstrate RobotStudio' s role in creating flexible, high-performing palletizing systems that can adapt to industry requirements.

2.4.9 Optimization Techniques

Advanced optimization methodologies, including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Machine Learning (ML), have been utilized to improve the efficiency of robotic palletizing. Genetic Algorithms optimize stacking sequences to get the most compact and stable designs, which is particularly crucial for managing mixed loads. Particle Swarm Optimization (PSO), emulating the behavior of swarming organisms, is utilized to enhance the direction and trajectory of robotic motions, facilitating expedited and seamless operations with little retracing or unnecessary actions.

Machine Learning, especially Reinforcement Learning, has been utilized to enhance adaptive responses in palletizing operations, enabling robots to modify their actions depending on real-time data or changes in product specifications. Research studies have shown that the implementation of these algorithms in RobotStudio markedly enhances performance measures, including speed, accuracy, and resource consumption, rendering these techniques indispensable for contemporary, high-efficiency palletizing systems.

These developments demonstrate the essential function of simulation and optimization in robotic palletizing, highlighting how the integration of tools such as RobotStudio with sophisticated algorithms may provide extremely dependable, versatile, and economical solutions.

3 Identification of gaps in the existing literature

3.1 Incomplete System Simulation and Representation

The simulation does not reflect all the stages of the product journey especially important transition as the boxing process, since the main attention for this simulation is to test the functionality of the vacuum gripper. The result is that this narrow vision often does not take into consideration many other factors which may affect the efficiency of the whole system.

Research Opportunity: Subsequent research may be gained from thorough simulations encompassing all phases, from initial processing to final packaging, facilitating a more complete assessment of possible bottlenecks or integration difficulties. This would provide more accurate insights into the system's comprehensive performance.

3.2 Eligibility of Vacuum Gripper without Comprehensive Testing

While the primary objective is to evaluate the vacuum gripper's eligibility for the specific task since the project is maid to be for a gripper that will be used in the palletizing of a certain product with certain measurements and fixed weight, there is limited focus on factors like product variation and operational demands that could influence the gripper's sustainability. Since the gripper's performance is studied in a controlled repetitive setting, where real-world applications with varied products might not see the same effectiveness.

Research Opportunity: Future research can be done on investigating the vacuum gripper's adaptability for products of different shapes, volumes, and weights, or even investigate modular gripper designs that can handle more flexibly. This would provide a more comprehensive understanding of the gripper's suitability for diverse applications.

3.3 Lack of Energy Efficiency Analysis

The energy consumption data is not included in the simulation, that will result us in the following gap opportunities to optimize power usage are unmapped. Since nowadays, energy efficiency is a very essential aspect of modern robotic systems and for following standards that are implemented for energy consumption, in order to have sustainable industrial automation.

Research Opportunity: Including an energy efficiency study may facilitate the identification of strategies to moderate idle energy consumption, optimize motion profiles and decrease power usage in high-cycle applications. Research including energy models in simulations may uncover new optimization opportunities and establish a baseline for energy-efficient vacuum gripper utilization.

3.4 No Consideration of Product Variability

The products managed within the system are identical, which facilitates the process but fails to consider potential variation in actual environments. Numerous industrial applications necessitate the management of mixed loads or products with minor variations in shape or size, thereby complicating the flexibility of the vacuum gripper.

Research Opportunity: Future studies can be made on variability into the product set, or in other simple words having different boxes size, all mixed, and then to test the gripper's adaptability. This could involve experimenting with slightly different shapes or weights that will provide insights into the gripper's range of application and its limitations.

4 Implementation and Results

4.1 DETAILED DESCRIPTION OF THE SIMULATION SETUP:

4.1.1 Overview of the Simulation Environment:

4.1.1.1 Platform Used:

Virtual commissioning using RobotStudio since the idea of virtual factories is getting popular among our customers and RobotStudio users. RobotStudio is intended to be a tool for large scale factory simulations. Currently RS can do cell sized simulations and production line. One example of this is a system integrator who wanted to make a packaging line simulation with RS, other example, as my case is to test the environment of the robot when using a different gripper and see how it may result as solution.

RobotStudio 2024

Figura 12: RobotStudio Logo

4.1.1.2 Simulation Purpose:

The purpose of this simulation is to assess the efficiency, functionality, and compliance of the IRB 460 robot when equipped with a vacuum gripper in a palletizing application. The analysis is meant to show how well such robotic simulation will handle repetitive palletizing tasks and gain insight on how the IRB 460 interact with the vacuum gripper, and test its compatibility, under simulated industrial conditions.

In our case, we chose the IRB 460 for its abilities to serve the purpose as a high-speed palletizing robot, specifically to handle materials in manufacturing and packaging industries. However, equipped with a vacuum gripper as these systems are particularly suited for handling flat, fragile or irregularly shaped items that traditional mechanical grippers struggle with. This setup allows the study to observe how the

IRB460 can manage product pick and place tasks investigating reliability and precision with which it stacks products on the pallet.

4.1.2 Assessing the Compatibility of the IRB 460 with the Vacuum Gripper:

The compatibility assessment of the IRB 460 robot with the vacuum gripper involves testing multiple parameters to confirm that the robot's capabilities meet the specific requirements related to vacuum gripping tasks. This is highly important in ensuring that a combined robot-gripper configuration can meet real-world production demands regarding speed, accuracy, and reliability in a simulated environment.

Testing Movement Precision and Control

The fact that IRB 460's movement is highly accurate played an important role, in that vacuum grippers depend on exact alignment to the product surface creating required suction. Hence, any misalignment during pick or place will lead to compromising grip and accuracy of stacking. the ability of the IRB 460 to approach the products from any angle at variable height, correctly position the gripper, and be stable through all phases of the lift and place cycle.

Testing Speed and Cycle Time

Industrial type palletizing is often a task which requires high throughput. This of course implies that robots have to carry out repetitive cycles within an extremely short time limit. Using the IRB 460 with the vacuum gripper in a controlled environment for testing the speed and cycle time enables us to identify how the robot can maintain fast movement without the loss of grip or misalignment of the product. This evaluation considers the maximum speeds by the robot for each phase in approaching, picking up, and placing the product. Further, it measures the holding capability of the vacuum gripper.

Reach and Workspace Suitability

The reach of the IRB 460 is also assessed to find if it is suitable for the workspace of the vacuum gripper as well as of the total area to be utilized for the palletizing process. Since the vacuum grippers might need to approach items from overhead or from side angles, the robot's reach and arm flexibility are reviewed for multiple stack heights, pallet sizes, and conveyor placements. The reach compatibility testing that is performed ensures that the robot can effectively cover the entire pallet area and reach various product locations without having to reposition excessively, which impacts efficiency.

Repetitive Task Performance

Industrial palletizing by a robot means performing regular cyclic motions for extensive time. This test step simulates several operation cycles to check if IRB 460 keeps up with the same performance concerning grip reliability even over repeated tasks. The assessment shall be such that the vacuum gripper will continue to perform effectively without major loss of grip or failure for extensive continuous operational periods. Alignment with Real-World Production Demand.

Evaluating the Gripper's Performance in Product Handling:

The simulation provides a controlled environment to test how well the vacuum gripper can securely hold, transport, and release items. Observing its performance in picking and stacking gives insights into its effectiveness in scenarios where consistency and precision are essential.

Understanding Operational Flow and Cycle Efficiency:

By simulating this setup, we aim to determine if the IRB 460 and the vacuum gripper can achieve a high-speed, continuous operation that would meet typical industrial requirements. This also includes evaluating the flow that conveyors and the robot have.

Identifying Areas for Optimization:

The simulation serves as a basis for identifying potential issues or inefficiencies in the setup, such as movement lag, or misalignment. Observing these aspects in a simulated setting allows for adjustments before physical commissioning of the robot.

4.2 COMPONENTS OF THE SIMULATION:

A detailed simulation setup for a palletizing station (layout) including various components and systems in the RobotStudio environment. The IRB 460-110-240 robot is one the main components of the simulation which is a high-speed palletizing robot commonly used in industrial applications where this model is specifically designed for tasks requiring quick and precise palletizing, that is paired with a custom vacuum gripper as explained before, the one we are trying to test to see its efficiency , this vacuum gripper is composed of 4 distinct sections that contribute to the gripping and handling process.

components include:

- **Laser sensor (Keyence):** This sensor ensures accurate positioning and product detection that will result as enhancing of precision in the robot's movement.
- **Mechanical gripper (Festo):** A versatile mechanical tool that is designed to securely hold the items, adding flexibility to the gripping process.

- **Balluff sensor unit:** This component monitors and provides feedback on the gripper's operational status.
- **Gripper flange structure:** A foundational structure that connects the gripper components help in stabilizing the attachment to the robot arm.
- **Pallet pickup mechanism:** Mechanically facilitates the secure grasp and release of pallets during the palletizing process.
- **Conveyor 950-4000**: A general-purpose conveyor for transporting products within the setup.
- **Product entrance roller conveyor**: Guides products as they enter the main conveyor line, streamlining flow.
- **Conveyor guides**: Maintain products on the intended path and prevent misalignment or spillage.
- **Human model**: Represents manual interaction within the station.
- **Elevator**: Transfers items between different levels or zones within the palletizing system.
- **Euro pallet**: Standardized pallet used for product stacking and stability during transport.
- **Labeling machine :** Automatically applies labels to products or pallets.
- **Robot base**: The foundation where the IRB 460 robot is mounted, providing stability and support.
- **Box closer**: Mechanism that securely closes boxes, completing the packaging process.
- **Intralox conveyor**: A specialized conveyor known for its reliability in handling diverse product types.
- **Separation paper magazine**: Dispenses separation paper to be placed between product layers on the pallet for added stability.
- **Hand pallet truck (Transpallet)**: Allows manual movement of pallets for initial positioning or removal after stacking.
- **Electric control box**: Houses the control system's electrical circuitry, managing the power supply and distribution.

- **Robot mounting bolts**: Secures the robot to its base, ensuring a stable and safe operation environment.

These components together form a comprehensive and efficient palletizing setup designed for high-performance industrial operations.

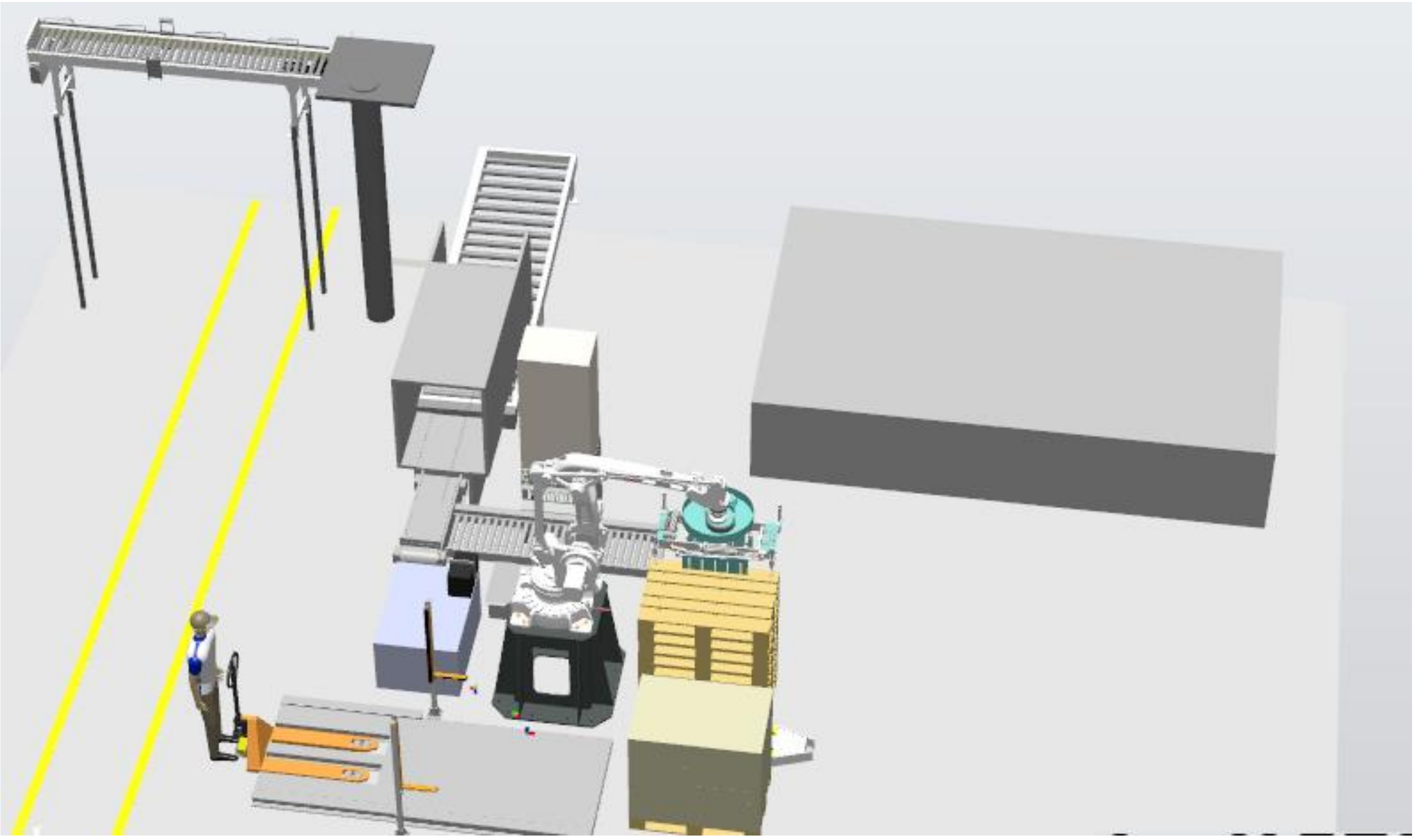


Figura 13: Simulation Layout

4.3 STATION LOGIC COMPONENTS:

In RobotStudio an offline programming environment for ABB robots, "PLANESENSOR", "LINEARMOVER"," LINE SENSORE", "AND, OR and NOT logic gate", "RAPID VARIABLE","TIMER","JOINT MOVER","HIDE and SHOW" and "ATTACH and DETACH" are essential components of the station logic RobotStudio utilizes smart components that enhance the simulation by adding intelligent behavior to objects. These components can send and receive signals, allowing for complex interactions based on sensor inputs or other conditions. For example, a smart component might trigger an action when a box is detected by a sensor, simulating real-world processes. The main purpose of the usage of the stated elements is for the following reasons: to control and simulate the movement of objects and of the robot we used (IRB460) in a virtual environment, often within the context of robotic automation tasks which is in this case palletization cell.

Key Aspects of Station Logic in RobotStudio

1. **Integration with RAPID Programming:** Station logic is often used alongside RAPID programming. RAPID programming can directly control robot movements and functions, the station logic handles the interactions of non-robot components such as sensors, conveyors, and other machinery within the simulation
2. **Signal Management:** The station logic framework allows for the management of various signals—both digital and analog—that facilitate communication between different components.
3. **Simulation of Non-Robot Elements:** simulate elements that do not directly involve robot control. This includes managing interactions between multiple processes that occur in a robotic cell but are not performed by the robot itself

4. **Visualization and Testing**: visualize and test robotic systems in a 3D environment before implementation. Users can simulate different scenarios, and optimize workflows without risking damage to actual equipment

the components that have been used in the simulation are the following:

1. <u>Plane Sensor:</u>

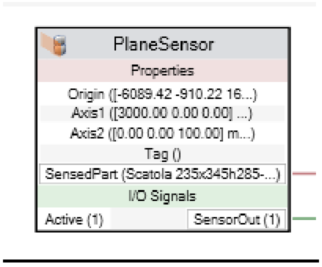


Figure I: Smart Component: Plane sensor

It is a virtual mechanism that is used to detects or controls movement within a specific plane in a 3D environment.

Key Characteristics of the Plane sensor:

1. Constrained Movement: it restricts the movement to a defined plane, typically along two axes (X and Y for example), it allows us to have object to move vertically or horizontally without changing its direction (going up or down).
2. Simulation Control: It is used to model sliding(moving) mechanisms or any other application where the movements are limited by our defined plane that will give us a representation of a real-life scenario in a virtual environment.
3. Interactivity: The Plane Sensor can interact with other components or sensors within RobotStudio to trigger actions or responses based on the object's position within the plane.

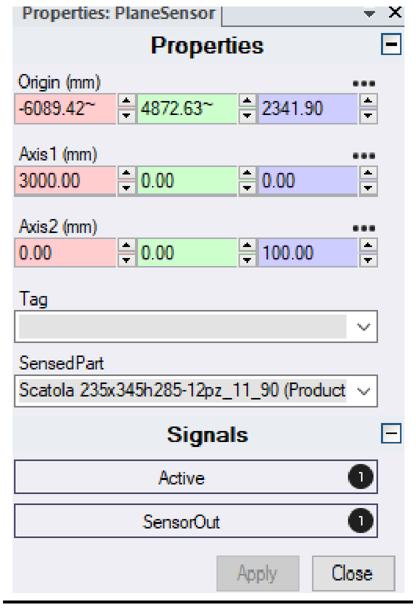


Figure II:PlaneSensor properties

Properties:

Origin: This property defines the reference point for the plane sensor's coordinate system. It's the point from which the sensor's axes (Axis 1 and Axis 2) are measured.

Axis 1 and Axis 2: These characteristics specify how the axes of the plane sensor are orientated. The direction in which the sensor detects things can be specified using them.

Tag: In the simulation, the plane sensor can be uniquely identified using the option tag. It can be useful in managing and organizing several sensors.

Sensed Part: This property specifies the object that the plane sensor is intended to detect.

Active: This property determines whether the plane sensor is currently active and detecting objects.

SensorOut: This property is an output signal that lets you know if the plane sensor has detected any objects. In the simulation, it is used to initiate actions.

2. LinearMover in RobotStudio

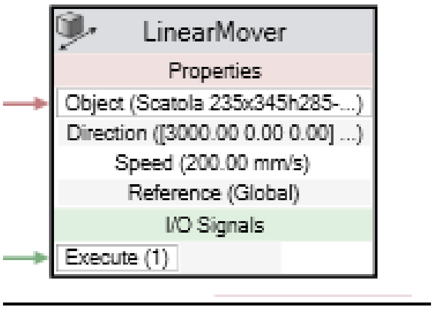


Figure III: Linearmover

Key Features:

- Linear Movement: The LinearMover allows the movement of objects, tools, or mechanisms in a straight line along a designated axis.
- Precise Path Control: This technique is used to accurately describe and simulate the movement of items in scenarios where precise linear positioning is crucial. Applications include pick-and-place procedures, object movement along a conveyor, or parts moving on a conveyor.
- LinearMovers are often used to simulate parts or objects moving along a linear path and integrating them with robots allows for realistic simulations of robotic interactions with these moving objects

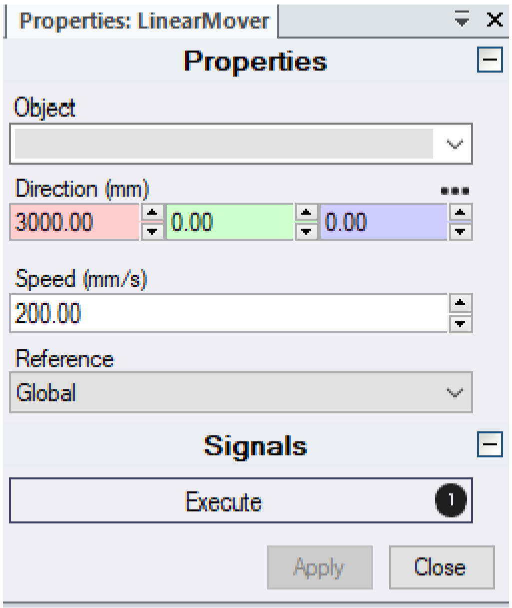


Figure IV: Linearmover Properties

The Linearmover mechanism is employed to control and simulate the linear movement of an object along a predetermined straight line. This mechanism determines the object's actions and how it interacts with other components inside the simulation.

the main features:

Object: Specifies the type of object the LinearMover represents.

Direction: we define the direction in which the object moves, in this example we had to move the object along x axis.

Speed: Set the constant speed of the object in mm/s.

Reference: The target point that the LinearMover seeks to reach is defined using the is used to specify the target point.

IO Signal: Execute: This is a signal that triggers the LinearMover to start or stop its movement. Once the signal is triggered, the LinearMover initiate the movement in the chosen direction at the selected velocity.

3. Line Sensor:

Line Sensor is used to simulate the detection of objects along a line that is typically on a conveyor system also can be implemented into the gripper depend on if this gripper has a sensor or no. It helps in creating more realistic simulations by allowing the robot to interact with moving parts or products on a conveyor.

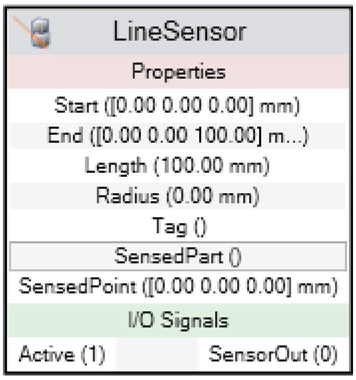


Figure 14:linesensor component in RS

Properties of the LineSensor

Start: Specifies the starting 3D coordinates (X, Y, Z) of the sensor line.

End: Specifies the endpoint of the sensor line.

Length: The total length of the sensor line. It controls how much of the conveyor path the sensor covers.

Radius: Sets the effective "width" around the line for detection tolerance.

Tag: A label to specify parts for the sensor to detect.

SensedPart: Holds a reference to the specific part detected by the sensor.

SensedPoint: Indicates the exact point on the sensor line where the part was detected.

<u>Active</u>: A Boolean setting that enables or disables the sensor. When true, the sensor can detect parts; when false, it remains inactive.

<u>SensorOut</u>: A Boolean output signal that turns true when a part is detected and false otherwise. This signal can trigger other actions in the simulation based on part detection.

4. AND/OR/NOT Logic gates:

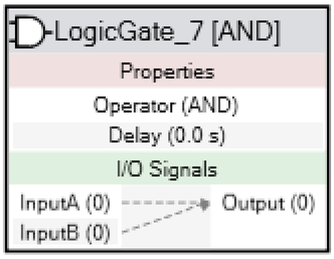


Figura 15:AND Logic Gate

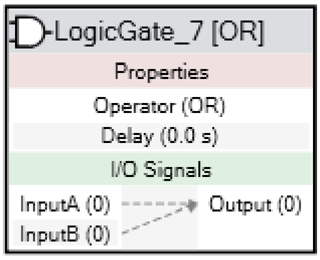


Figure 16:OR Logic Gate

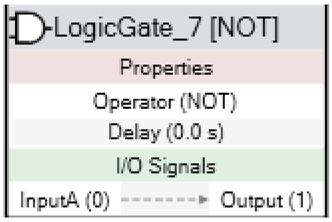


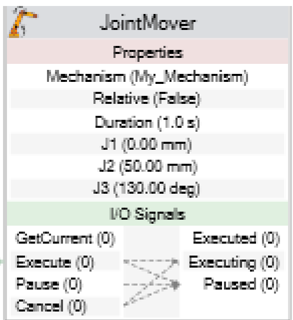
Figura 17:NOT Logic Gate

<u>AND</u> gate requires all input conditions to be true for the output to be true.

<u>OR</u> gate will output true if at least one of its inputs is true.

<u>NOT</u> gate, also known as an inverter, it reverses the input signal: if the input is true, the output is false, and vice versa.

5. <u>JOINTMOVER:</u>



The JointMover is a tool used to control the movement of specific joints in a mechanism that can be such as a robot or other articulated machinery during specified duration. Thus using the joint mover, we would be able to have precise manipulation of individual joints, which is helpful for setting up movements testing paths or calibrating positions in a simulation.

<u>Properties of the JointMover</u>

<u>Mechanism</u> Specifies the robot or mechanism that the JointMover will control.

<u>Relative</u> This Boolean property defines whether the movement is relative or absolute.

Duration Sets the time (in seconds) for the movement to complete. This helps in synchronizing joint movements.

J1 (mm) Define the target position for Joint 1 in millimeters. This property allows precise linear movement control of the first joint

J2 (mm) Sets the target position for Joint 2 in millimeters. It controls the movement of the second joint which represent an additional axis or direction in the mechanism.

J3 (deg) Defines the position of Joint 3 in degrees for rotational joints.

6. HIDE/SHOW:

Figura 18:Hide Smarcomponent

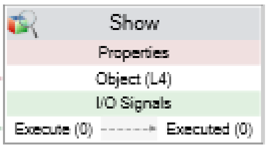


Figura 19:Show Smart component

HIDE and SHOW are used to control the visibility of objects within the simulation such as parts, boxes or any other components. This feature allows us to hide objects temporarily or show them again that will help us with testing and managing what's visible or hidden at any given moment. The way its is used in our simulation can be as an example, hiding a part(box) after it's been processed and showing a new one as it arrives.

7. ATTACH/DETACH:

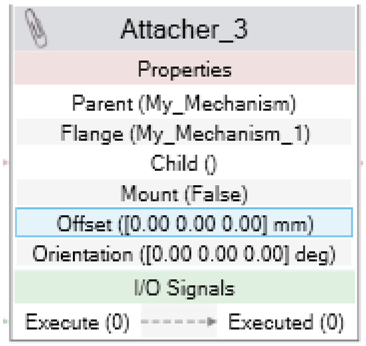


Figure V:Attach smart component

In RobotStudio, the Attach and Detach commands are used to simulate the interaction between robots and objects that is typically for tasks like pick and place or transferring parts in the virtual environment.

Key Features of Attach and Detach

1. Simulating Gripping and Releasing: This command allows users to virtually attach the parts to the robot, or detach them, which is similar to the real-world operation of gripping tools like vacuum grippers or mechanical clamps.
2. Dynamic Object Control: Attach and Detach enable objects to move with the robot (attached) or remain stationary/independent (detached).
3. Improved Process Visualization: By using these commands we can visualize how objects are picked, carried, and placed within the simulation.

8. Comparer

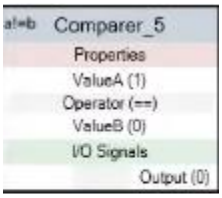


Figure VI:comaprer SC

The Comparer in RobotStudio is essential for decision-making by evaluating various inputs. It primarily compares values signals or states to generate outputs that influence other components.

Key Features:

- Multiple Input Handling: Can process several inputs simultaneously for complex evaluations.
- Output Generation: Produces outputs to control other components or initiate actions.
- User-Friendly Interface: Accessible through a graphical interface for easy setup without extensive programming.
- Real-Time Evaluation: Responds immediately to changes in input values, crucial for high responsiveness in simulations.

4.4 Introduction to the Code Implementation

This chapter is dedicated to the description of the code forming the backbone of the simulation developed for the virtual commissioning of the palletizing station. In setting up this program, the programming language RAPID has been used-a proprietary programming language by ABB for industrial robots. It defines major procedures and instructions necessary to control the robotic movements, gripper functionalities, and overall coordination of the system components. This code does everything, from setting and resetting digital outputs to control robotics movements, defining accurate target positions of moves, to the logic for attaching and detaching pallets, products, and separators. Such operations are of value when creating naturalistic simulations in the virtual environment, where precision has to go hand in hand with logic of flow.

The following are the key highlights of this code:

1. Target definitions: The robtarget constants are set to define spatial coordinates and orientations of the different tasks to be performed, providing the places where the robot can be positioned.

2. Organizing procedures: The procedures like the PalletAttachPrg and ProductAttachPrg encapsulate certain actions and hence provide better readability of code and maintainability.

3. Motion instructions: The code uses motion instructions such that linearly moving with MoveL and joint-based movement with MoveJ emulate the robotic operation as smooth and fast as possible.

4. Digital Signal Management: Manipulation of digital inputs and outputs to simulate sensor triggers and actuate the gripper systems. In the process, the simulation will be realistically performed to imitate the actual processes done by the robot. Testing can then be done without the risk of accidents in a virtual setting. The parts of code are described in the logic, functionality, and each part's significance below.

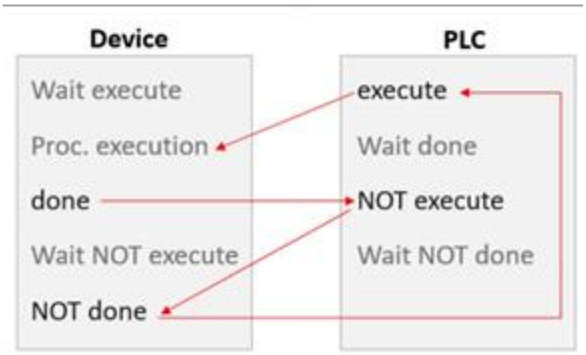


Figure 20:workflow of robots controller

The provided R program is structured to control a robotic system, for tasks involving palletizing and product handling. I'll break down and explain each section.

1.Constant Definitions:

“ CONST robtarget Target_Home := [[1505,0,1436], [0,0,1,0], [0,0,0,0]];”

robtarget: This defines a specific point in 3D space for the robot to reach.

Each target consists of:

- (x, y, z) Coordinates for the robot’s position.

- Orientation (using a quaternion (x, y, z, w)) that defines how the robot tool is oriented.

- Target_Home: This is the home position of the robot (where it rests or starts).

Similar definitions are made for other targets such as Target_PalletAttach, Target_PalletDetach, Target_ProductAttach, etc., representing specific points where the robot will move to perform actions like attaching, detaching, or picking up products.

2.Persistent Variables:

“ PERS num counter := 0;

PERS num productcounter:= 0;

PERS num seperatorDetached := 0;”

PERS means these variables persist through the program execution.

-counter keeps track of a count, used to loop through specific actions (handle products in batches).

- productcounter tracks how many products have been handled.

- seperatorDetached tracks whether the separator component has been detached.

3.Main Program (PROC main):

PROC main()

Reset doPalletAttach;

Reset doPalletGripperClose;

Set doPalletGripperOpen;

counter := 0;

productcounter := 0;

seperatorDetached := 0

```
    HomePrg;

    PalletAttachPrg;

    stop;

ENDPROC
```

- The `PROC` (procedure) section defines a main workflow for the robot. It resets several signals and sets others to control the grippers, gripper open or close actions, and product attachment or detachment.

- Reset: Clears the state of a specific output (gripper actions).

- Set: Activates the output (opening or closing a gripper).

- The main program calls different procedures like `HomePrg`, `PalletAttachPrg`, `PalletDetachPrg`, which are defined later in the program.

4. Movement Commands (MoveJ, MoveL):

- `MoveJ` Move Joint: Moves the robot to a target using joint movements.

- `MoveL` Move Linear: Moves the robot in a straight line from one point to another.

```
MoveJ Target_Home, v1000, fine, tool0\WObj := wobj0;
```

This command moves the robot to the Home position at a speed of `v1000` (1000 mm/s), with "fine" meaning it should stop precisely at the target. The tool and work object are specified with `tool0` and `wobj0`.

5. Pallet Attach Procedure (PROC PalletAttachPrg):

```
PROC PalletAttachPrg()

    Movej offs(Target_PalletAttach, 0, 0, 300), v500, z100, tool0\WObj := wobj0;

    MoveL Target_PalletAttach, v1000, fine, tool0\WObj := wobj0;

    Reset doPalletGripperOpen;

    Set doPalletGripperClose


ENDPROC
```

- offs(Target, 0, 0, 300): Offsets the target position by (0, 0, 300) mm in the Z-axis. This is used to move slightly away from a previous position for safety.

- Reset and Set: Controls outputs (grippers). `doPalletGripperOpen` is reset (opened) while `doPalletGripperClose` is set (closed), enabling the robot to grab the pallet.

- **‘PalletDetachPrg’**

- Purpose: Detach a pallet.

- Steps:

1. Moves above the detachment point and lowers to release the pallet.

2. Resets attachment signals and retracts the gripper for safe detachment.

3. Returns to a safe height.

6. Product Handling Procedures (Attach and Detach):

- ProductAttachPrg handles the attachment of products to the gripper:

```
PROC ProductAttachPrg()

    productcounter := productcounter + 1;

    counter := counter + 1;



    Set doProductAttach_1;



ENDPROC
```

- The robot counts the products and updates `counter` and `productcounter`.

- It waits for sensors or signals `WaitDI diProductCame_1, 1` indicating that products are ready to be attached, then proceeds with the attachment actions `Set doProductAttach_1`.

<u>7. IF-ELSE Logic and Counters:</u>

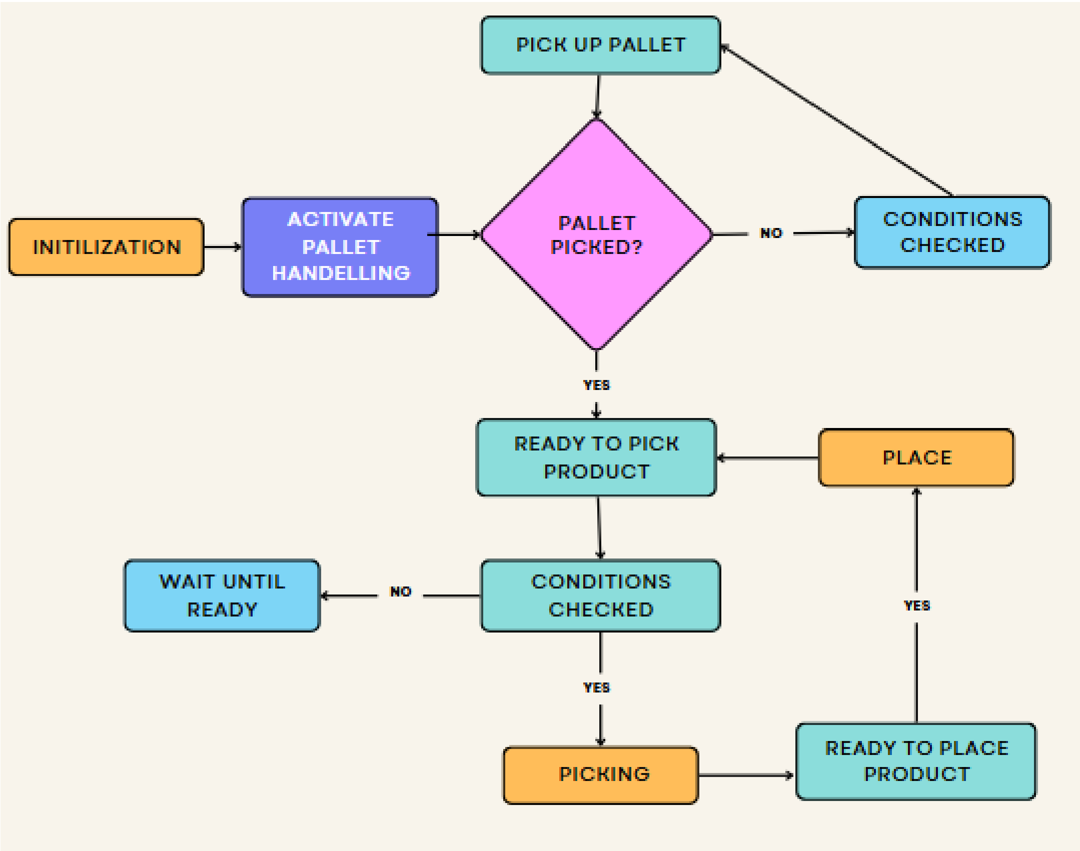
- IF counter = 5 THEN counter := 1;: This resets the counter after reaching 5.

- Conditional logic allows the program to handle different scenarios based on the number of products processed, as seen in the `ProductAttachPrg`.

<u>8. End Procedures:</u>

- Each procedure concludes with a MoveJ or MoveL command to return the robot arm to a safe position after performing its task.

4.5 SIMULATION WORKFLOW:



1. Initialization

Prepare the robot and system for operation.

Actions:

Reset all signals to ensure the robot starts in a neutral state:

“Reset doPalletAttach;

Reset doPalletGripperClose;

Reset doPalletGripperOpen;

Reset doProductAttach_1;

Reset doProductGripperBackward;

Reset doProductGripperForward;

Reset doSeperatorAttach;

Reset doVacuumGripperForward;

Reset doVacuumGrippeBackward"

Move the robot to the home position using HomePrg.

"PROC HomePrg()

MoveJ Target_Home, v1000, fine, tool0\WObj:=wobj0;

ENDPROC"

Result: The robot is in a known and safe state, ready for the first task.

2. Pallet Handling

Attach and place a pallet for the operation.

Attach Pallet:

Move to the pallet's location (Target_PalletAttach):

MoveJ offs(Target_PalletAttach, 0, 0, 300), v500, z100, tool0\WObj:=wobj0;

MoveL Target_PalletAttach, v1000, fine, tool0\WObj:=wobj0;

Activate the gripper (doPalletGripperClose) to attach the pallet:

Reset doPalletGripperOpen;

WaitTime 1;

Set doPalletGripperClose_2;

WaitTime 1;

Set doPalletAttach;

Place Pallet:

- Move to the target location for the pallet (Target_PalletDetach):

  MoveL Target_PalletDetach, v1000, fine, tool0\WObj:=wobj0;

- Release the gripper (doPalletGripperOpen) to detach the pallet:

  Reset doPalletGripperClose_2;

  WaitTime 1;

  Set doPalletGripperOpen;

A pallet is placed at the designated position, ready to receive products.

3. Product Handling (Loop for Each Product)

Attach products, move them, and place them on the pallet.

Steps for Each Product:

Product Attachment:

- Move to the product's location (Target_ProductAttach):

  MoveL Target_ProductAttach, v1000, fine, tool0\WObj:=wobj0;

- Check if the product is present using sensors (diProductCame_1)

  WaitDI diProductCame_1, 1;

- Activate the gripper to attach the product (doProductAttach_1):

  Set doProductAttach_1;

  WaitTime 0.1;

Move to Pallet:

- Move along the predefined path to the target pallet position.

Detach Product:

- Use one of the detachment programs (ProductDetachPrg_1, ProductDetachPrg_2) based on the counter value:

  MoveL Target_ProductDetach_1, v1000, fine, tool0\WObj:=wobj0;

  Reset doProductAttach_1;

  WaitTime 0.1;

Products are sequentially attached and placed on the pallet.

4. Separator Handling

Place a separator to divide product layers on the pallet.

<u>Attach Separator</u>:

Move to the separator's location (Target_SeperatorAttach) using SepretatorAttachPrg:

MoveL Target_SeperatorAttach, v1000, fine, tool0\WObj:=wobj0;

<u>Place Separator</u>:

Move to the designated position on the pallet (Target_SeperatorDetach) using SeperatorDetachPrg:

MoveL Target_SeperatorDetach, v1000, fine, tool0\WObj:=wobj0;

- Release the separator:

Set doVacuumGrippeBackward;

The separator is placed, dividing product layers.

4.6 Controller :

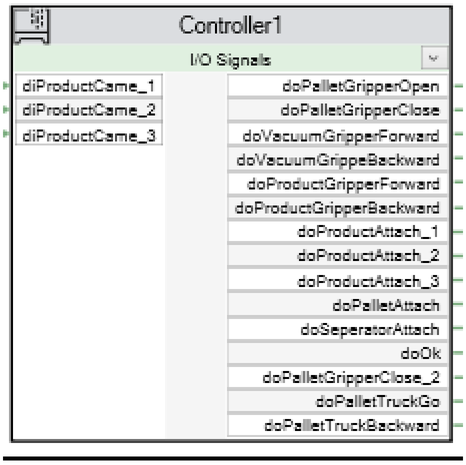


Figure VII:simulation controller

The Controller1 in your simulation is the central hub that coordinates the input and output signals across all components of the system.

Input Signals (di): **diProductCame_1**, **diProductCame_2**, **diProductCame_3**:

These signals indicate that a product has arrived at specific points in the system, such as different positions on the conveyor. Also these inputs are triggered by sensors detecting the presence of products (plane sensors).

Output Signals (do)

1. **Gripper Control**:

   doPalletGripperOpen and **doPalletGripperClose**: those digital outputs command the pallet gripper to open or close to handle the pallets.

   doVacuumGripperForward and **doVacuumGripperBackward**: these 2 Dos control the forward and backward motion of the vacuum gripper used for moving the 4-axis robot in order to do the product pick and place.

2. **Product Gripper Control**:

   doProductGripperForward and **doProductGripperBackward**: Manages the motion of a gripper specifically designed for handling products.

   doProductAttach_1, **doProductAttach_2**, **doProductAttach_3**: Triggers attachment actions for individual products at different stages.

3. **Pallet Handling**:

   doPalletAttach: Secures the pallet in place for further processing.

doPalletTruckGo and **doPalletTruckBackward**: Controls the movement of the pallet truck for transporting pallets.

4. **Separator**:

doSeperatorAttach: this Do control the attachment of separators for layering (that serves as protection for products on pallets that will be further taken away).

5. **Status Signal**:

   doOk: Indicates that the system is ready (to start the palletization process) or has completed successfully (to do the operation of the palletization again).

Role of the Controller

- **Central Coordination**: It ensures that all components (conveyor, gripper, pallet truck) work in synchronization by processing input signals and issuing the necessary commands.
- **Logic Execution**: Implements the logic for the sequence of operations. For example, if a product is detected on the conveyor, the controller trigger a vacuum gripper action (doVacuumGripperForward).
- **Modularity**: By using clearly defined I/O signals, the controller maintains modularity, making it easier to integrate additional components or modify existing logic.

4.7 station logic

Station logic in the RobotStudio environment refers to the system of managing and controlling the interactions between various components within a robotic simulation, it is like the brain that manages how all the components work together. It controls the behavior of robots, conveyors, and other elements to simulate a real-world process. This logic is essential for visualizing how everything interacts in a realistic way, even though we are only working in a virtual environment.

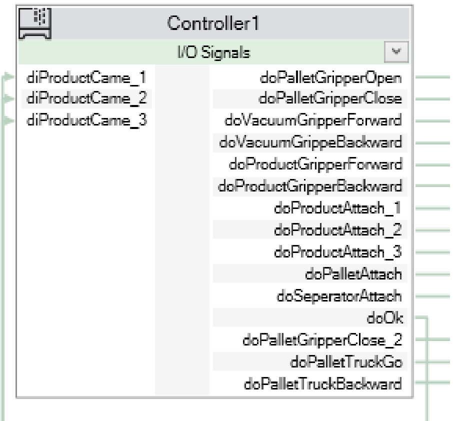


Figura 21:virtual Controller 7.15.1

SC_conveyor:

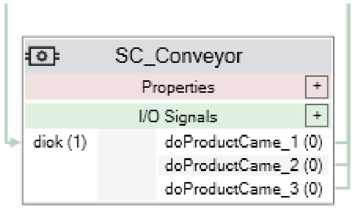
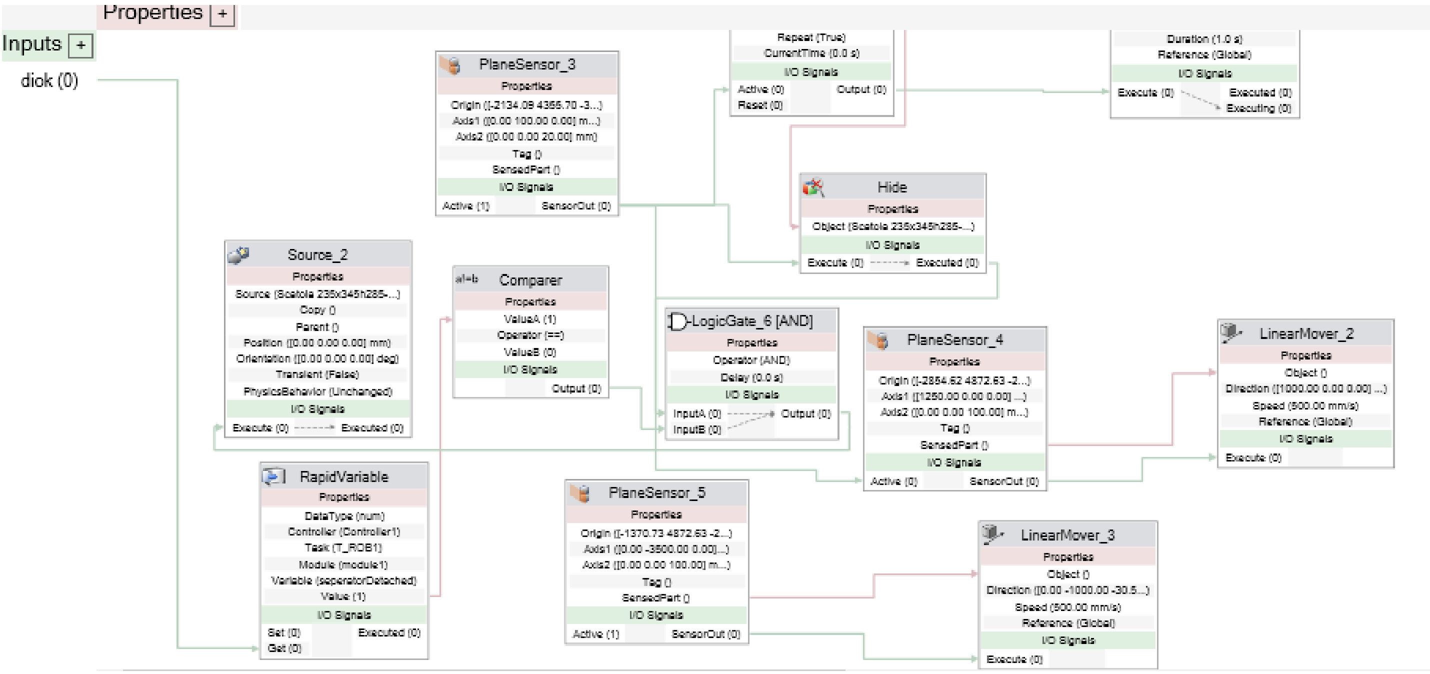


Figure 22: the smart component that's responsible for the movement and creation of boxes along the conveyors



SC_Conveyor station logic

The process begins with the SC_conveyor, which is activated when it receives a signal from the controller the doOk signal. This activation triggers the DIok, that has a crucial role in managing the flow of boxes within the simulation.

Once activated DIok the connected to a component known as RapidVariable. This component is linked to a Comparer, which compares two values—referred to as valueA and valueB. The output from this Comparer is linked to input B of AND logic gate. Input A of this gate is connected to another signal, creating a condition that must be met for the subsequent actions to occur. Output of the AND logic gate is then connected to Hide. The execution within Hide is activated by the output from a Plane Sensor. When this sensor detects a box, it activates Hide, which literally hides the box from further processing.

Simultaneously, Hide initiates the creation of another box using the same source component after a delay specified by a Timer Component (set to 5 seconds).

The first box is detected by Plane Sensor. This detection activates a Linear Mover, which facilitates the downward movement of the box, that operates at a predefined velocity, moving the box downwards in a linear way, through an elevator-like mechanism.

As the box moves downward, it eventually moves out of range of Plane Sensor, this absence of detection indicates that the box has completed its designated travel distance, thus consequently the Linear Mover stops its operation. Upon reaching the ground floor conveyor, the box continues its passage along this conveyor. The movement is again managed by another Linear Mover, ensuring that it travels in a predefined direction and speed.

At this stage, two additional sensors become useful. When Plane Sensor 6 detects the box while Plane Sensor 7 does not, both signals are fed into another AND logic gate. This configuration allows for continuous linear movement of the box. Once Plane Sensor 7 detects the box it triggers a NOT logic gate that terminates all linear movement. This stopping mechanism ensures precise control over the box's trip through the station.

The final step of these sequences are completed, an important output signal 'DoProductCame_1'is set to 1. This signal indicates that a product has successfully navigated through the system and reached its intended destination. Then other pick and place operations are triggered.

SC_RobotGripper:

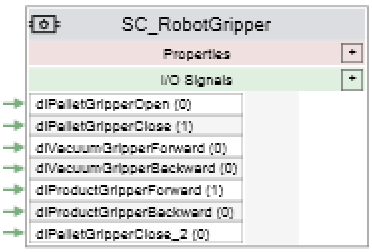


Figure 23:smart component of the gripper managing, that get its input signals from the controller

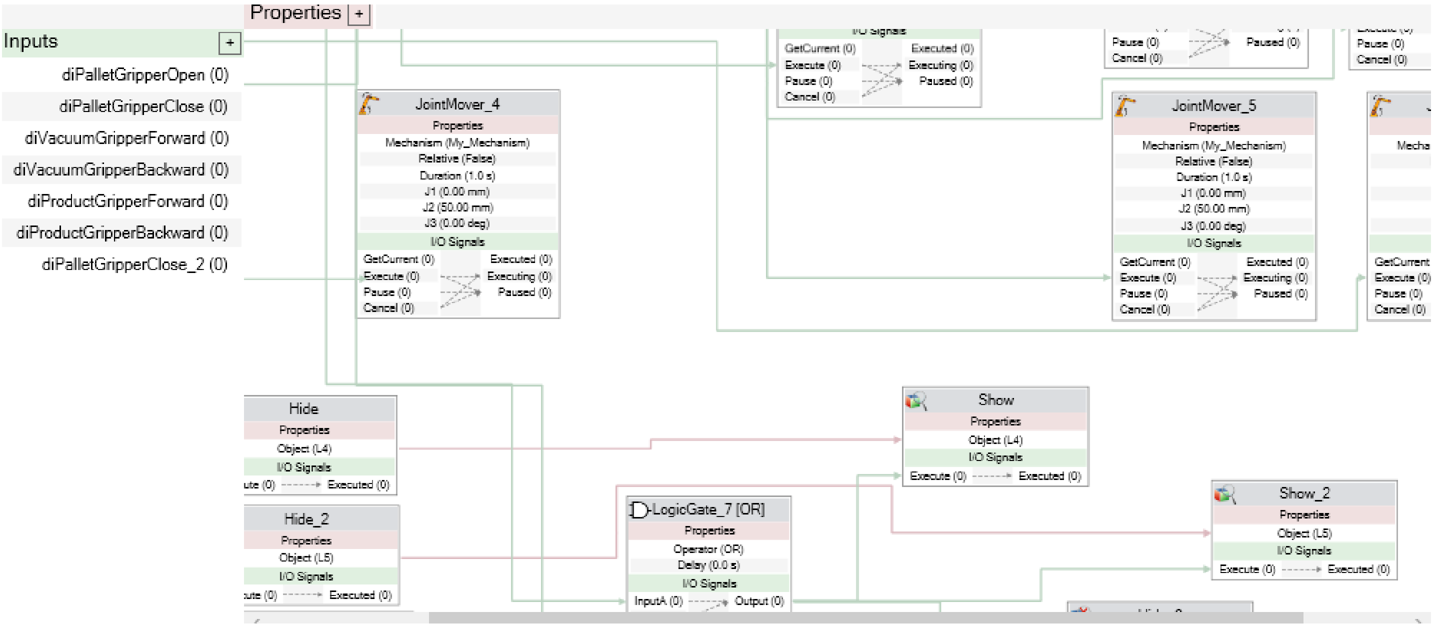


Figura 24: SC_Robotgripper staion logic

The SC_RobotGripperSmart Component is designed to execute precise instructions for opening and closing the gripper, as well as moving the vacuum gripper forward and backward. These functionality are to the pick-and-place operations involving boxes and pallets.

Within this Smart Component all digital inputs derive their values from the controller which operates through the RAPID code. The controller uses SET and RESET commands to toggle the digital inputs between 0 and 1, depending on whether a specific operation needs to be executed or concluded.

The Hide and Show functionalities embedded in this component serve: they manage the visual representation of objects such as boxes and pallets during the simulation, these commands ensure that when a box or pallet is picked up, it disappears from its original position and reappears as attached to the gripper. The final point of the robot predefined path, the box detaches from the gripper and is shown at its new position same goes for the pallet. This sequence of operations ensures the continuous execution of pick-and-place tasks in the simulation while maintaining realistic behavior and visualization of the process.

Smart_Component_1

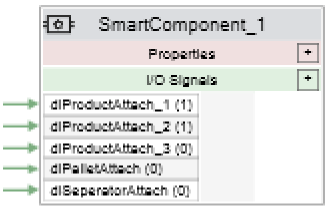
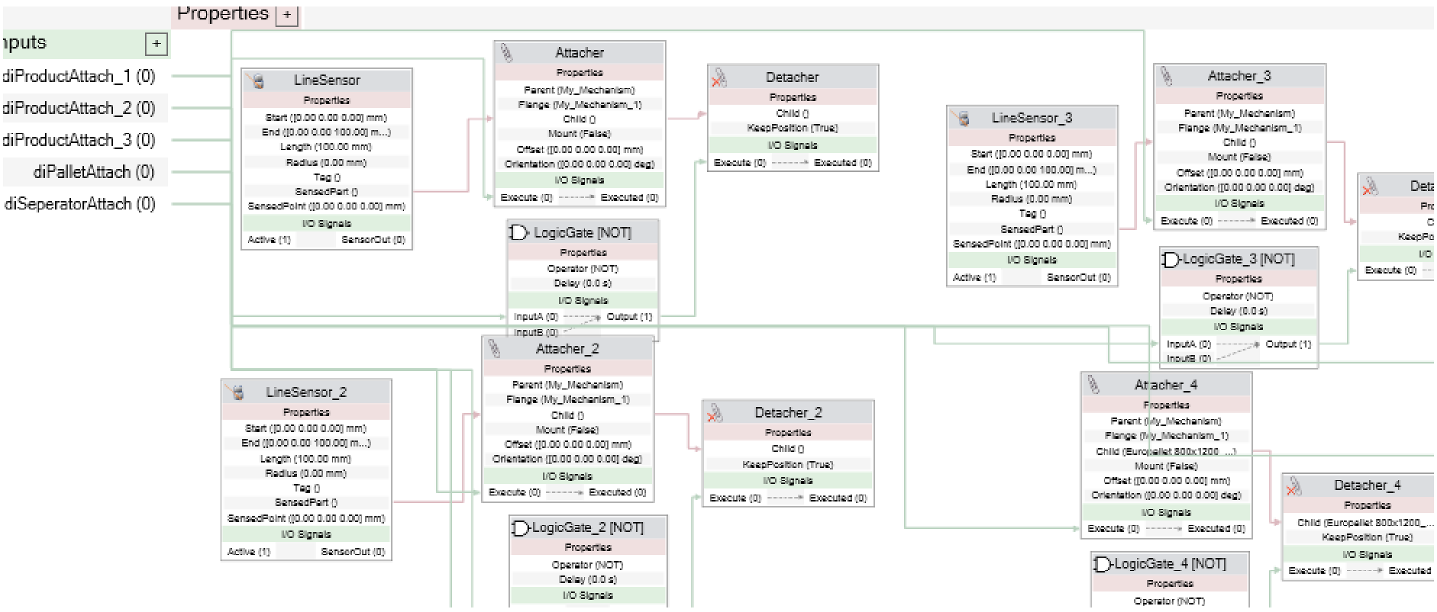


Figure 25:the smart component that manage the attachment and the release of boxes and pallet



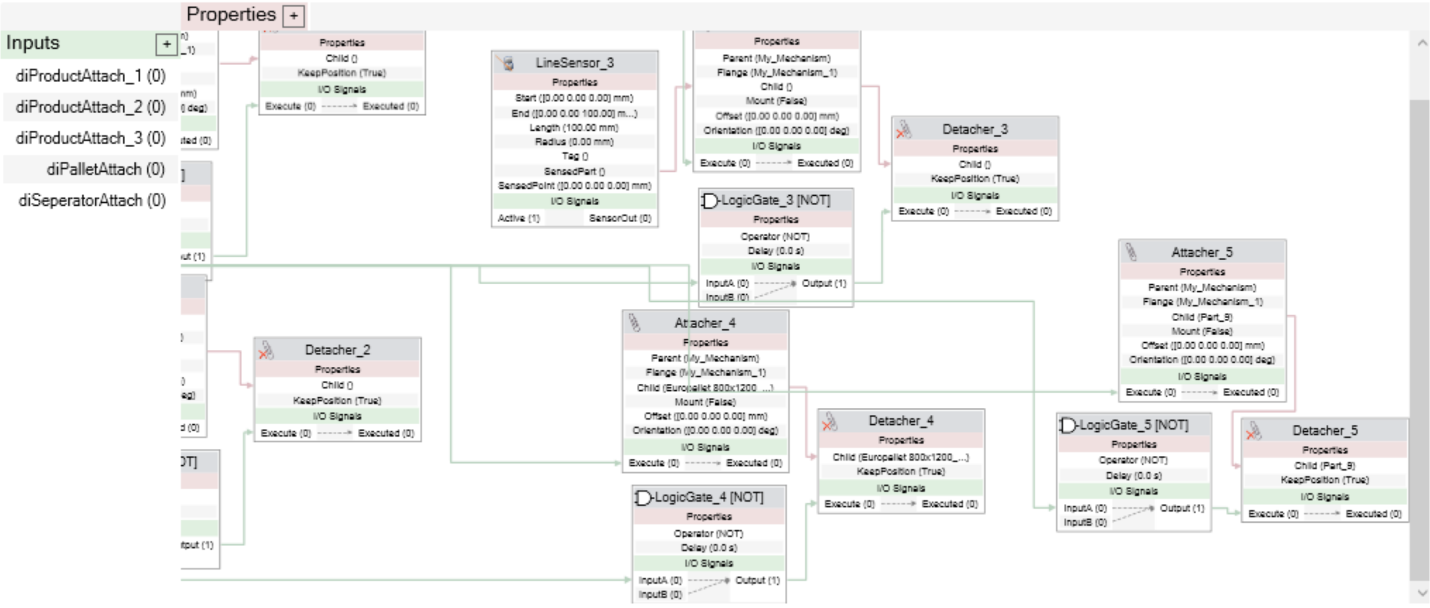


Figura 26: Smart_component1 Station logic

The Smart Component 1 receive all its digital inputs from the controller via the RAPID code.it is specifically designed to handle the attachment and detachment processes for both boxes and pallets. This functionality is achieved through the use of Attach and Detach components, which coordinate the interactions between the gripper, the boxes, and the pallets.

The operational flow is as follows: when a line sensor detects a box, its output triggers the Attach component, instructing the attach of the box to the gripper. After a specified time corresponding to the duration needed for the robot to traverse its predefined path the Detach is activated that results in the box being released and placed onto the pallet.

A similar process applies to the pallets. in this case, no box is involved. Instead, the pallet itself is attached to the gripper, transported along the predefined path, and subsequently detached and placed in its designated position. This sequence ensures efficient and precise handling of both boxes and pallets within the simulation.

Smart component 2

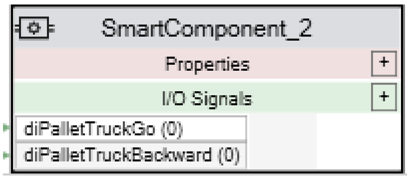


Figure 27: Smart component that is responsible of the movement of the pallet and the Human

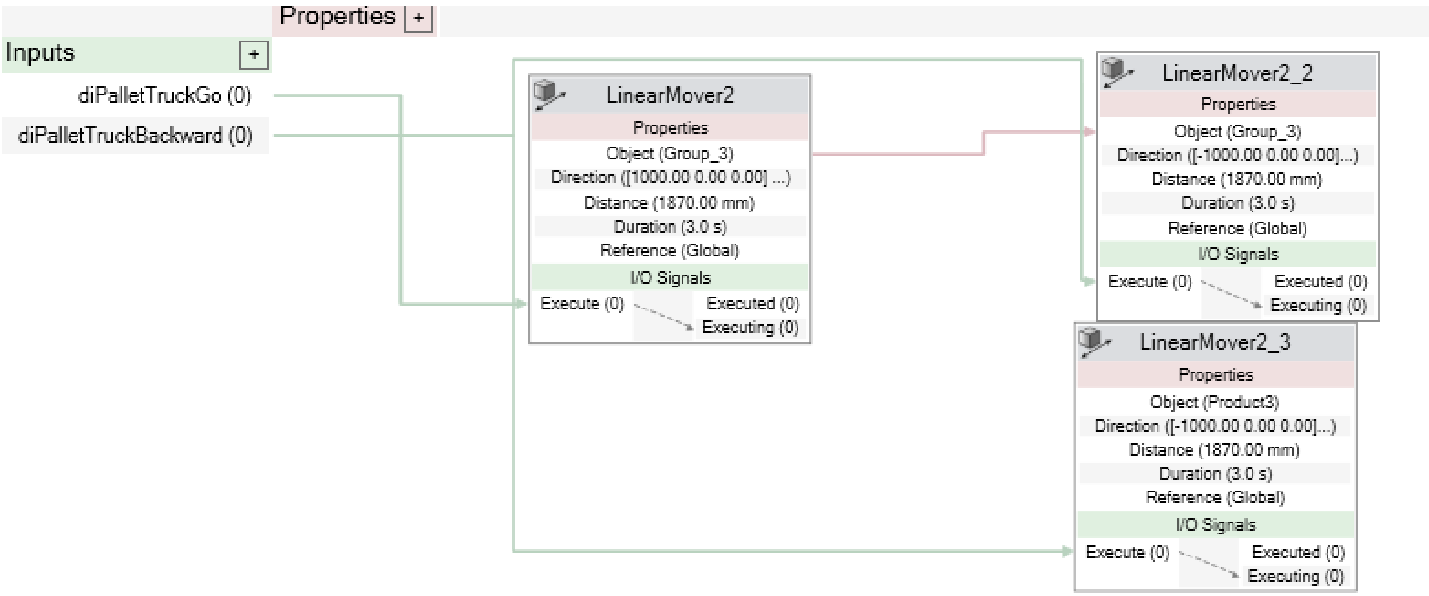


Figure 28:Smart_component 2 station logic

The smart component receives its input signal from the controller. Upon completion of all pick-and-place operations, the DI activates the Linear Mover of the pallet, facilitating the movement of pallets. The operational sequence is as follows: a human operator approaches the pallet, which is connected to a presa pallet. Subsequently, both the operator and the pallet, along with the presa pallet, move outward to simulate the action of the operator retrieving a fully loaded pallet. Following this operation, the palletization process recommences, involving an empty pallet and the placement of boxes onto it.

4.8 Results

Initial setup (conveyors, sensors, products, robot):

In the initial setup, the system begins with the creation and movement of boxes using a combination of conveyors, sensors, and components that manage their flow:

Conveyors and Products The source component generates boxes one after the other at specified intervals. These boxes begin their journey on the first conveyor, where the motion of the boxes is controlled by a Linear Mover. The Linear Mover ensures that the boxes keep moving with a constant speed on the conveyor belt until they reach the lift system. At this point a Plane Sensor detects the presence of a box. The lift mechanism, also driven by a Linear Mover, was engaged, and the box lowers to a second, lower level conveyor. Once the box is on the second conveyor, another Linear Mover continues its movement forward, maintaining a controlled speed and direction. Sensors placed strategically on this conveyor monitor the position of the box, ensuring smooth flow and accurate stopping at key points.

Intermediate steps (product movement, gripper action):

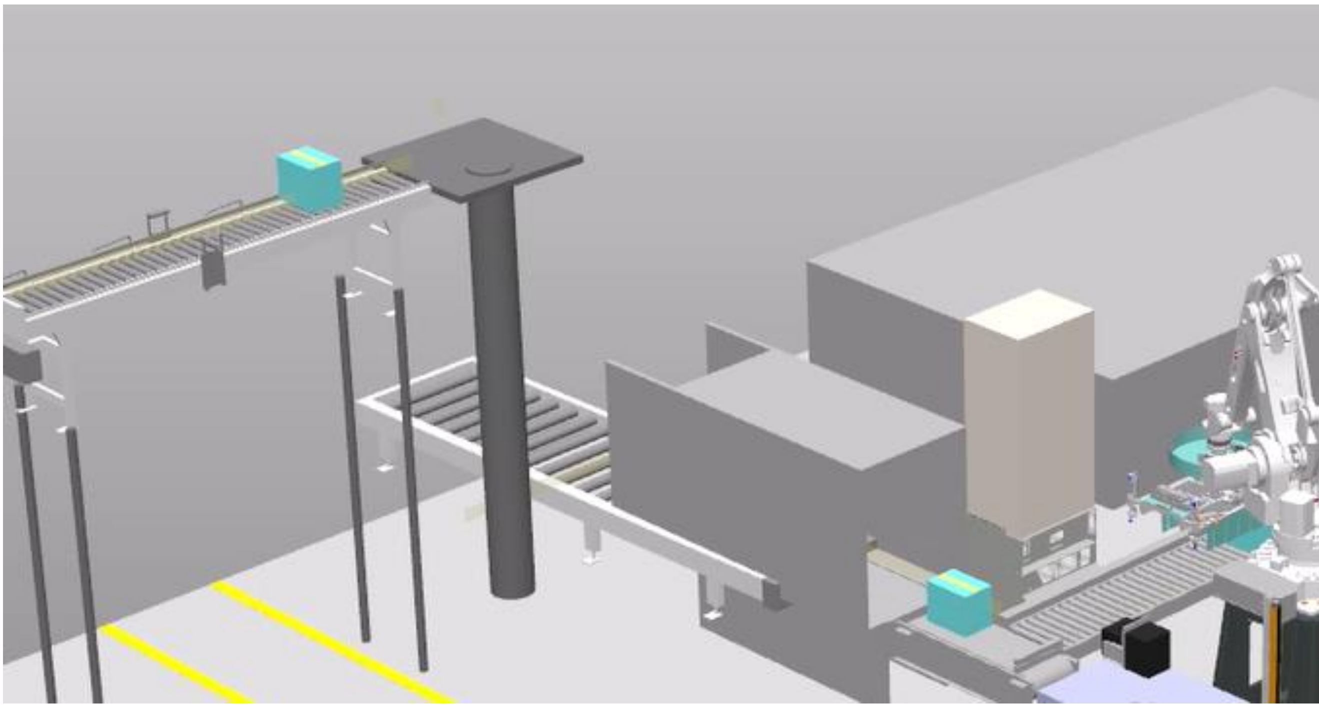
Once the products have traveled along the conveyors, they continue to move towards their designated endpoint, where they are intended to stop. The movement of the boxes is controlled by the Linear Mover but at a specific point in the process, the flow of the products is halted, this occurs when a Plane Sensor detects the presence of a box at the correct position. The sensor then sends a signal that deactivates the Linear Mover that will stop the movement of the boxes.

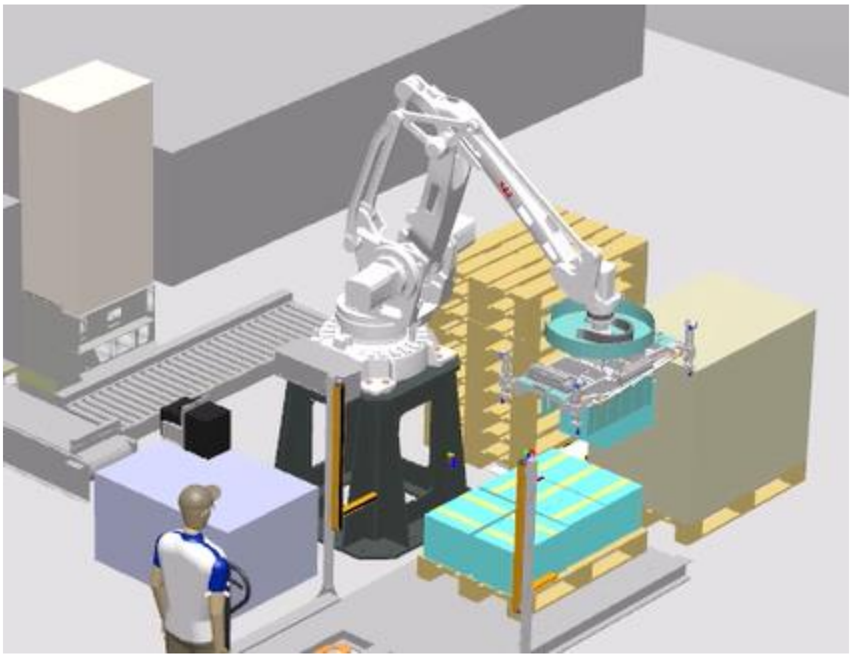
Before any pick-and-place operations can begin, the gripper must first pick up a pallet. The process works as follows:

1. The gripper receives a signal from the controller, instructing it to open.
2. The pallet is then placed in position by the controller's signal, and the gripper closes around the pallet.
3. Once the gripper successfully attaches to the pallet, the robot's predefined path is activated, allowing the gripper to move the pallet to its designated location.

4. Once the pallet has been properly positioned, the gripper detaches from it and the pallet remains in place.

After the pallet is set in position, the pick-and-place operation starts. The gripper now picks up the first box, moves it along the robot's path, and places it onto the pallet. This sequence of operations is repeated as the gripper continues to pick and place boxes onto the pallet, ensuring a smooth and continuous operation. The precise movement and timing of the gripper are controlled by the signals from the controller, which manage both the attachment and detachment of boxes, as well as the movement of the gripper throughout the process.





Final stages (palletizing complete or products hidden as processed):

Final stages of the process, whether palletizing complete or the products have been hidden as processed: As the pick-and-place continues, the final stages begin when all the boxes have been placed onto the pallet.

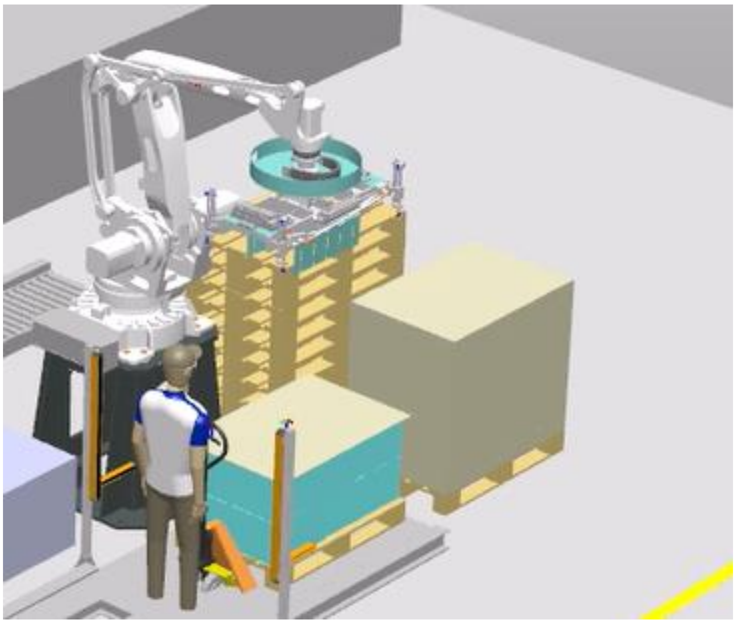
1. Palletizing complete: The system will provide an indication when the last box has been placed on the pallet.   Generally, it is done through a digital output signal from the controller by an indication that the pallet has achieved a full load and therefore is ready to move to the next process. At this step, a sheet is placed on top of products to secure them for any kind of transport. That task is handled by the gripper, it opens, dropping the sheet onto the pallet so that the products on it remain covered.

2. Products occluded at processing result: Every time one of those boxes is positively processed-separated, moved, and left on a pallet-the product must stop being seen hanging around on the conveyor. This is done through the Hide feature, which is triggered by the Plane

Sensor. Once a box has been placed onto the pallet, the sensor detects the absence of the box and sends a signal to the system to hide the processed product from the conveyor. At the same time, the system starts creating a new box to maintain the flow of the simulation.

3. Human operator interaction: When the pallet is completely loaded and topped with a sheet, a human operator is simulated coming to take the pallet. The signal from the system triggers an action by the operator, that will make it move the pallet to rest at its next destination. This movement is managed by the Linear Mover moving the pallet and thus the operator as they approach into position. It simulates human interaction with the pallet, hence allowing the creation of a realistic view when an operator retrieves a fully loaded pallet.

By the end of this process, all the products become palletized, covered, and ready for transport, continuing the cycle of creating new boxes and processing them. In this way, the simulation can create a continuity in the flow of products with realistic interactions.



5 Sales:

5.1 Technical benefits

Virtual commissioning can be very effective for sales purposes, in automation and robotics. Here is how it will be used to persuade the potential customer:

Realistic Demos without Physical Setup

- Virtual commissioning allows one to present the complete, realistic simulation of the solution, for example, a robotic system or an automated production line, without actual equipment. It diminishes the cost and logistical obstacles in setting up demo units, especially for the large or complex systems.

Customized Presentations

- The virtual model can easily be adapted for each prospective customer based upon their needs. This further enhances the chances of the customers understanding how the solution will work in their facility.

Improved Demonstration of Capabilities

- What may not be easily demonstrated with a static demonstration, or a generic demonstration can be highlighted in a virtual model. For example, you can show complicated scenarios, production efficiencies, or safety features within the simulation that will help the prospective customer understand the full value of the system.

Faster Sales Cycles

- Because VC can generate simulations and changes due to customer feedback fast, it speeds up the decision-making process. The sales cycles can be compressed since potential buyers see the solution capability immediately, and this gives them the confidence to move forward much faster.

Testing and Troubleshooting Before Purchase

- Through VC, customers can see the system performance in various simulated scenarios. In high-value, high-stake purchases, when one knows a product has gone through virtual commissioning to run well, that raises confidence in the product by a lot.

Remote Access and Presentations

- Virtual commissioning also enables remote sales presentation. The sales teams can present the VC models over video calls and engage stakeholders not physically present. This does widen up the circle of sales effort.

5.2 sales and marketing in manufacturing

It is increasingly recognized that virtual commissioning brings added value not only from the technical validation point of view but also as a tool for sales and marketing in manufacturing. In fact, VC allows companies-with the creation of the so-called digital twin, meaning a very accurate virtual model of a system-to visually show and test the capability of a production line in advance of any physical setup. This could greatly enhance a sales presentation where clients see correct simulations of the processes in production, interact with virtual models of the products, and visualize customizations. An immersive experience that can help clients much better understand what the potential outcomes and benefits of such a system can be; this increases their confidence in a purchase decision.

This includes the use of virtual commissioning on specific industries, such as automotive and manufacturing, to solve client-specific needs by system tuning in simulation, early problem identification, and performance improvement demonstrations. It will also let enterprises simulate changes for special production requirements of customers by saving time and costs involved in physical prototyping. Besides, VC can also show customers how different components of a system interact in real time, which is quite useful for industries with complex machinery and strict compliance requirements, such as in smart manufacturing and automotive settings.

For those companies that do not have a starting point, the identification of pilot projects and laying out concrete objectives can establish, at least at the outset, the value of virtual commissioning in the longer term both for sales and marketing-related applications, as well as operations themselves.

5.3 The cost of virtual commissioning

The cost of virtual commissioning projects may be relatively broad, as this would depend on the complexity, scale, industry, and other factors leading to a certain degree of customization. Simplistically speaking, basic virtual commissioning for a small-scale project can cost in the range of $5,000 to $50,000. For large projects, particularly those pertaining to sectors dealing with automobiles or large-scale manufacturing concerns, costs may increase manifold to $200,000 or even more, considering advanced simulation requirements and digital twin technology.

That cost is also rising due to other factors, such as real-time collaboration features, the accuracy of the digital twin, and some special software tools. Other companies go with "full-service" solutions that have simulations and analysis directly managed by experienced providers. This can save money on training and internal development but could add more upfront costs. This may be very positive for companies that are just starting to work with VC, since they avoid setup costs associated with internal competencies.

5.4 Contribution to the Company Through This Thesis Project

This thesis project gave so much needed support to the company since they were challenged due to the fact that they were not able to prioritize this Virtual Commissioning Project because they were still busy with other projects. The company, with limited resources to develop this particular project in-house, offered me training in order to handle it on my own. This training provided technical skills for carrying out a detailed simulation and virtual commissioning setup in RobotStudio, hence serving the aim of my thesis. Upon successfully completing the training, we reached an agreement that allowed me to take full responsibility for this project. This partnership created a new, revenue-generating service for the company. Virtual commissioning now adds to the company's service offerings, allowing them to provide a specialized, simulation-based validation of robotic setups before deploying them physically, which can be adapted and scaled based on client requirements.

For this initial project, the client was charged $5,000. This fee covered the validation of the vacuum gripper's functionality, including testing and ensuring its performance within the palletizing setup. The results demonstrated that the gripper met operational standards, providing confidence that the system could handle the specified palletizing tasks reliably.

In addition, this project established a sustainable service model for the company. Future upgrades to the client's system can be tested within RobotStudio before physical implementation, allowing the company to offer continued, on-demand simulation services. These future simulations will be billed based on the complexity and scope of each specific service provided. This arrangement benefits the client by providing a reliable testing platform for any new configurations, while the company gains an additional revenue stream by offering cost-effective, customizable virtual commissioning services to various project needs

6 Conclusion

This research successfully demonstrated the implementation and benefits of virtual commissioning for a robotic palletizing system. By leveraging ABB’s RobotStudio, a detailed and precise simulation of the IRB 460 robot with a vacuum gripper was developed, enabling comprehensive performance analysis and validation before physical deployment. The study highlighted the significant advantages of virtual commissioning, including reduced setup time, cost savings, and enhanced system reliability.

The results emphasize the effectiveness of virtual environments in identifying and resolving design and operational inefficiencies. The IRB 460 robot proved highly compatible with the vacuum gripper, meeting the demands of high-speed, precision palletizing tasks. This integration showcases the potential for advanced robotic solutions to address the challenges of modern industrial automation, particularly in environments requiring adaptability and efficiency.

Future work can expand on these results by incorporating energy efficiency studies, testing the system under diverse product configurations, and integrating Industry 4.0 technologies for enhanced operational intelligence.

The successful outcomes of this project affirm the transformative impact of virtual commissioning in optimizing robotic systems, setting a foundation for further advancements in industrial automation.

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