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AS/RS AUTOMATED STORAGE SYSTEM WITH MIXED PALLETIZING – OFFLINE SIMULATION

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Abstract: *The study is realized during the bachelor project developed for robotics specialization and presents the mixed palletizing operation into the automated storage system, called AS/RS. The paper is based on the research through which the industrial robots integrated in the system and process are analyzed, end-effectors which can be used, possibility to load-unload the highest storage, types of objects that can be palletized or how the order will be on pallets. The most important step was to see what other companies developed and how they integrated the entire systems in the process. That involved a lot of work and research to find patents, scientific articles, animation and how the automated storage system can be improved. It was studied the patent developed by the Bastian Company, which had an automated storage system with mixed palletizing. In the patent it could not be found the loading-unloading system, shuttle system, and pallets supplier. Almost all systems were shaped and designed in NX-CAD software, except conveyors, industrial robots and translation module produced by ABB Company. After that, all components were loaded in the Process Simulate – dedicated software for achieving offline simulation.*

Key words: *industrial robot, mixed palletizing, storage system, offline simulation, Process Simulate.*
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1. INTRODUCTION

The paper describes all steps done in modeling and simulation of a complex robotized system up to offline simulation: research, comparison, components shape and design, systems kinematics and offline simulation.

The purpose of this application was to highlight the advantages of offline simulation and of mixed palletizing, and also to show the possibilty of integrating the industrial robots into an automated and complex system. In addition, this article confirms how important the automation process is.

2. SYSTEM CONSTRUCTION AND MODELING

2.1. Actual Study

This study was based on the research on industrial robots, which can be integrated in the process, the End-effectors which can be used, how to load-unload the highest storage, what kind of objects can be palletized or how it will be the order on the pallets. The article is based on the bachelor project developed for robotics specialization and presents the mixed palletizing operation into the automated storage system − AS/RS.

Also, for palletizing the objects, the end-effector type and the industrial robot were chosen. Because the manipuated objects were parallelipipedic boxes filled with different food, the end-effector type must be vacuumatic. The industrial robot was one produced by the ABB, with open-chain kinematic (IRB6620), because the payload was 150 kg, enough to handle the maximum load: vacuum end-effector and the box. To have a better time, two industrial robots IRB6620 have been integrated.

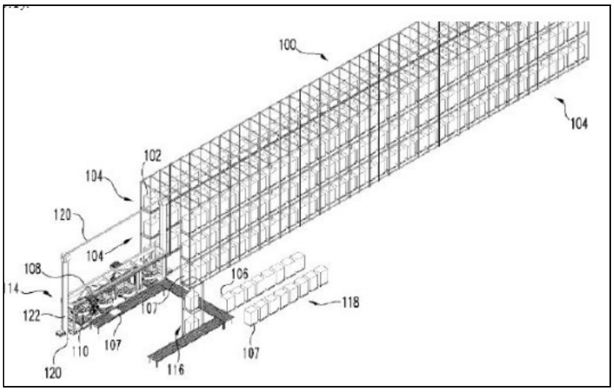

Fig. 1. Patent Bastian − automated storage system [6].

One of the most important sources was the Bastian Company patent US20110238207 [6] presented in Fig. 1.

The project was developed based on the patent Bastian, but between both systems there are many differences, such as:

- the industrial robot used by Bastian was a gantry robot, not an articulated robot;
- the loading – unloading system in the patent Bastian does not exist. It was developed in the bachelor project which has a Shuttle system integrated; this system can be observed in the following picture (Fig. 2).

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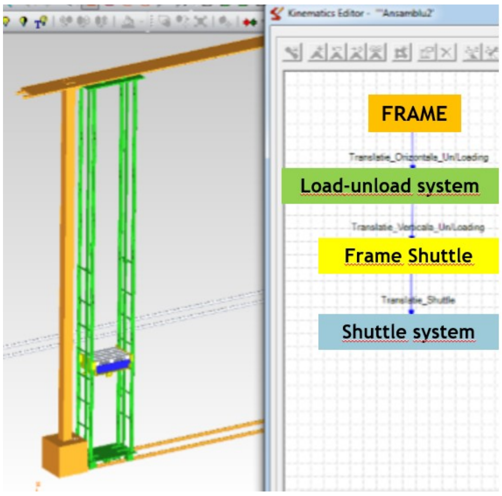


Fig. 2. Loading-unloading system [2].

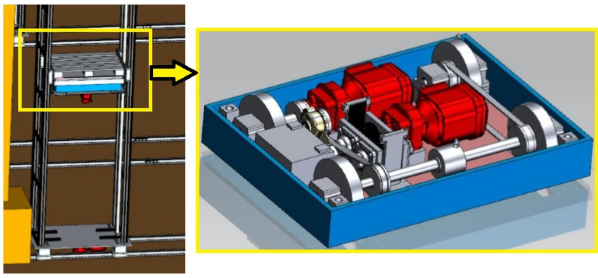


Fig. 3. Shuttle systems [2].

- the storage system developed have integrated a shuttle, which takes the empty pallets or let the filled pallets with objects in the storage [2]. This shuttle system is presented in the following in Fig. 3.

The main advantages of integrating such an automated storage system are: lower costs, mixed pallets, high precision, short time.

2.2. Mixed palletizing with industrial robots

Palletizing represents the ordered volumetric arrangement in the homogeneous height layers in horizontal form or in multiple layers in the vertical plane which are transported on the conveyor's devices, called pallets. During the palletizing operation, various objects, for example: bulk granules or powders, parallelipipedic boxes, can be handled with an end-effector, which is attached to the industrial robots. In order to facilitate the storage unification, transport and the palletizing operation, pallets are used, which have regulated dimensions by international standards.

An industrial robot is an automatically controlled, reprogrammable, used in many applications, mostly in industry, such as painting, pick and place, palletizing, manipulating, welding and arc-welding. It is important to specify that an industrial robot must have high speed, high precision and high endurance. Fig. 4 shows the industrial robot used in the project – IRB6620 [7].

The IRB6620 is an articulated arm robot which has six-degree of freedom: 3-rotations (RRR) for the positioning system and 3-rotations used for the Roll, Pitch and Yaw orientation system. Also, in the application, the robot has an external translation axis for performing a horizontal motion.

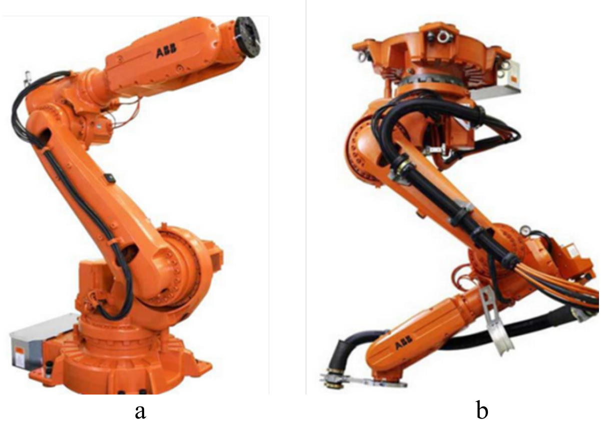


Fig. 4. Industrial robot (IRB6620 – ABB)[7]:
a – ground mounted; *b* – module mounted.

Both industrial robots have the maximum payload of 150 kg and weight of 900 kg. They were equipped with vacuum end-effectors, which were realized from frames produces by Schmaltz Company. For these robots, two translation modules were integrated, produced by the same company – ABB, to have more space and to increase time management.

2.3. Automated storage system

Before loading the subsystems in the virtual software, a map of the automated system was created (Fig. 5).

The logical displacement of the subsystems gives a global view of the mixed palletizing operation. These systems are:

- two industrial robots equipped with vacuum end-effectors which have the role of palletizing in a specific order;
- chain conveyors which have the role of transporting or/and lifting up the pallets empty/ filled;
- storage system – large storage filled with pallets;
- platform system where the robots are mounted. Also, on this system are the fourth stretch systems which have the role to secure the filled pallets;
- pallets supplier – placed near of the platform. The link between the empty pallets and platform is done by the chain conveyors;
- loading–unloading system which have the role to supply the storage with filled pallets or to get the empty pallets from the storage. This is done by Shuttle subsystem.

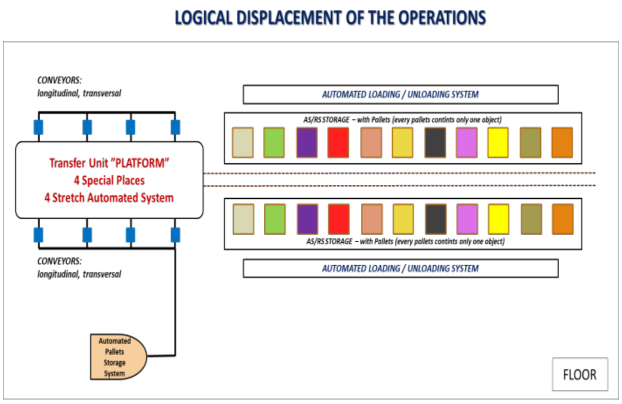


Fig. 5. Automated storage system MAP.

The order is requested by the customer / client and it will be delivered in the short time due to automation. The automated storage system is presented in Fig. 6 where all the mentioned systems were integrated:

All components were integrated in the offline simulation software and were placed on the floor. The version of the software was Process Simulate 12.1, as Fig. 7 shows.

After the systems / subsystems were imported in the Process Simulate software to compute the offline simulation, every kinematics couple for each system / subsystem has been defined.

For example, the robot and the platform kinematics couplings are represented in the Fig. 8.

For palletizing operation, the industrial robots were equipped with vacuum end-effectors. For them it was defined the TCPF (Tool Central Point Frame) and also the coordinate system of the output flange. Using the command *Mount Tool*, both systems were defined: the robot and the end-effector, and also the frames which were realized before. This command is presented in Fig. 9 [1].

The type of movements that can be achieved in software are translation and rotation. These movements can be combined so that the whole process is completed in the shortest time [3]. For example, to define the seventh translational couple of the robot on the module, an additional axis for the robot was defined using the command *Robot Properties* → *External Axes*, as Fig. 10 shows.

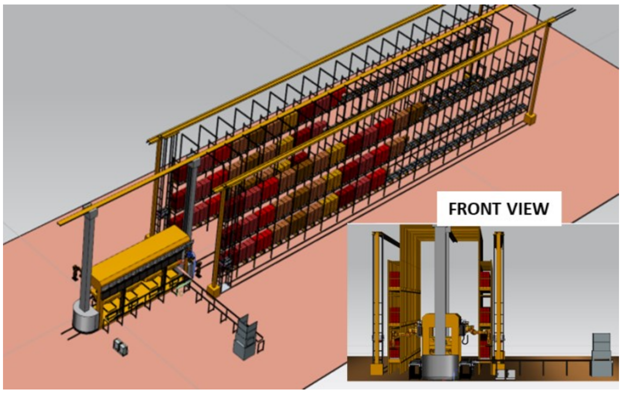


Fig. 6. AS/RS – Automated storage system.

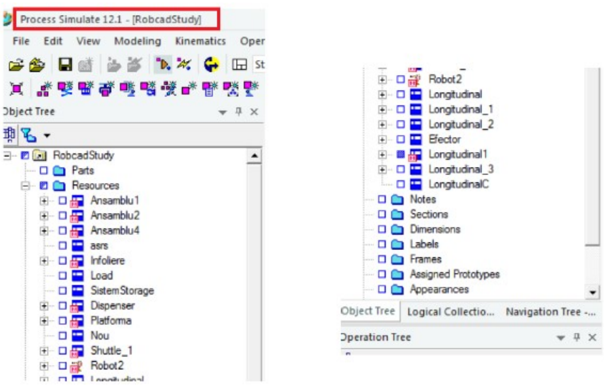


Fig. 7. Automated storage system imported in Process Simulate.

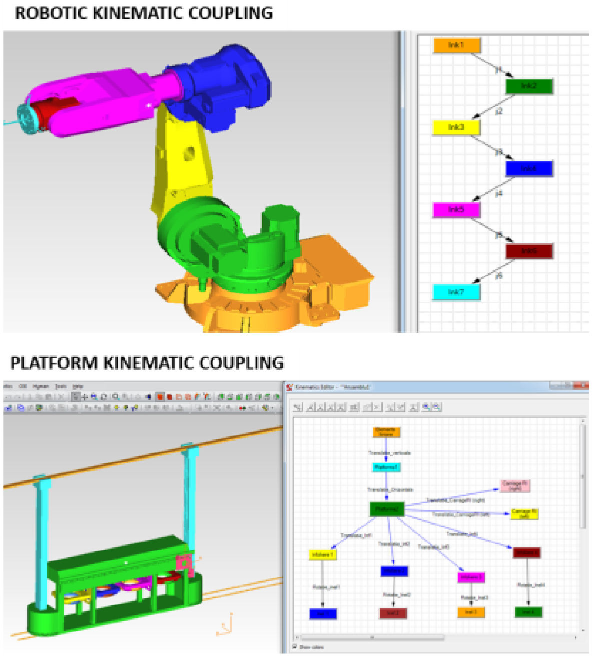


Fig. 8. Kinematics Couplings.

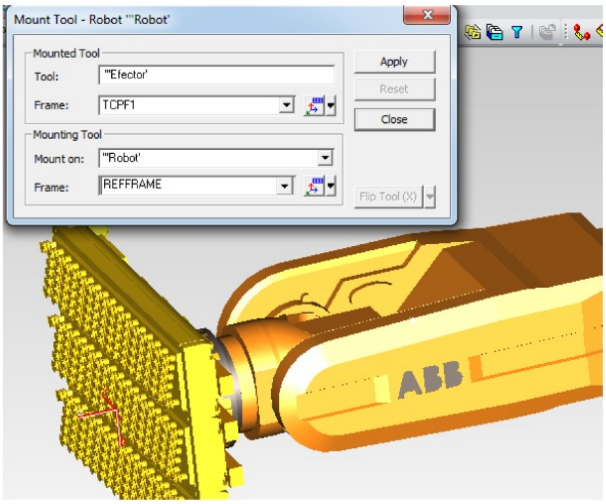


Fig. 9. Equipped robot with vacuum End-effector.

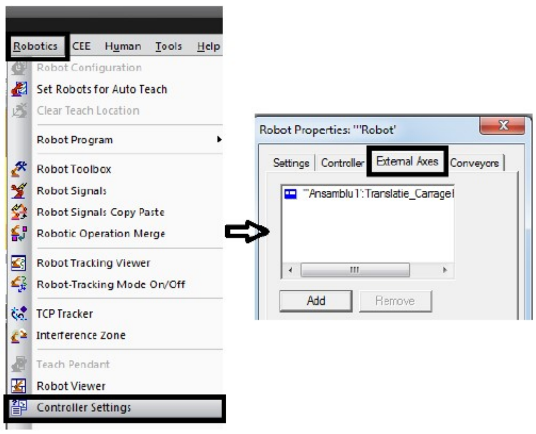


Fig. 10. External axes (translational).

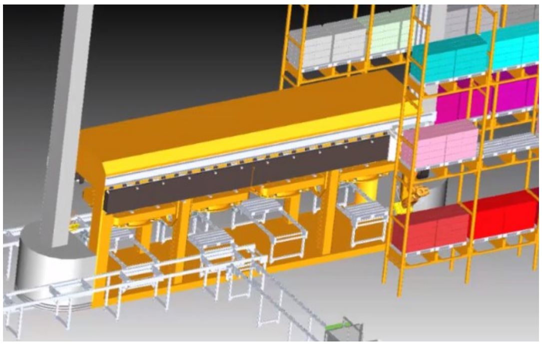


Fig. 11. AS/RS: phase 1.

3. LOGICAL OPERATIONS

Process Simulate is the most complex software used for industrial applications, which can include robotic simulations, machines and production systems, conveyors and sensors. It can integrate 3D data of products and resources, optimizes and simulates production processes which are complex. It means that the customers can get a higher quality in a shorter time.

The software can verify the feasibility of an assembling process by validating accessibility and percentage of collision. This is done by simulating the process and the necessary tools or end-effectors, which allows the optimization of the accidents / scenarios that may occur during the process.

3.1. Phase 1 − pallets supplier

The first operation is to supply the fourth empty places, which are located on the platform, from the pallets supplier and to assure the movement of the platform into the storage. The fourth stretch systems are in the initial position until the pallets will be mixed palletizing. The motion of the platform is presented in Fig. 11.

3.2. Phase 2 − palletizing robot (platform X axis)

The second step was to start the palletizing operation, in which the platform is performing the motion only in the X direction along the storage system. Starting from the phase two, the robots have access in the storage area and can start palletizing the boxes. In the same time, the loading-unloading system will assure the load – unload operations for the storage system. In Fig. 12, the platform and the robots in different positions are presented.

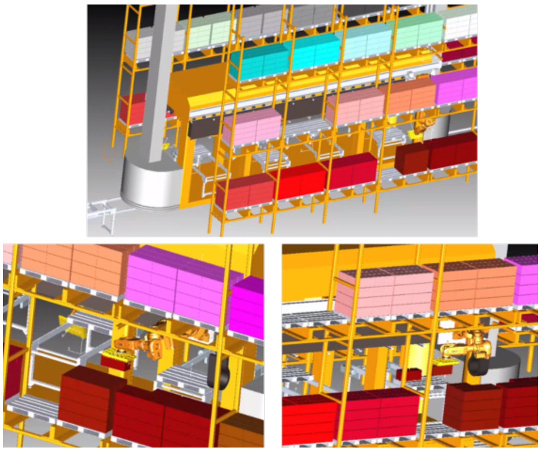


Fig. 12. AS/RS: phase 2.

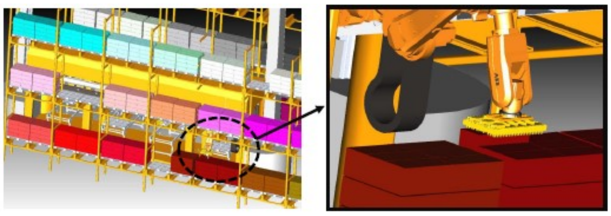


Fig. 13. Palletizing robot: phase 3.

3.3. Phase 3: palletizing robot (platform X/Z axis)

In this phase, the platform has the motion also in Z direction. That is why now the robots can achieve mixed palletizing. An example of it is presented in Fig. 13.

Regarding the technical characteristics of an operational subsystem, they are determined by the role / application which the robot has to perform within a flexible cell. These technical characteristics are in fact given by the characteristics of each component within the kinematic chains contained in the internal structure of the robot. They that can be divided into segments, couplings, translation or rotation modules.

In the case of the ABB IRB 6620 robot, it has 6 rotation couplers belonging to two systems:

- positioning system which have the first axes of rotation: *Rx*, *Ry*, and *Rz*;
- guidance system which have the following axis of rotation: Roll, Pitch and Roll.

Some end-effector characteristics are the following: vacuum-type elements must be constructed so that they can retrieve the parallelepiped objects; suction power must be enough to support the objects without causing some incidents, such as leakage during the robot movement; the actuator mode of the end-effector is a vacuum type; the weight of the end-effector is reduced to the minimum to improve the robot's dynamic behavior [4, 5] and to allow it to handle as much load as possible without producing any incidents during the operation.

The industrial robot which is mounted on the Platform and equipped with the vacuum end-effector is presented in Fig. 14.

3.4. Phase 4 − platform system – pallets finished

This it is the final step. The pallets should be filled, and the platform must arrive in the initial position. Also, the stretch systems will secure all the four mixed pallets. This step is presented in the next picture (Fig. 15).

3.5. Phase 5 − filled pallets transport

The next phase is to transfer and transport the mixed pallets from the platform to the longitudinal chain conveyors to an AGV which has the role to transport the pallets at a special container.

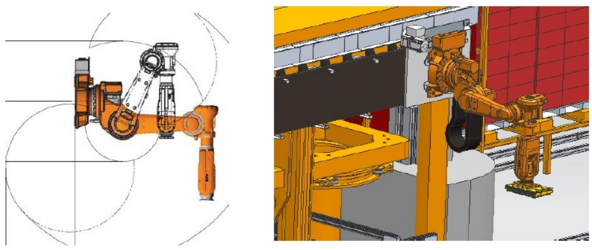
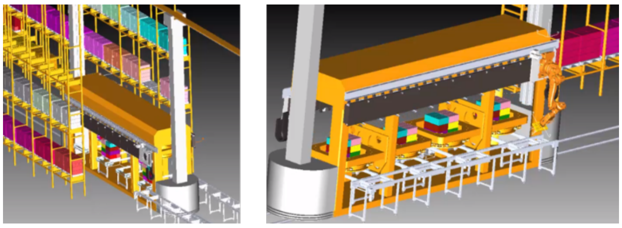


Fig. 14. Industrial Robot mounted on the Platform.



a b

Fig. 15. AS/RS: phase 4:
a – Platform to the initial Pos.; *b* – Pallets secured.

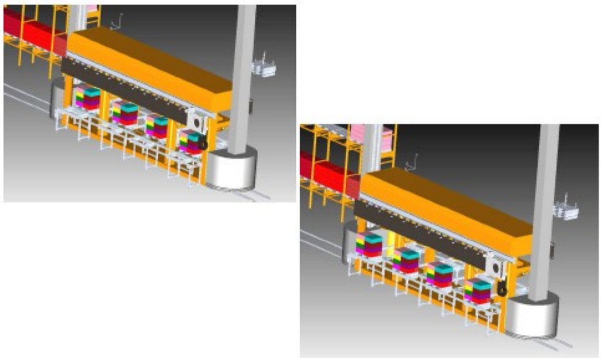


Fig. 16. Filled mixed pallets.

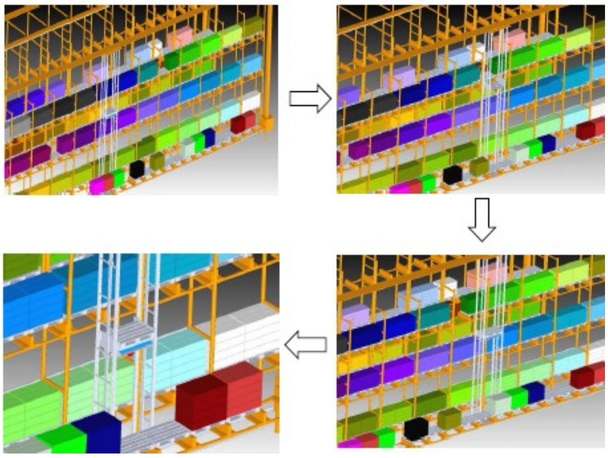


Fig. 17. Loading-unloading storage system.

From there, they are transported to the customers. In Fig. 16 it is represented how the lifting motion of the pallets was programmed.

3.6. Loading-unloading storage system

It was mentioned at the beginning that the patent Bastian does not present any loading-unloading system for the storage system. In the application, the system presented in Fig. 17 was developed for loading and unloading the storage.

4. INPUT-OUTPUT SIGNALS

4.1. Simulation Panel

Also, it was necessary to implement in the simulation of the input-output signals another important factor for realizing the mixed palletizing operation. This signal ensured the control quality and in addition a safety production process. Therefore, to achieve the input-

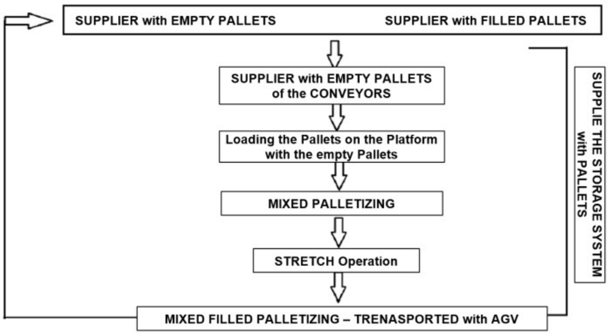


Fig. 18. Input-output signals.

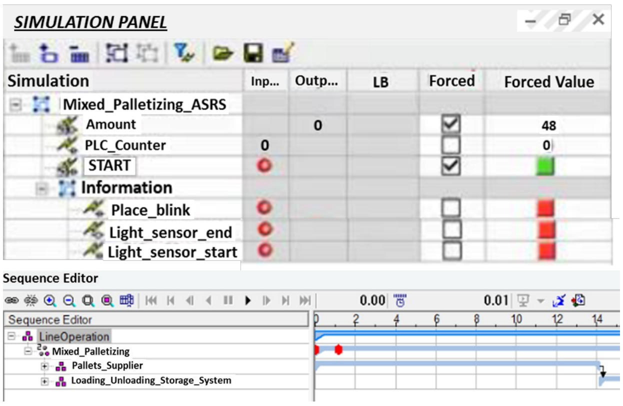


Fig. 19. Simulation panel.

output signals a block diagram was started for the whole system, aiming to accomplish all the operations specific to each subsystem (Fig. 18).

Signals are received from proximity sensors, which detect the objects presence or the operations that are performed. Therefore, they transmit the signals to the Programmable Logic Controller (PLC), which manages the entire process. The defining tool signals is called *Simulation Panel*, being a virtual panel through which every operation can be followed step-by-step.

Figure 19 presents in the Simulation Panel one of the operations.

In Process Simulate, the simulation can be done based on events or on sequence. The difference between them is:

- The event based simulation depends on the logical process and also on the different events that can occur while running the simulation.
- The simulation based on the sequence depends only on time and a pre-defined sequence flow. The different events which can occur in a simulation based on the event comes from the industrial robots or from other subsystems that are connected at the PLC devices. The logic in a robot cell simulation is controlled by three different logic types. This can be used to describe the real behavior of the industrial robot. Each of these works independently, but can also be combined (Fig. 20 − example).

These three different logic types in the Process Simulate software are:

- sequence transition condition which controls the device and the operations which cannot use PLC signals;

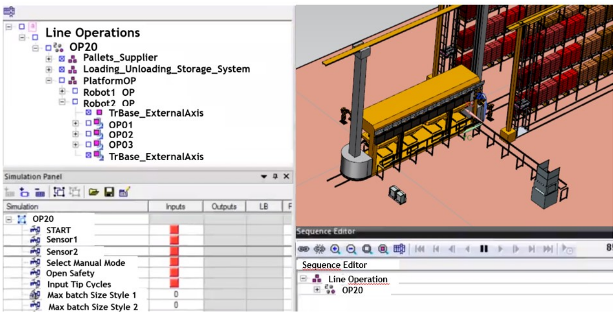


Fig. 20. Example with − Line Operations.

- logic block which controls the industrial robots logic and the processes the input signals;
- modules condition which control all the devices connected to the PLC. These devices can be: robots, conveyors, etc.

4.2. Sensors

In the Process Simulate the sensors are not defined in the model, they must be created. The sensors can be matched to their corresponding parts using the descriptions which is found in the PLC tags list. These sensors will identify an obstacle, objects or systems, and depending of the signals if the process may or not continue.

For example, in the area where the conveyors were placed, proximity sensors were also created (or defined) having the role to identify the empty pallets or the mixed pallets. This is presented in Fig. 21.

In Fig. 22 every simulation line is shown. It contains all the phases mentioned below:

- OP10 = Phase 1, the Platform is filled with the four empty pallets by the chain conveyors and the pallets supplier (Fig. 22).

The Pallet Supplier is loaded with empty pallets during Platform is loaded with these empty pallets which will be filled with boxes.

- OP20 = Phase 2, the Platform is moving on the X direction, along the storage. This is how the industrial robots can have access and can complete the palletizing operations. In this OP20, other four empty pallets will be transported to the lifting systems and the loading-unloading the storage with filled pallets or unload the storage of empty pallets.

Also, the industrial robots were started to be moved along the ABB modules. The operation is presented in the Fig. 24.

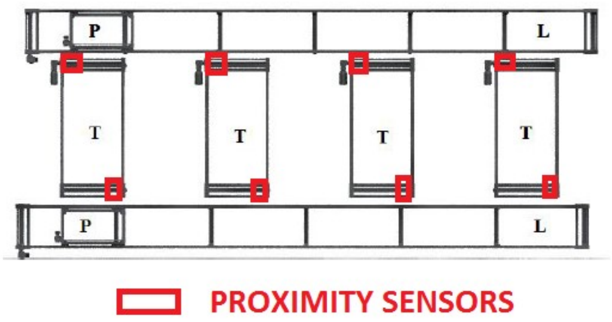


Fig. 21. Proximity sensors – conveyors area.

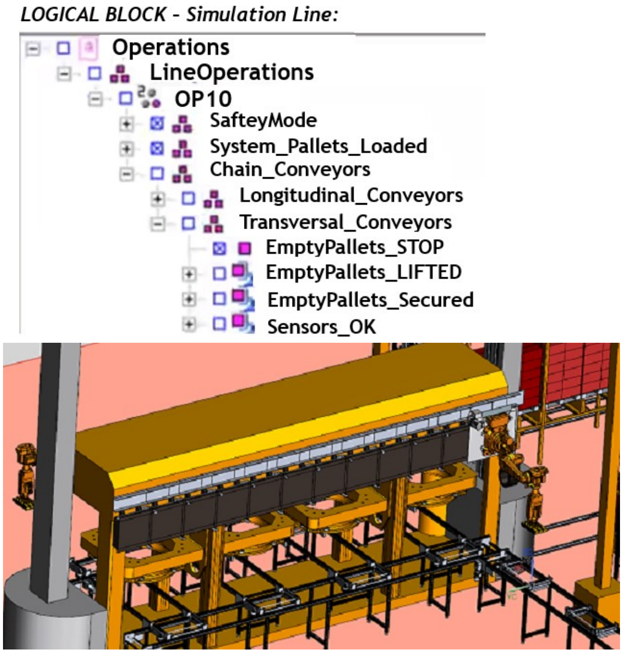


Fig. 22. Line operations – OP10; contents: *Phase* 1.

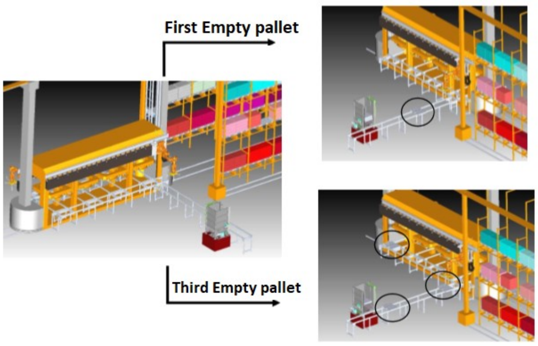
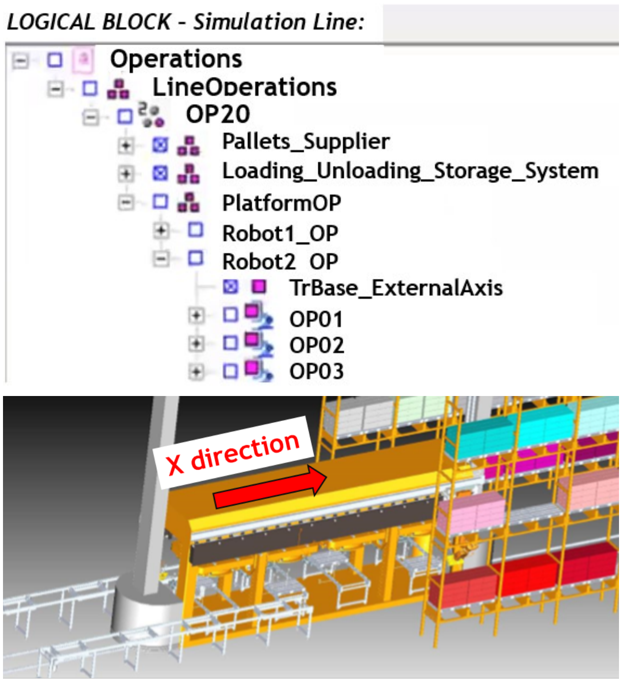


Fig. 23. Platform loaded with empty pallets.



24. Line operations – OP20; contents: *Phase* 2.

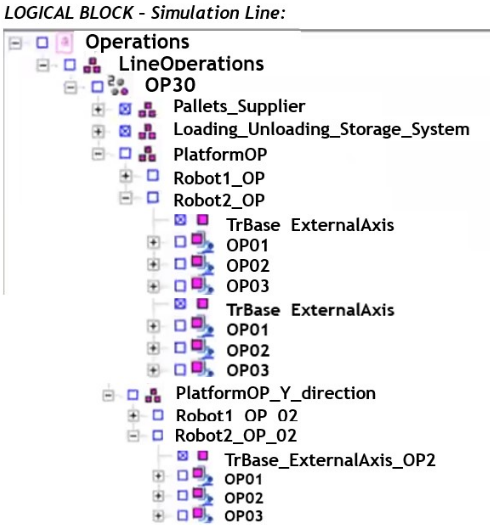


Fig. 25. Line operations – OP30; contents: *Phase* 3.

- OP30 = Phase 3, the Platform is moving in *X* and Y direction, along the storage. The industrial robots equipped with End-Effector are palletizing the empty pallets until the mixed pallets are filled. The operations for the Platform and the industrial robots are presented in Fig. 25.

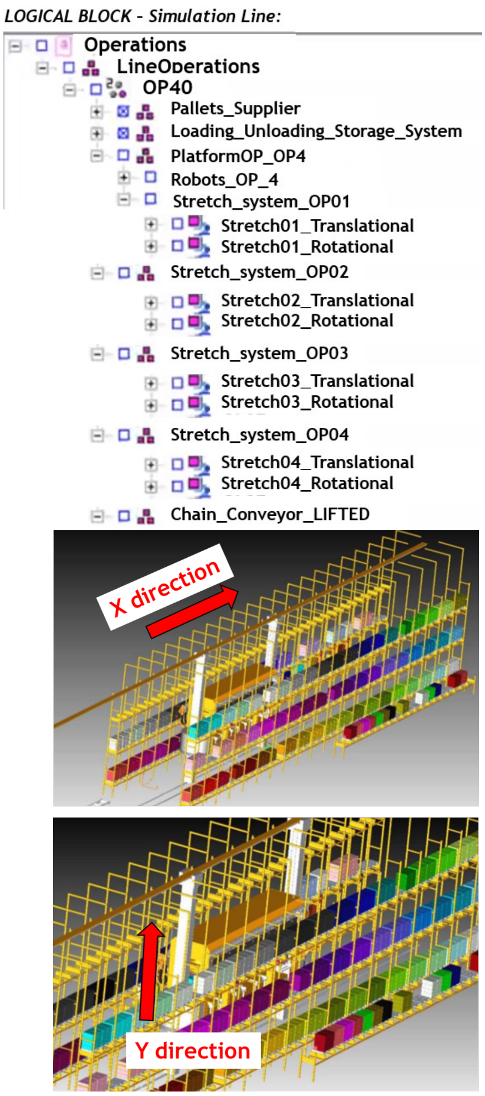


Fig. 26. Line operations – OP40; contents: *Phase* 4.

Fig. 27. Industrial robots – collision.

- OP40 = Phase 4 is the last Phase. In this operation, the stretch systems are moving in *Z*-rotation and *Z*-translation to secure the mixed pallets. Also, in this phase the Platform arrives in the initial position, and the chain conveyors are transporting these pallets to the containers (Fig. 26).

4.3. Collision and synchronization

Determining the collision and synchronization conditions between two or more subsystem is one of the main advantages using a virtual environment. It is possible to simulate several tests or simulations without incurring additional costs. This ensures a good system operation, safe conditions and also high precision.

In order to ensure a good synchronization between two or more subsystems, the program calculates for each subsystem the volume generated along its own trajectory. Having two or more volumes, depending on the number of subsystems, Process Simulate calculates the interference area, which means: the area where the volumes interfere or have an intersection. For example, in Fig. 27 two robots which have an interference between their volumes are presented.

6. CONCLUSIONS

Palletizing means ordering operations in a certain way, which can have a defined form or not, manipulated by different industrial robots equipped with dedicated end-effectors. The industrial robot can replace different complex systems of palletizing, which have a great flexibility. That involves costs reduction of maintenance, high speed and precision.

The most important advantages of this system are the following:

- increased production in a shorter time due to the industrial robots that are integrated in this complex process;
- mass production or, in this case, many mixed pallets;
- using the Process Simulate leads to a better accuracy of different operations; through this software, changes can be made to the process without additional costs;
- the possibility of obtaining mixed pallets without involving human presence.

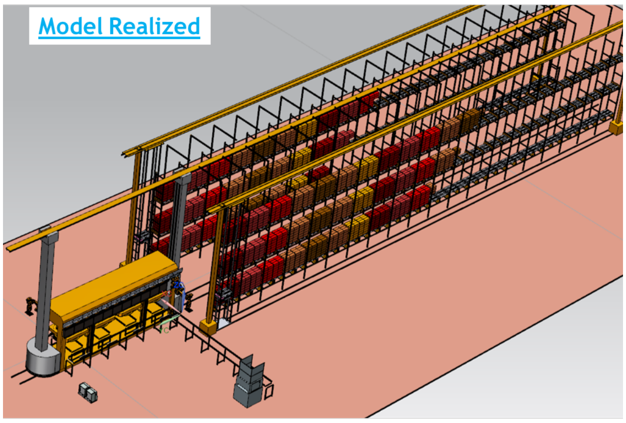


Fig. 28. AS/RS model realized.

The profitability of the automated storage system presented in which two industrial robots have been integrated depends on the programming methods used, in this case Process Simulate. The simulation program performs a sequence of complex movements that are transmitted to the robot controller. This was possible through simple instructions and various programming methods. Therefore, the entire manufacturing process was automated.

After offline simulation applied in the case studied, the main capacities of the software Process Simulate that stand out are:

- 3D kinematic simulation;
- static and dynamic collision detection;
- 2D and 3D sections;
- automatic planning of the assembly geometry;
- resource modeling: 3D and kinematic geometry;
- line and workstations;
- friendly interface 3D and documentation.

The main purpose of the article was to present the facilities of mixed palletizing in an automated storage and retrieval system, called AS/RS. The automated storage and retrieval system are a combination of equipment and controls that can store, handle and retrieve material or objects with precision, speed and accuracy under a defined degree of automation.

There are several differences between the Bastian concept (Fig. 1) and the model achieved. In this new system some new systems were added, such as: loading-unloading system for the storage system, the two industrial robots with open-chain kinematic (IRB6620), two translational modules (produced by ABB), shuttle system for loading-unloading the storage (Fig. 28).

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