

Multiple products management system with sensors array in automated storage and retrieval systems

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Abstract. Automated Storage and Retrieval Systems (AS/RS) have now been widely used in a number of industries due to its capability to automatically manage the storage of products in effective ways. One of the key features of AS/RS is that each rack is not assigned for a specific product resulting in the benefit of space utilization and logistics related issues. In this research, sensor arrays are equipped at each rack in order to enhance this feature. As a result, various products can be identified and mixed in each rack, so that the space utilization efficiency can be increased. To prove the concept, a prototype system consisting of a Cartesian robot that manages the storage and retrieval of products with 9 variations based on size and color. The concept of Cyber-Physical System and self-awareness of the system are also implemented in this concept prototype.

1. Introduction

The warehouse is one of the most common and important sections in factories. It is used for storing goods which can vary from raw materials to finished products. Traditionally, in order to prevent confusion, raw materials and finished products need to be completely separated. In addition, each type of product needs to be in their own slot and rack without mixing with others. As a consequence, the space may not be utilized efficiently due to the dead space that needs to be reserved for particular types of goods. To resolve this problem, the concept of a "Smart Warehouse" or "Automated Storage and Retrieval Systems (AS/RS)" have been introduced and used in a number of industries these days.

AS/RS is an automated system that fully utilizes the storage space by using information system in order to systematically organize the products to achieve certain optimal conditions. It is generally employed in the industries that deal with a high volume of products that need to be stored densely in a certain location with space constraints. It is also employed in applications where accuracy is a primary concern. The system consists of robots and automation used for physically loading and unloading the products to and from the particular storage locations thus eliminating the uncertainties due to human error. Products will then be able to be stored and retrieved accurately and safely with minimal possibility of damage.



Much research was conducted in order to improve the level of intelligence of the warehouse. For the AS/RS, [1] proposed a smart Warehouse Management System (WMS) and Warehouse Control System (WCS) that will increase the efficiency of warehouse operations. However, it is not limited to only AS/RS but also incorporates human operators. For instance, [2] used smart sensors and wearable device to assist the user to efficiently search the products and organize the inventory. [3] study the effects of smart glasses on the operators' activities in warehouses.

In Industrie 4.0, "Cyber Physical System"(CPS) is one of the key concepts that enhances the capability to monitor and control systems. Sensors network, control system, and Internet-of-Things (IoT) are integrated in order to enable the smart interaction between machines and/or human that is capable of achieving specific purposes. This concept has been implemented in a number of industrial applications [4-6]. CPS is also known as "digital twins", where items in reality can be visualized, monitored, and controlled in the virtual world. The interaction can be performed in a smarter way in comparison to the traditional monitoring system. CPS is implemented in AS/RS to enable the full control of the system. To reveal the information of each product, technology of RFID and barcode are normally used, e.g. [7, 8].

In this research, a prototype AS/RS that is able to store products with various types and sizes is developed. The products can be mixed and the space utilization can be optimized according to the desired goal. Sensor arrays are equipped at each slot in order to enable the concept of CPS and self-awareness of the system. As a result, the accuracy and security of the system will be improved.

2. Methodology

2.1 Cyber-Physical System

The concept of CPS is implemented in this project in order to enhance traceability of the products and the condition monitoring of the inventory. In general, RFID or barcode tags are tagged on each product so that the product can be identified by using a reader [7, 8]. However, extra cost and process are needed due to the tags that must be on every product.

In this project, the tagging system is replaced by an array of sensors and a camera that are permanently installed at the inventory. Therefore, none of the extra process and cost is needed for individual products. The system can identify the *size*, *type*, and *existence of the products* by using (a) an array of proximity sensors installed at each slot of the storage and (b) a camera equipped at the load-in dock. The sensor arrays, in this case: contact switches, are used to identify the size and existence while the camera with vision system is used to identify the type of products. The data obtained from these sensors will be aligned with the data in the database in order to update the current condition of the storage.

2.2 Storage slot and product variations

In this conceptual prototype, one storage rack can contain a maximum of 6 unit-size products. Therefore, 6 contact switches are placed according to this storage capacity, meaning that each contact switch is able to sense the condition of one unit. The arrangement is shown in figure 1. The contact switch located at the back of the slot will be on if the product exists.

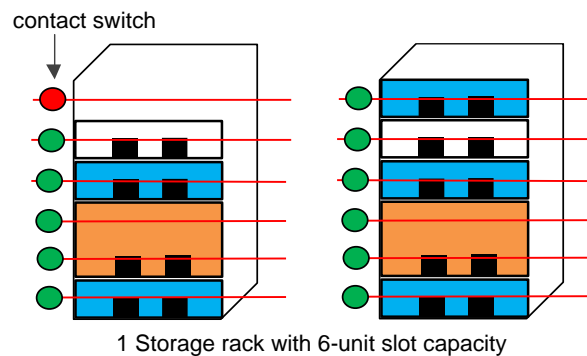


Figure 1. Product detection with sensor array

According to the product samples, 9 variations of products are used in order to demonstrate that the type and size of the products can be identified. The nine variations are the combination of 3 sizes (1-unit, 2-unit, and 3-unit) and 3 types (red, green, and blue). The summary is shown in figure 2. As a result, the sample of grouping methods – by size and by type – can be demonstrated as shown in figure 3.

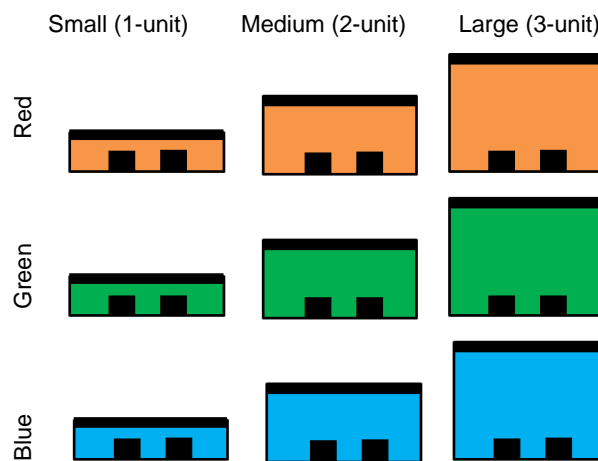


Figure 2. Product variation summary

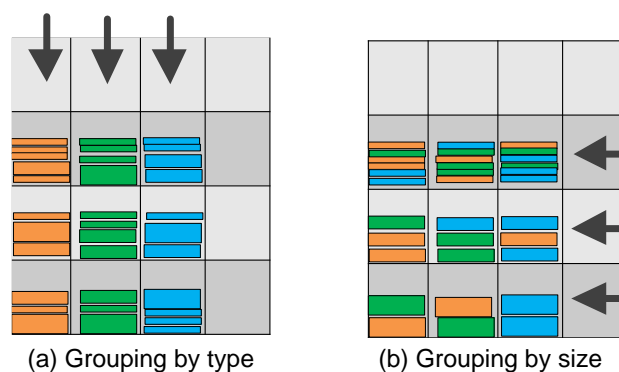


Figure 3. Grouping method

2.3 System overview

The prototype in this research is an automatic system consisting of (a) an inventory warehouse with sensors, (b) a Cartesian robot arm with a gripper, (c) software for the control system with database. The system overview is shown in figure 4.

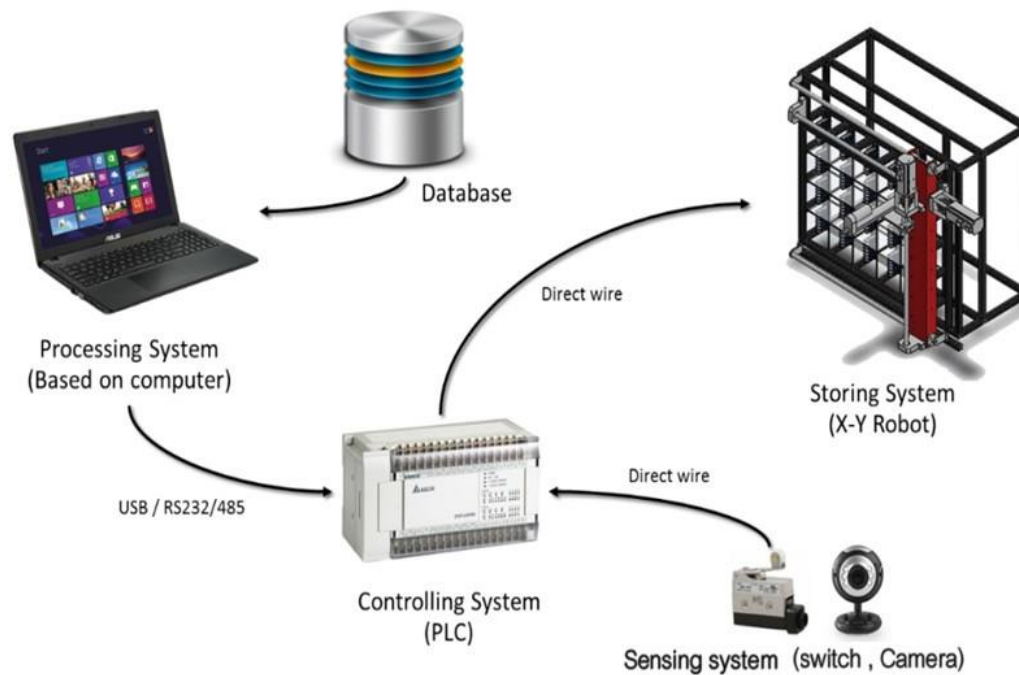


Figure 4. System overview

2.4 System architecture

As an overview, this system is a PC-based control system. The system consists of 3 levels of control layer: *high-level*, *mid-level*, and *low-level*. The system architecture is shown in figure 5. The software and hardware in three layers work together seamlessly via a number of communication protocols.

2.4.1 High-level control layer. The Intelligent Agent (IA) is responsible for sequence planning of the products and storage arrangement. The sequence planning deals with the sequence of actions that the robot gripper will pick the products to insert or remove from the slots. The IA works based on the information regarding the current statuses of the storage which is in the database. The system also consists of a graphical user interface (GUI) in which users can monitor and control the operation. These are operated on the main computer. The computer is connected to a Programmable Logic Controller (PLC), DVP-SV2, which is at the *Mid-level* layer, by using RS-485 protocol.

2.4.2 Mid-level control layer. Two primary modules are operated which are *Signal controller module* and *Vision system module*.

(a) *Signal controller module* consists of a PLC with digital input expansion. The PLC is responsible for signal acquisition and processing. The input signal is mainly obtained from the sensor array, where the acquisition is through the digital input expansion module. This signal passes to IA for being processed in order to obtain the status of the storage slots. This digital input expansion is directly connected to the sensor arrays at the low-level control layer.

Regarding the robot's movement, the locations (x,y,z) of each slot, products, and its corresponding position due to the actions of product manipulation are predetermined and stored in PLC's program.

(b) *Vision system module* is developed based on EmguCV (OpenCV in .NET) [9] which is operated on the computer. The main function is to detect the type of the product according to their color. The vision system module is connected to a webcam via a USB which is at the low-level control layer.

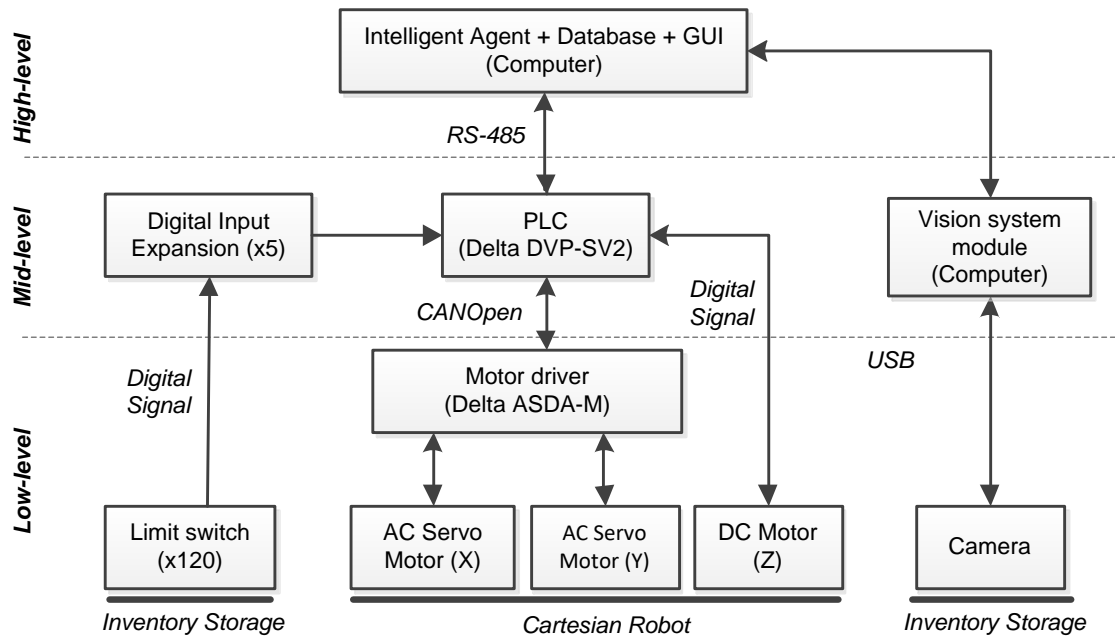


Figure. 5 System architecture

2.4.3 Low-level control layer. Hardware is considered in this level. The hardware consists of 3 motors, sensor arrays of 120 contact switches (only 112 switches are used for the demonstration of this prototype), and a webcam.

The positions of the slots and products in *xyz*-space will be used to command the motors. For *x*-axis and *y*-axis, the motor driver ASDA-M is used to perform motion control of two AC servo motors to drive the robot to particular locations. CANOpen is used to connect between ASDA-M and the PLC. For *z*-axis, DC linear motor is used and controlled directly from the PLC. Besides, the limit switches connect directly to the digital input expansion module. The webcam is plugged into the computer with USB.

3. Prototype development

3.1 Mechanical design

3.1.1 Inventory storage. The inventory storage of the prototype consists of 14 racks (12 storage racks, 1 load-in rack, and 1 load-out rack). For each rack, 6 contact switches (representing 6 slots) are mounted at the back of each slot. The dimension of the slot is designed based on the dimension of the product required. In this case, the dimension of the sample product of 1-unit size is 80mm x 120mm x 10mm*. The height (*) is 20mm or 30mm, in case of 2 and 3-unit size product. The sample product is inspired by wellplates that are normally used in clinical labs as this project will be applied to be used in that field.

The main structure of the system is constructed with Aluminium profiles. The dimension of the entire structure is 500mm x 500mm x 300mm. The inventory storage prototype is shown in figures 6 and 7.

3.1.2 Cartesian robot. The driving mechanism for x-axis and y-axis is based on power screws in order to convert rotary motion to linear motion. The $\phi 16$ mm lead screws with linear guide rails are used due to the firm structure and able to the object with high payload. AC servo 400W motors are used for driving both axes. With respect to z-axis, a DC linear actuator equipped with a gripper at one end is used. The gripper is designed to be passive similar to the platform of forklifts. Therefore, no extra actuator is needed for operating the gripper. The robot prototype is shown in figures 6 and 7.

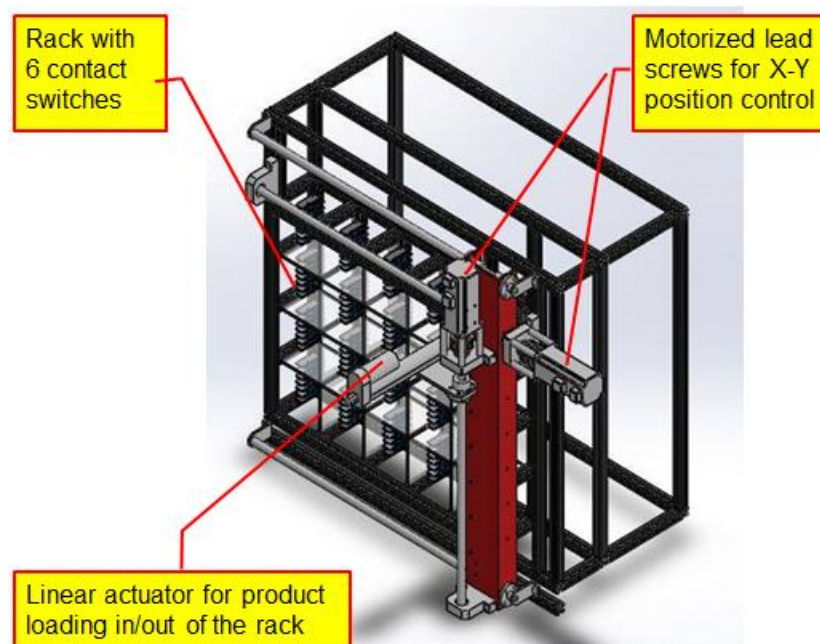


Figure. 6 Prototype design - Isometric view

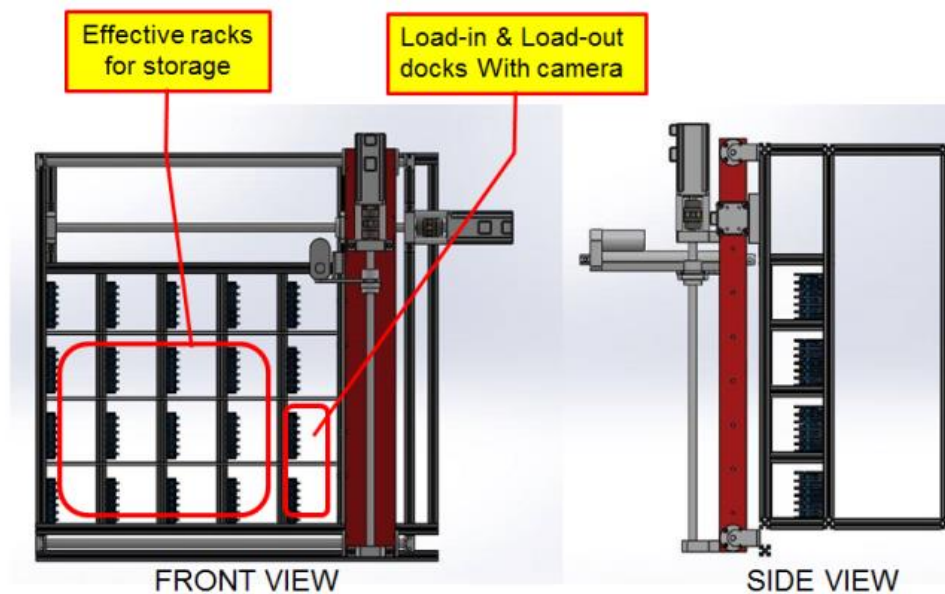


Figure. 7 Prototype design - Front and side views

3.2 Electrical Design

The PLC is the primary component that controls all the signals of commands transferred between high-level and low-level. The PLC DVP consists of the 3 primary modules and 5 digital input expansion.

(a) DVP-28SV is a main controller PLC which is connected to the computer with RS-485. The linear actuator is connected through 2 relays. (b) DVP-PS02 is a 24VDC power supply unit which was converted from 220VAC input. (c) The digital input expansion module connects to the terminal board with sensor array of 120 contact switches. (d) DVP-COPIN is a communication module for connecting to the motor driver ASDA-M by using CANOpen. The complete wiring diagram is shown in figure 8.

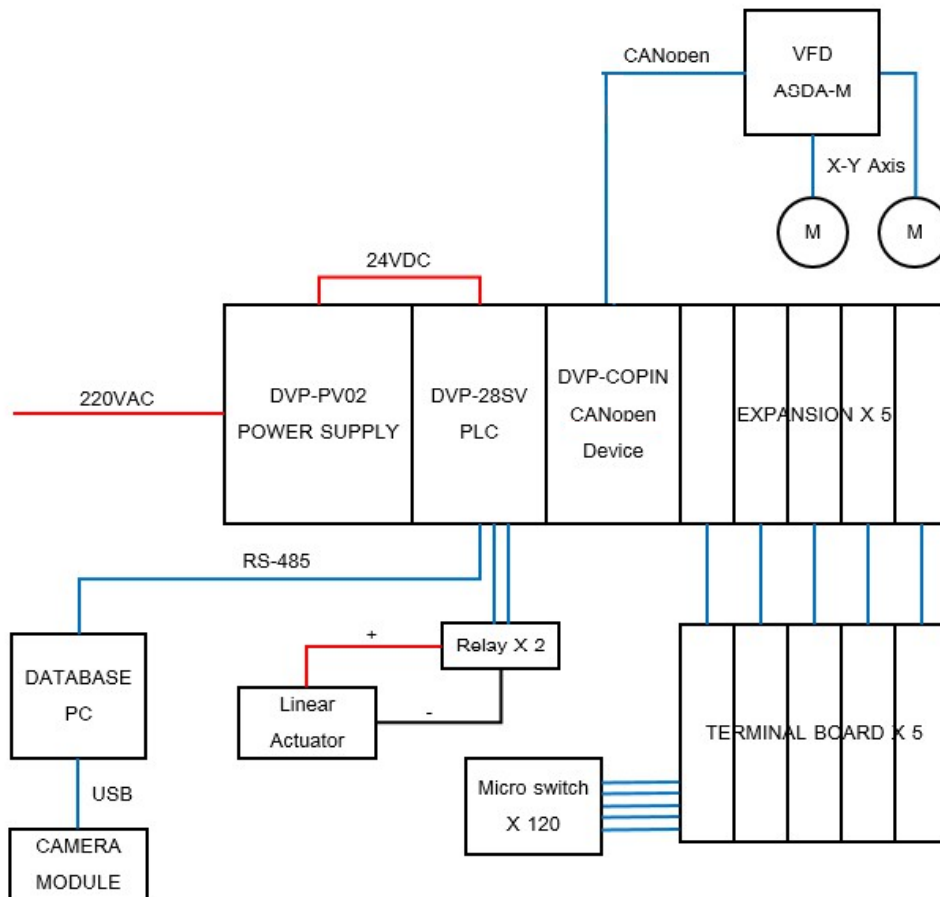


Figure. 8 Wiring diagram in detail

3.3 Programming

3.3.1 Identity checking. The product's identity - size and type - is firstly checked at the load-in dock. To ensure the accuracy, it will be checked again at the retrieval process.

The *size* of the product is checked according to the number of the occupied slots, which are checked by the status (0 = free, 1 = occupied) of the switch array (see figure 1). The *type* of the product is identified with the color detection from the camera. Hue-Saturation-Value (HSV) color space is used as it is robust to the change of illumination from the ambient [10]. As the detected color is sensitive to the ambient light temperature, color balance correction is needed. In summary, for the variables: *size* = 1,2, or 3 and *type* = 'r', 'g', or 'b'.

3.3.2 Database. The structure of database is shown in figure 9. The location of the storage rack is indexed with (i,j) where $i = 1,2,3,4$ and $j = 1,2,3$. In each rack, there are 6 slots which are represented with $k = (1,2,...6)$. In summary, the location of each slot is represented with $slot(i,j,k)$.

The IA will check and update the information with the database and the sensor array in every operation cycle. In case that the products have been removed from the storage by someone (not the robot), the system will acknowledge the absence of the product. Hence, this behavior improves self-awareness of the system resulting in an increase of security level.

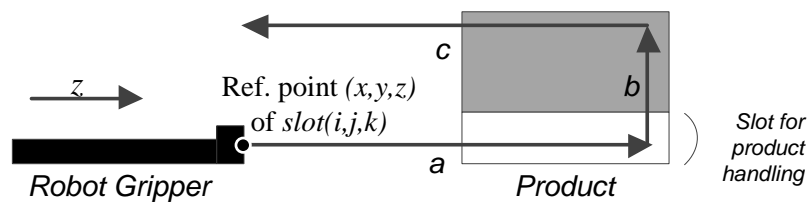
$j=1,2,3$ (y-axis)	rack(3,1)	rack(3,2)	rack(1,3)	rack(1,4)
	rack(2,1)	rack(2,2)	rack(2,3)	rack(2,4)
$(x,y) = (0,0)$	rack(1,1)	rack(1,2)	rack(1,3)	rack(1,4)
	slot(1,1,6)			
	.			
	slot(i,j,k)			
	.			
	slot(1,1,2)			
	slot(1,1,1)			
	$i = 1,2,3,4$ (x-axis)			

Figure. 9 Data structure in database

3.3.3 Robot movement. For each operation cycle, the robot is responsible for picking product from one rack and placing to the target rack. The picking and placing locations are accurately referred to the reference position (x,y) corresponding to $slot(i,j,k)$ that is described in the previous section.

For the movement in z-axis, the sequence of robot's movement is predefined for picking and placing procedure. The predefined movement is illustrated in figure 10 where the sequence for picking is $a-b-c$ while the sequence for placing is reversed.

In summary, the action for picking and placing a product in the storage are $pick(slot(i,j,k))$ and $place(slot(i,j,k))$. The term *slot* is substituted by *LoadInDock* and *LoadOutDock* for the load-in and load-out process.

**Figure. 10** Predefine movement path for pick and place

3.3.4 Program flow and communication. The IA will gather the information from each component including database in order to generate the command for operating the robot. The operation can be divided into 2 modes: load-in and load-out. The procedure for loading-in is shown in the flowchart in figure 11 and briefly described as follows:

(1) User selects the grouping method. In this case, 3 grouping methods are available which are group by type, group by size, and optimal space. The product with the desired qualifications will be grouped, e.g. place all red product in the one column-i.

(2) Product is loaded at the load-in dock

(3) Identify the loaded product type and size with the camera and sensor array at the load-in dock. This is performed by *checkSize()* and *checkType()*

(4) IA checks the slot availability with DB. Checking will be done for each rack. It will move on to another available rack if the free slots are not big enough to store the product.

(5) IA sends a string representing the location of the slot that the Cartesian robot will go to store the product. This is performed by *pick()* and *place()*.

(6) IA update the DB for the type and size of the product in regard to the slot occupied.

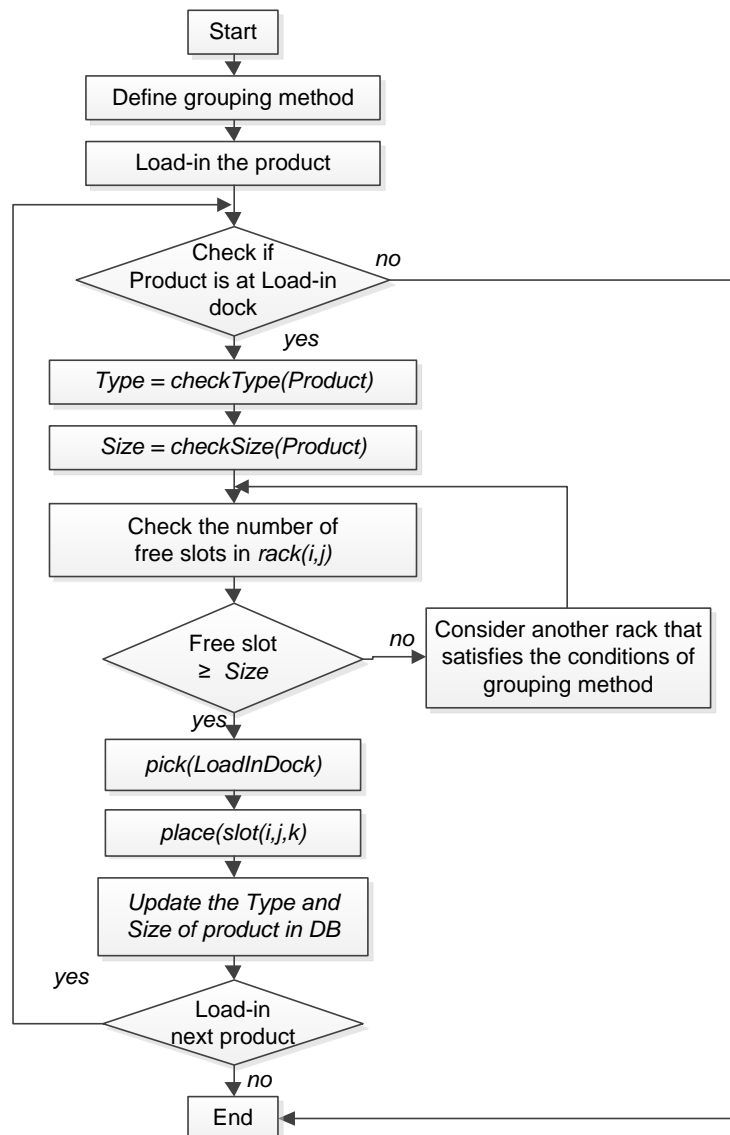


Figure. 11 Flowchart of load-in procedure

Regarding the Load-out process, the user needs to select the product to be loaded-out from the GUI. Then the robot will go to that slot to pick the product and place it on the loaded-out rack. In case there are other products stacked over the desired one, the products on the top will be temporarily moved to a free slot. Then they will be transferred back to the original rack after the desired product has been loaded out. The IA will update the current status with the DB.

4. Experiment and discussion

The goal of the experiment was to demonstrate the proposed functions which are (a) load-in and load-out the products, (b) to group the products according to the type, and (c) to group the product according to the size.

4.1 Load-in/out experiment

The actual prototype as shown in figure 12 was used. First, the robot is able to pick-and-place the products according to the command generated automatically by the system. The movement to the reference position of the gripper was accurate. However, error occurred due to the imprecise mechanical parts and assembly resulting in the failure of products handling. Second, the sensing from contact switches sometimes was inaccurate due to the installation that lead to a small gap between the contact point and a product. Non-contact sensors are recommended to resolve this problem.

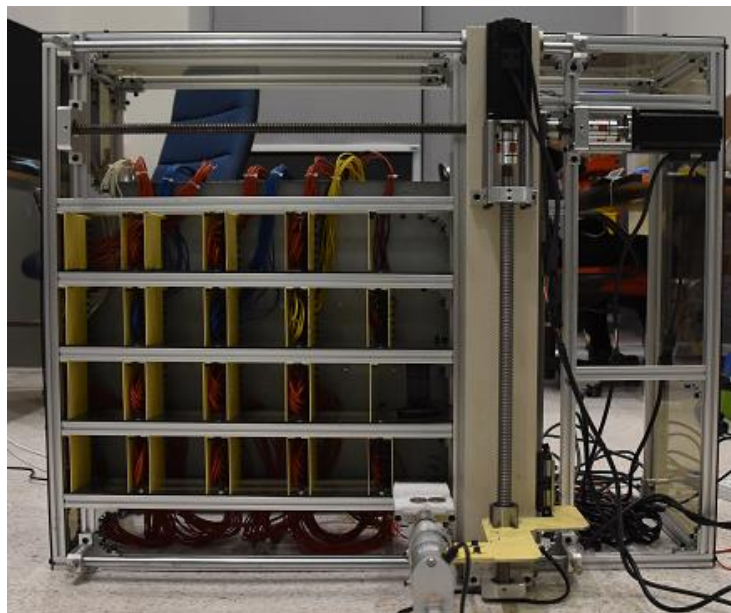


Figure. 12 Prototype

The grouping experiments (b) and (c) were tested in the mathematic simulation software. The system was able to organize the products according to the locations that satisfied the goals. The utilization of storage capacity is more efficient than a conventional warehouse that the product with various sizes and types cannot be mixed in each rack.

5. Conclusions

A prototype AS/RS that is capable of storing a variety of products has been developed. When the products in a rack can be mixed, the storage space can be utilized with higher efficiency in comparison to conventional AS/RS that the products in each rack are fixed. The proposed sensor array together with IA enables the system to be able to organize the storage with mixed products efficiently. In addition, the function of CPS is enabled by using the sensors array. As a result, the security and accuracy of the system has been improved. The concept has been proved with the current version of prototype.

For future work, the mechanical and sensors system of the concept prototype will be improved to achieve better reliability. The design will be more specific according to the application. In this case, it is expected to be used for personalized bio-samples storage where a high level of security is needed.

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