Low-Cost Automated Storage and Retrieval System for Chemicals Warehouses and Central Refrigerators

Maroof Qaid Al-Mahjari (*,1)
Ahmed Abdullatif Yassin [1]
Ahmed Abdullah Sultan [1]
Aseel Rashad Al-Zabidy [1]

[1] Department of Electronics Engineering, University of Science and Technology, Sana'a, Yemen
* Corresponding author: m.almahjari2@ust.edu

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Abstract:

The Automated Storage and Retrieval Systems are known as ASRSs which is moved by a mechanical system and controlled by electronical system. The system has introduced many advantages in the production, storage, distribution, and customer services. Many of the proposed systems use high techniques, complex programs, and an intractable interface, and besides their complexity in programming and using, they still at a high cost. The paper proposes a simple and low-cost Automated Storage and Retrieval System using Arduino boards to control the whole system. This work has been studied on specific sites, which are Chemicals Warehouses and Central Refrigerators. The system has been designed and implemented based on two components, Hardware and Software. The proposed system determines the types of goods, pick them up and put them on the suitable shelve depends on its type. The system was designed with a database to store information and an executable file installed in computers to follow up on entered quantities and to order quantities when needed.

Keywords: ASRS, Low-Cost ASRS, Chemical Warehouses System, Central Refrigerators System, Automation saves lives.

نظام تخزين واسترجاع آلي منخفض التكلفة لمستودعات المواد الكيميائية والثلاجات المركزية

الملخص:

تُعرف نظم التخزين والاسترجاع الآلية (ASRS) بأنها أنظمة يتم تحريكها بواسطة نظام ميكانيكي ويتم التحكم فيها بواسطة نظام إلكتروني. وقد أدى إضافة هذا النظام إلى تقديم العديد من المزايا لمجالات الإنتاج والتخزين والتوزيع وخدمات العملاء. إن الأنظمة المقترحة والمتعارف عليها تستخدم تقنيات عالية وبرامج معقدة قد تحتوي على واجهات يصعب التعامل معها، وإلى جانب تعقيدها في البرمجة والاستخدام، فتكلفتها لا تزال عالية. إن هذه الورقة البحثية تقترح نظامًا بسيطًا وبتكلفة منخفضة للتخزين والاسترجاع الآلي باستخدام لوحات الأردوينو للتحكم في النظام بأكمله، وقد تم دراسة هذا المشروع للعمل في مواقع محددة كمخازن المواد الكيميائية والثلاجات المركزية. تم تصميم النظام وتنفيذه على أساس عنصرين هما الكيان العتادي والبرمجي. إن النظام المقترح يقوم على أساس تحديد أنواع البضائع، ومن ثم حملها ووضعها على الرف المناسب بحسب نوعها، وتم تصميم النظام بقاعدة بيانات لتخزين المعلومات وملف تنفيذي يتم تثبيته على أجهزة الكمبيوتر لمتابعة الكميات المدخلة من خلاله وطلب الكميات عند الحاجة.

الكلمات المفتاحية : نظام تخزين آلي، مخازن المواد الكيميائية، مخازن الثلاجات المركزية، أتمتة العمليات الخطرة.

1. Introduction

In the broadest sense, this definition of Automated Storage and Retrieval System (AS/RS) covers a wide variety of systems that vary in degrees of complexity and sorting size[1]. With the advancement of industries, the automation improves the marketplace, manufactures and warehouses by adapting operators in the increasing of consumer's demand. Further, industries, such as food, beverage and pharmaceutical, operate under stringent regulations that require safe and secure product handling in some sensitive environments [2]. Automated warehouse from its beginning to now has gone through roughly stages. In 1963, the United States was the leader in using computer control technology in elevated warehouses to establish the first computer-controlled three-dimensional warehouse. Since then, the automated warehouse has developed rapidly in the developed industrialized countries of the EU and has formed a special discipline [3]. The automation of specific warehouses will have many benefits for its safety and for the good of worker's lives. As the human life is always the priority, a study by Injury Claim Coach was about "How many fatal injuries could be averted if dangerous occupations were automated?". The study managed to highlight one of the main benefits of automation – saving human lives. Experts analyzed which fields are most deadly and the likelihood of their automation according to predictions. To do so, they compared job automation estimates from the University of Oxford to data from the U.S. Bureau of Labor Statistics (BLS) for fatal workplace injuries. Estimated fatal injuries until 2026 were predicted and calculated using employment projections released by the BLS and the number of fatal injuries in 2016 reported by the BLS. Referring to the study, the numbers represented are purely hypothetical and not meant to serve as an actual estimate or projection for automation or fatal workplace injuries. It states that by increasing automation in many industries from 0.4% to 14%, it can be clearly seen how this will save human lives, and it indicates that it is possible to save approximately 3,450 workers in all occupations by 2030 [4]. Some statics about jobs that may have fatal injuries are shown in Figure 1.

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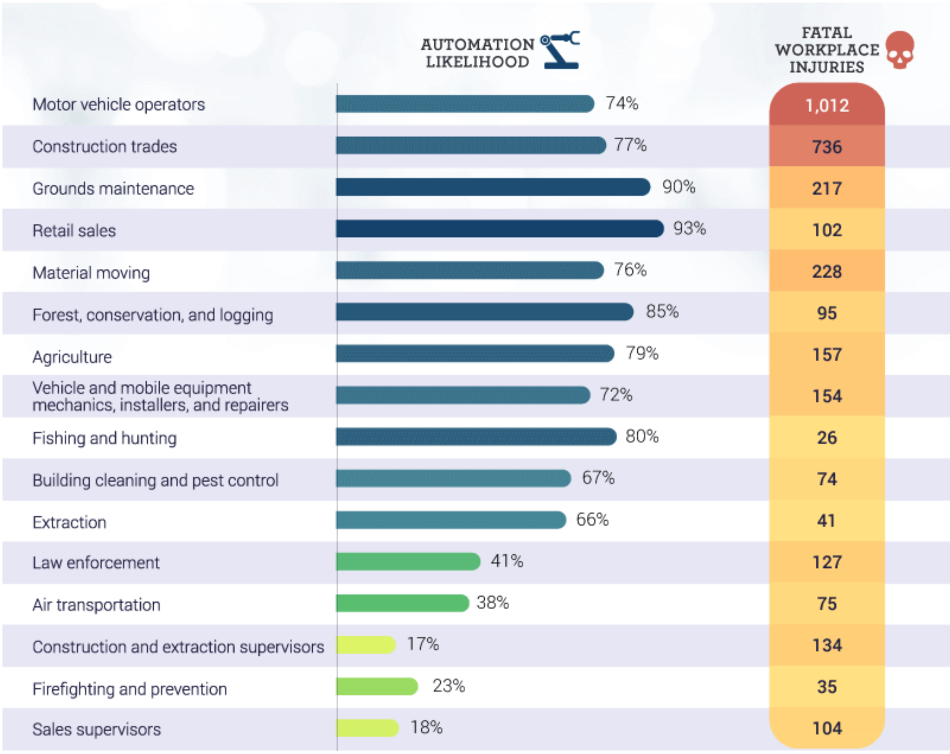

Figure 1: Total Number of Fatal Workplace Injuries [4]

Likewise, the storing of high-danger materials, such as chemicals, or materials saved in low degrees of temperature must follow stringent general storage requirements to prevent unintended reactions. In such work, the automation will minimize the human loses in the years to come and avoid danger in the environment that may threaten them or from the materials that would be stored. From such points, the study began to be designed and optimized to meet the requirements depending on safety or demanded by the owners. As well, the system aims at decreasing the number of sorting errors, increasing productivity through long running time and reaching shelves that are difficult to be reached, more easily.

Many ASRS systems were proposed and most of them consist only the hardware system and the controlling Unit. The differences between these systems depend on the type of the hardware. Through the previous studies, students and researchers have reached to many conclusions using different and unique ways. This study tried to go far with some additions and changes.

Those additions and changes came to satisfy our aims and to simplify more the project such as the software design, using Arduinos, using the steps of the stepper motor instead of using the Radio-Frequency Identification [RFID] itself and trying to make matches between the ASRS components as a system in speed and time, not only focusing on the crane. The following paragraphs explore a brief explanation of the papers and projects.

The first project presented a computer simulation model of an Automatic Storage and Retrieval System (AS/RS). The computer simulation model of the AS/RS was consisting of 5 storage conveyors, 5 retrieval conveyors, 2 bi-directional conveyors, 2 order-picking stations, 7 narrow-aisle cranes, and 9,3 x 10 storage locations, which was created in ARENA version 1.1. It was used to examine the operational logic of the entire system in order to determine the operational deployment strategy that yields the optimal number of rail-guided vehicles (RGVs), the utilization of the narrow-aisle crane, and also, the maximum throughput of the system. The increase of conveyor capacity from 1 to 2 effectively reduced the number of movements of the narrow aisle cranes to avert deadlock by 94%, while the change in the topology of the RGVs from 1 zone to 2 yielded a slightly improved retrieval time AS/RS and a reduction in the number of RGVs from 5 to 4 [1].

The second project used an educational instrumentation by Fischer Technik, which includes a set of building blocks, to build a scale model of an ASRS. An associated icon-based program was used to control motor on-off and rotation operations. A PLC was used to determine when and which motor has to be on and in what kind of rotation, given the status of switches on the ASRS. Thus, output from the ladder diagram was used as input to the icon-based program. The researchers explain that integration of icon-based programs and ladder program Two AS/RS models were constructed using Fischer Technik components, and they provide an available I/O port from the two components. The final product from such a project can be used as a demo for prospective. They included that future directions include the development of a central computer which can keep track of the availability of each storage cell within an AS/RS and adding a retrieval function to the S/R machine. In addition, the scale model of the AS/RS can be incorporated into other systems, such as production systems and material handling systems[5].

The third project presented a simulation-based performance analysis of an autonomous vehicle storage and retrieval system (AVS/RS). The aim of that

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study is to find near-optimal values for the number of AVs and lifts in the system that result in high performance under various pre-defined storage rack configuration scenarios. They find that having a large number of lifts (zones) and a large footprint yields better performance [6].

The fourth paper presented an automated storage and retrieval system (AS/RS) which controls logistics operations using radio frequency identification (RFID) system. The system has been designed and constructed focused at warehouse needs, especially for the transportation of pallets at short or long distances as well as accurate positioning of the pallets on the shelves. Therefore, they have designed it to support Internet-of-Things (IOT). They included that future research will include optimization of travel times and optimization of the interface between the AS/RS and the conveyor system, as well as wireless control of the whole system[7].

The fifth study proposed future research directions as a literature. It takes the English Journal literature of the past 5 years (20182022-) in the Social Science Citation Index database in the Web of Science database. There were 238 literatures and only 27 papers were obtained and classified. The scientists presented this paper that classifies their literature into three categories: Physical design (including depth, configuration, and number of tiers); control strategy (including scheduling rules, storage strategies, scheduling command, and interface); and performance evaluation (including through-put time, and energy). These categories are all factors that warehouse designers must consider when designing a system. The article found that these three categories influence each other to some extent. It found that if the designer of the warehouse system wants to design the most reasonable sustainable warehouse, he needs to choose different strategies according to the performance requirements of the designed system [8].

Our project presents a practical study for a low-cost ASRS customed for chemical warehouses and central refrigerators. The project was built with two branches, software and hardware. With a I2C connection, the project uses two for controlling the operations, and it has a database system for saving all the data gathered through the operations. The items will be identified by a Radio Frequency Identifier [RFID] to be sorted properly depending on their types and then be picked up by a three-axes conveyor for storing or retrieving. The initial results of operating the system, as well as the first registration in the system, were calculated in time, and the preliminary results appeared well.

This paper is organized as follows. Section 2 explains main technologies and components. Section 3 shows the system visualizing. Section 4 describes the System hardware and software design of the system. Testing the system is presented in section 5. Finally, conclusion and future work are summarized in section 6.

2. ASRS System

The ASRS technologies on the market handle different volumes, types and velocities of non-palletized inventory. Some of the main technologies are shown in Table 1 [9], [10].

Table 1: Some of the main technologies of ASRSs

Category	Technology of AS/RS	Suitable for	Investment	Advantages
Bin-based Picking	Mini-Load	Totes, trays, and cartons. up to 75 lbs. (near 34 kg)	$750,000+	- Ideal for bulky loads - Minimal use of labor - Maximum space utilization - Suitable for freezer environments
Shelf-based Picking	Horizontal Carousel	- Small items and parts, as well as documents or raw materials, High depth of inventory - Small to medium heavy items - Large batch sizes and order numbers - Large areas Low ceilings	$75,000+	- High throughput - Very high pick rates - Great storage density - Faster than vertical - Most economical
Shelf-based Picking	Vertical Carousel	- Heights up to 15-18 feet (4.5 -5.5m) - Secure/controlled items - Items requiring climate control - Uniform bin sizes and shelf weights	$100,000+	- High throughput - Can be temperature or humidity controlled - Automatic security - Very small footprint

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Table 1: continued

Category	Technology of AS/RS	Suitable for	Investment	Advantages
Shelf-based Picking	Vertical Lift Modules	- Heights of up to 100 feet (30 m) - Secure/controlled items - Items requiring climate control - Heavy items - Non-uniform sized items	$90,000+	- High storage density—tiny footprint - Ergonomic pick height - Automatic security - Can be climate controlled
Automatic Picking	Cube-Based Storage	- Space optimization - Maximized productivity and accuracy - increase performance by adding more robots. - Highest security. - Energy efficient.	$1,500,000+	- Highest ASRS storage density - Ergonomic pick height - Automatic security - Can be climate controlled

The components of an AS/RS should come with robust and well-designed hardware and software to facilitate scheduling of retrieval and storage operations. ASRS as a system has four major components[11], [12]:

A. Storage and retrieval (S/R) equipment

The shuttle is responsible for moving materials. It retrieves and stores these materials in the racking.

B. Input/output system

Getting materials into and out of the AS/RS system can be accomplished by automated conveyor lines and shuttles.

C. Storage Rack

The storage shelving is comprised of standardized and easily extensible racking that has been modified to operate with the AS/RS system.

D. The Control System

The control system handles the loading and unloading of merchandise in an AS/RS system via a dedicated software that keeps track of inventory details such as the specific location of items and how long they were in storage.

3. System Visualization

To create a comprehensive idea, a 3D Simulation Modeling and Analysis Software was used using FlexSim. It is a powerful and easy-to-use modeling and simulation software tool and was used to construct a three-dimensional computer simulation model of a real-life system and runs experiments on the model. In order to build the 3D model, the components can be divided into three main components: fixed resources, task executers and conveyors, and their ports must be connected to each other in a sequential manner to perform tasks.

Fixed resources are Sources, Queue and Racks, which can be illustrated as follows

- Sources create the flow items and releases them.
- Queues continue to receive flow items until it reaches its maximum content and will release the flow item as soon as it arrives in the queue.
- Racks receive flow items until its maximum content value is met.

The task executers are the ASRS vehicles and the cranes, and as for the conveyors, they transport and connect between the fixed resources and the task executers. The system visualizing is shown in Figures 2 and 3.

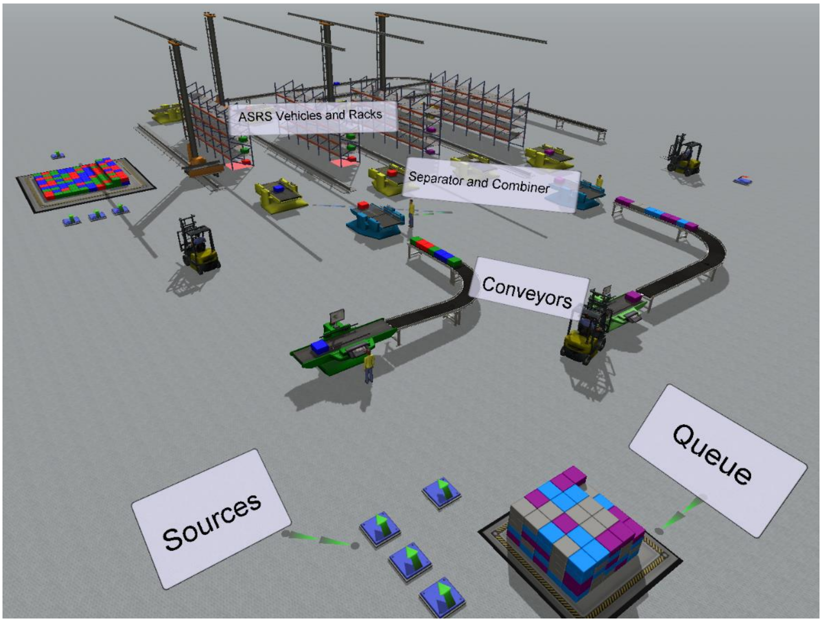

Figure 2: A View of the 3D Simulation Model

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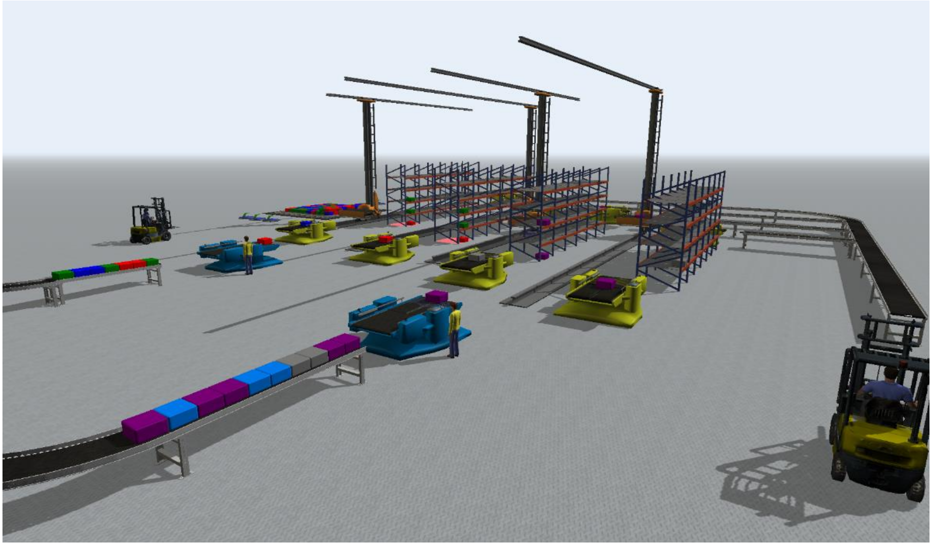

Figure 3: Another View of the 3D Simulation Model

4. System Design

The project uses Arduino for controlling the operations and has a Database system for saving all the data gathered through the operations. Every item will be counted, when sorted or shipped, in the database system. When an item arrives, its type will be identified by a Radio Frequency Identifier [RFID] to be sorted properly. When they are identified, the main conveyor will continue to the next step where a three-axes conveyor will pick up the items and put them down on the shelves. As well, the process of goods retrieval will be done by the three-axes conveyor. It will pick up the item from the shelve and put it down on the conveyor that will get it out to be shipped. The proposed system's block diagram, as shown in Figure 4, illustrates the two main units, the hardware and its controller and the software, which will be explained in more detail below.

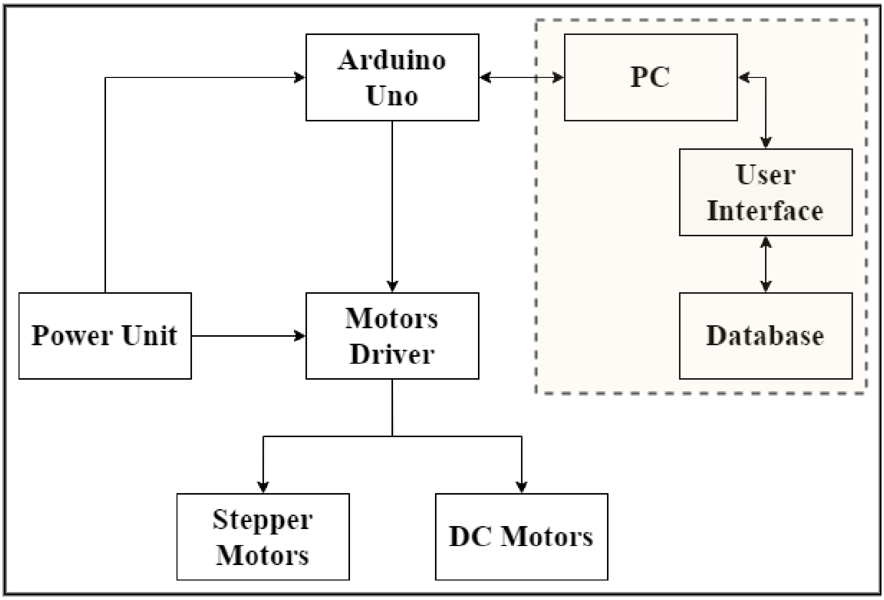

Figure 4: System Block Diagram

First, there are two branches in the system's software of the project. The first branch contains Java application with a user interface which by the storage status can be monitored [13], [14], [15]. The storage information will be stored in the system Database [16], [17]. The User Interface is used to get the information from Database and displays it to the user. The second branch of the system's software is used to control the physical components such as belts speed, crane, and input/output procedures inside the warehouse.

The control system has special procedures which are responsible for the storing or the retrieving. The algorithm of the System procedures is shown in Figures 5, 6 and 7.

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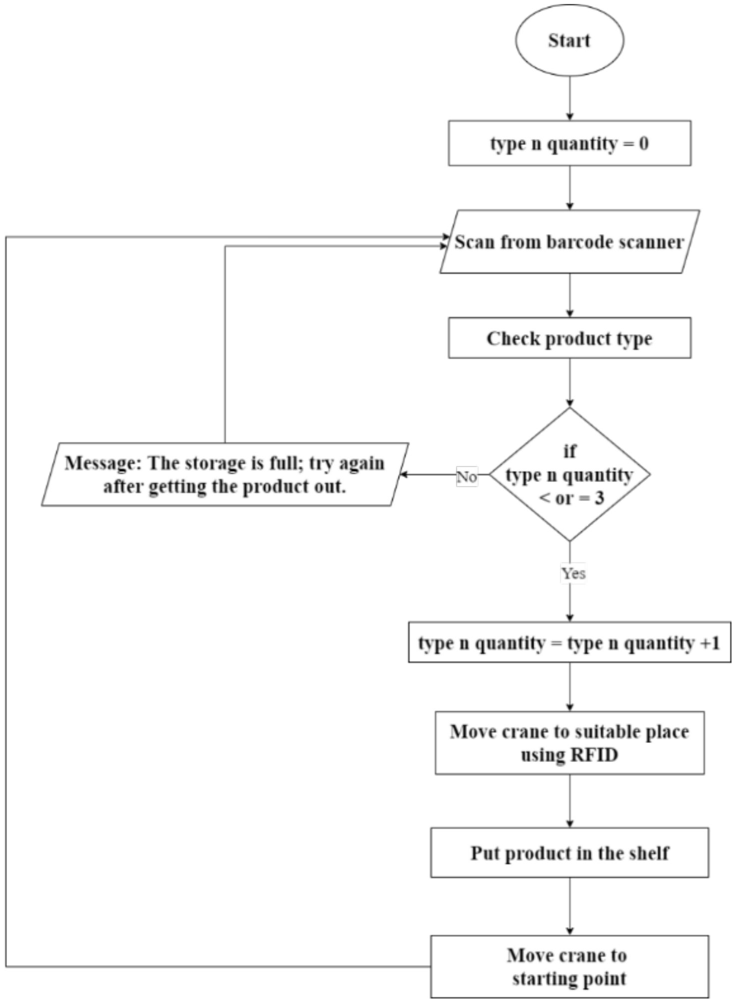

Figure 5: The In Procedure

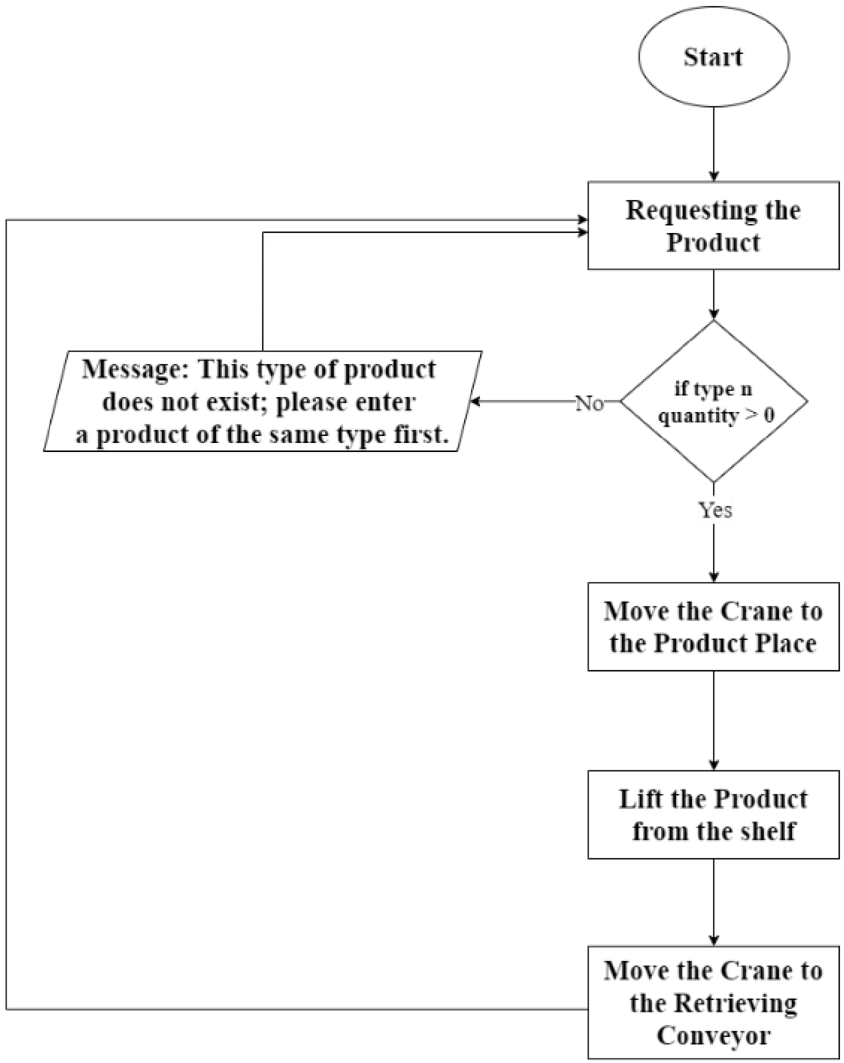

Figure 6: The Out Procedure

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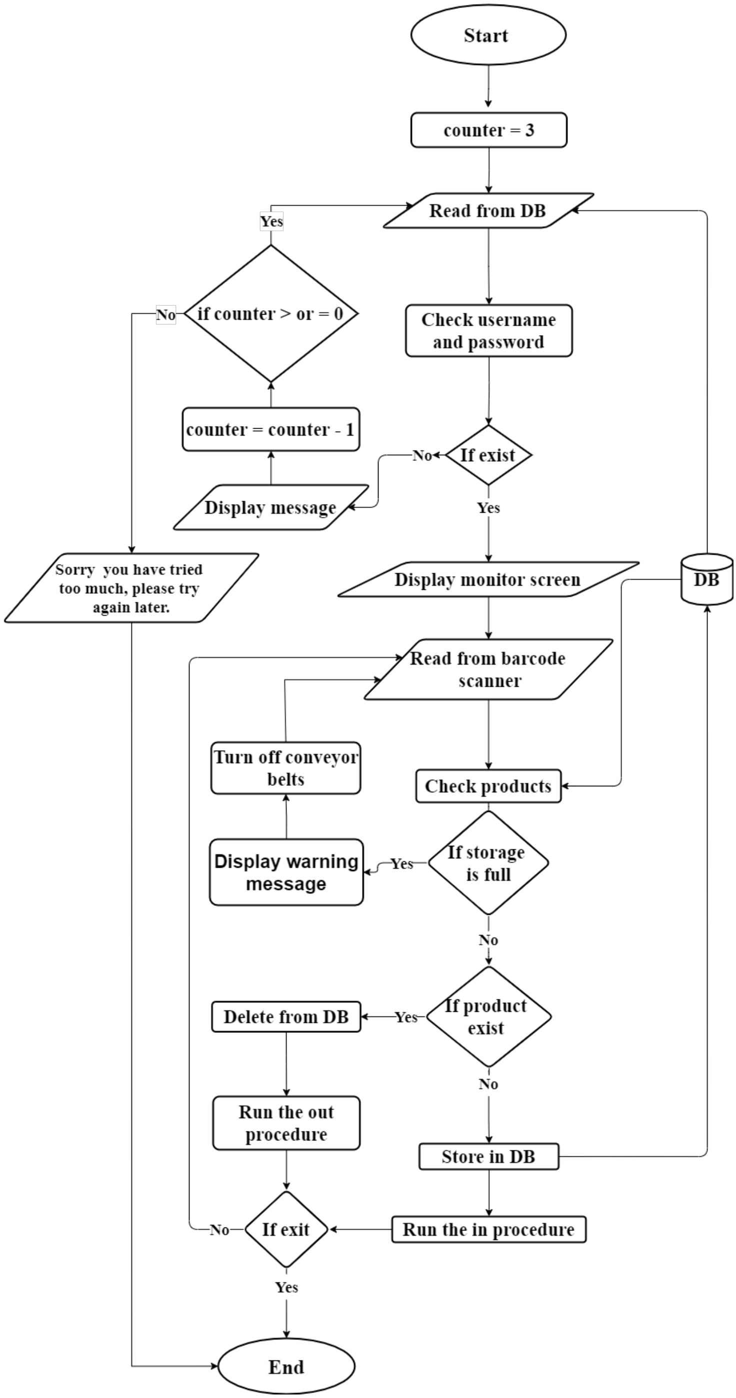

Figure 7: The Detailed System Process Algorithm

Second, after researching and considering several types and technologies available for the same project, the hardware design was built based on motors. Motors were studied to choose the most beneficial types for the project's prototype[18],[19], [20]. Stepper motors [21], PMDC motor [22], Arduinos[23],[24] and RFID[25, 26],[27] were chosen to build the project. The most important hardware components are illustrated as follow:

Stepper Motors: In this project, two stepper motors were used to move the crane in x and y axes. Steppers can give an excellent speed control, precise positioning and repeatability of movement.

PMDC Motors: The PMDC motor was used mainly to move the z axis forward and backward when storing and retrieving. Due to the lack of field winding, PMDC does not need a field circuit nor does it have a copper loss.

Arduino: Arduino Uno board is the control component of the terminal units. Two Arduinos were connected in an Inter-Integrated Circuit connection, so one of them is the master and the another is the slave.

In this paper, two Arduinos was used for controlling the operations using L293D motor driver shield[28],[29]. The project has a Database system for saving all the data gathered through the operations. When an item arrives, its type will be identified by a Radio Frequency Identifier [RFID] to be sorted properly. A three-axes conveyor will pick up the items and put them down when storing or retrieving. Figure 8 shown below demonstrates the final proposed hardware system.

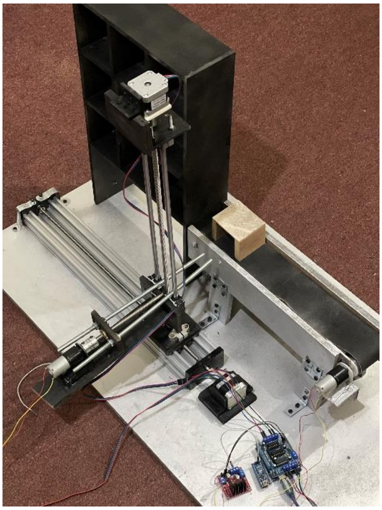

Figure 7: The Final Proposed Hardware System

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5. System Testing

The system was tested from different aspects to see the efficiency of the system. The test included the system's ability to correctly classify the goods, enter them in the right place, and retrieve them correctly. The changes that may occur within the database during the storage and retrieval process, as well as the time taken for these operations, were also studied.

The process of storing and retrieving was done properly, as the system can recognize the type of goods, sort them, and deliver them to the appropriate place based on the algorithm on which it was built. The system also identifies the type of goods to be taken out, goes to the appropriate place and retrieves them. When these processes occurred, the system database changed based on them to accurately record the data. Each item has been classified in the database according to its type and registered based on the type and the date of entry.

For the initial results of operating the system, it gave good results as a practical experiment for the first registration process of the system. The first registration process of the system was during a time of 4.16 seconds for element P (0,0), back and forth from the launch area, and a time of 60 seconds for element P (2,2) back and forth as well. The time, whether the movement is horizontal or vertical, increases at an almost constant rate and in increments of 7.25 seconds for each position of the goods in the shelves. Table 2 shown below illustrates the time required to move back and forth, whether for storage or retriecval.

Table 2: Time required to reach a specific shelf

P(2,2) = 31.08s	P(2,1) = 23.38s	P(2,0) = 16.85s
P(1,2) = 23.83	P(1,1) = 16.58s	P(1,0) = 9.33s
P(0,2) = 16.58s	P(0,1) = 9.33s	P(0,0) = 2.08s

6. Conclusion and Future Work

The Low-Cost Automated Storage and Retrieval System for Chemicals Warehouses and Central Refrigerator is mainly designed to store materials in environments that may pose a threat on workers and to store danger or chemical materials, and the desired goals have been reached as the system can store and retrieve those dangerous materials. The system uses Arduinos to control motors and has a database system with an exe appliction to monitor the operations or to order items.

For Future work, supporting the project with the image processing feature and the necessary sensors to increase security inside the warehouse from leakage or any potential dangers and minimizing the time cycle from single cycle to double cycle. In addition, improving the crane by making the z-axis moves forward and backward to cover the front and the rear shelves.

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