Development of Low-Cost Multi-Input Automated Storage and Retrieval System (AS/RS) for Educational Purposes

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Abstract. Nowadays, learning about automation technology in higher education is important to produce graduates who are ready to work. However, in developing countries, this learning is often constrained by the problem of limited costs and places to procure practice tools. To overcome this problem, this research focuses on developing automation technology learning tools that are inexpensive and less space. The object is Automated Storage and Retrieval System (AS / RS) which is commonly used in various industries for material handling but is too expensive and large for learning. The AS / RS developed is an Arduino based AS / RS with multi-input modes that are pendant, coordinate, and RFID. The AS / RS is designed to facilitate students to learn the work system, electrical circuit, and programming algorithm. The research was held in several stages: problem identification, electrical hardware design, mechanical design, algorithm and programming design, prototyping and testing. The AS / RS prototype only costs $ 230 and requires 600 x 400 x 550 mm space. The testing was carried out on functionality, usability, and educational ability using task completion and essay post-test method. Based on the test, the three aspects of the designed AS / RS were very satisfying.

Keywords: Automation, Low Cost, Multi-input, Automated Storage and Retrieval System, Higher Education

1. Introduction
Entering the era of industrial revolution 4.0, companies in various industrial sectors try to apply various technologies to their processes and products to increase efficiency and effectiveness in their business. Industry 4.0 has changed the way we develop products and processes significantly, specifically in terms of design, process, operation, and service [1]. The technology which is used in various industrial sectors to improve efficiency and productivity is the automation of production or distribution system. Automation is a technology used to carry out various processes or procedures with little or no human assistance [2]. The application of automated processes in production or distribution system has various advantages, such as increasing labor productivity, improving product and process quality and reliability, reducing labor cost, improving worker safety, improving product quality, reducing lead time, accomplishing what cannot be done manually, and so many more. Although the application of automation within a company can cause an increase in the investment and maintenance costs, the significant positive impact caused provides more financial and non-financial benefits than the costs.

The rapid development of automation technology makes the world of education (especially higher education) should quickly adapt and educate the development of the technology to its students. This statement appears since the majority of graduates from higher education will work in companies that are...
most likely to utilize various technologies. If the higher education graduates are not prepared for the automation technology, they would have failed to meet the expectations of the workplaces because they do not have sufficient competence to work. Nowadays, higher education should be able to face the demands of the workplace in terms of automation and artificial intelligence, both understanding theory and how it is applied in real cases [3].

Learning theory and practice related to automation technology in various industrial sectors are very important, especially for several departments that are closely related such as industrial engineering, mechanical engineering, electrical engineering, chemical engineering, food engineering, computer science, logistics, and many more. However, the implementation of this learning should be supported by the ability and readiness of the lecturers, appropriate learning methods, and good facilities. The challenges that often arise in developing countries are very expensive learning tools and limited space. In some countries, especially developing countries, the procurement of good facilities and practice tools is often constrained by the problem of excessive costs and limited space. In some universities that have these limitations, students just can learn a variety of automation technologies from slideshows or learning video, without being able to practice more. This phenomenon makes its students cannot practice what they have learned. The impact of This phenomenon led to the tendency that they do not have the skills they should need in the workplace. In the long run, it will cause a big gap in the quality of graduates because the students of poor universities never have an adequate learning practice to prepare their students for the workplace demands.

To prepare engineering students to work in many industries, there are variety of automation technologies that need to be learned, such as rapid prototyping technology for product design, machine vision technology for inspection, automated storage and retrieval technology for material storage, flexible manufacturing system, cloud computing technology for data integration, and so many more. This research focuses on supporting the automated system learning for material handling and storage activities, where this activity is needed by so many kinds of industry. Automated Storage and Retrieval System (AS / RS) is an automated system of storing, retrieving, and moving material activity that is familiar in various industries. Material handling activity using AS / RS has so many advantages over the manual method using human, such as process acceleration, increased productivity, improved work health and safety, reduced labor costs, increased density and storage capacity, and increased storage security [4]. The movements that occur in the AS / RS system based on three axes of linear motion along the X-axis, Y-axis, and Z-axis. The movement along the X-axis is the AS / RS positioning movement in the storage rack column, the movement along the Y-axis is used to move the AS / RS to the appropriate storage rack line or level, and the movement along the Z-axis is used to position the fork against the specific rack in picking up or placing the material.

AS / RS is one of the automated systems in the industry that is commonly used for both small and large industries. Therefore, learning the AS / RS system is very important for many higher education students, especially engineering students who are closely related to the industry. However, AS / RS for industrial- scale are generally very large in size and very expensive, so that most universities have a limitation in the procurement of AS / RS in their laboratory to hone the practical ability of their students to operate and understand how AS / RS works. The production of most AS / RS at this time should be made custom to a few AS / RS sellers with very expensive price, relatively large size, and specific programming language that are difficult to learn. This phenomenon makes it difficult for universities to procure AS / RS for their students and makes it difficult for students to gain practical skills related to AS / RS mechanical system and programming.

Until now, some research has been carried out regarding the theoretical AS / RS exposure and AS / RS development over time [4], the AS / RS modeling and optimization to obtain optimal performances [5], the AS / RS design for various industrial sector [6], and many more. Unfortunately, no research developed the AS / RS system that is specifically intended for educational purposes to overcome the problems that have been described previously. Seeing the problems in the field of higher education in developing countries that arise and the absence of research to overcome these problems, this research aims to develop a low-cost multi-input Automated Storage and Retrieval System (AS / RS) for
The AS / RS system uses multi-input so that the students can understand how AS / RS works with various possibilities of input. The AS / RS system also uses an Arduino Mega Microcontroller which uses an open-source programming platform using the C programming language to facilitate students in learning and practicing how to program and remake the AS / RS.

2. Method
On this research, the AS / RS system design has a specific purpose, that is for educational purposes. For making the development research more directed, we’ve made a mission statement containing the direction of the AS / RS system development. The mission statement is developed based on the educational problems on automation technology discussed in the previous chapter. The mission statement of AS / RS system development for educational purposes can be seen on Table 1.

Table 1. Mission Statement.

| Project Specification | Statement |
|-----------------------|-----------|
| Description           | Low-cost multi-input Automated Storage and Retrieval System (AS/RS) to support students in higher education to learn about the operation system, mechanism, and programming of the AS/RS. |
| Benefit Preposition   | • Low material and development costs.  
                        • Using multi-input (pendant, coordinate, and RFID) so that students can learn more mechanism.  
                        • Open-source programming using Arduino that is easy to learn the program and easy to remake.  
                        • Modular hardware system that is easy to assemble and disassemble.  
                        • Relatively small dimension so that it is easy to place. |
| Market                | Primary : Higher Education, especially for engineering majors  
                        Secondary : Industrial training center and high school |
| Scope and Assumption  | • The AS/RS load capacity is small because the AS/RS is designed to focus on educational activity  
                        • The input data command of AS/RS is retrieved from pendant, coordinate, and RFID.  
                        • The AS / RS design uses a dedicated storage type.  
                        • each rack or bay is only used to hold one type of component with one unit load (tote pan or other storage areas). |
| Stakeholders          | Designer, Engineer, Manufacturer, Government, Distributor, Consumer, and User |

Based on the mission statement above, we developed a research method to produce an AS / RS system that is consistent with the mission statement. The research method can be seen on Figure 1.

Figure 1. Research Methodology.
3. Result and Discussion

Based on the research methodology in the previous chapter, the AS / RS system is developed under the specified mission statement. The AS / RS type developed is a dedicated unit load AS / RS that uses an Arduino Mega 2560 Microcontroller with RAMPS 1.4 Shield Motor Driver that uses an open-source programming platform with C language that is easy to understand by the students. The development focuses on making AS / RS system that are inexpensive, have a lot of input modes, and have a simple program and electricity mechanism. If compared with the real AS / RS system in industrial scale, there are some simplifications made in this AS / RS system because it is devoted to educational purposes, such as smaller dimensions, smaller capacity, smaller loads dimension, open-source programming platform, and more varied input data. A detailed explanation of the stages of developing the AS / RS system for educational purposes can be seen in the sections below.

3.1. Electrical Hardware Design

The working system of the AS / RS developed was centered on the Arduino Mega microcontroller. All input components are connected to the microcontroller to be able to provide information to Arduino to be processed by the program algorithm in Arduino. However, because the number of pins on the Arduino Mega is limited and the need for a stepper driver to run all the stepper motors, all the inputs and outputs connected to the Arduino microcontroller through an intermediary shield namely Ramps 1.4 Shield. There is a power supply that is also connected to Ramps 1.4 Shield to provide voltage to the AS / RS circuit. The control system used in the AS / RS system is an open-loop control system because there is no feedback given from the motion mechanism and actuator. The AS / RS system electrical hardware design can be seen on Figure 2.

![Electrical Hardware Scheme](image)

**Figure 2. Electrical Hardware Scheme.**

Arduino Mega 2560 is paired with Ramps 1.4 to facilitate the application of stepper motor in Arduino and also to increase the number of pins that can be used by other modules. Furthermore, all modules needed are installed such as NEMA 17 stepper motor, 16x2 LCD Display, 4x4 keypad, toggle switch, and RFID scanner. In the stepper motor module, the A4988 stepper driver should be installed first before attempting the motor in order to control the motor's performance. A heat sink is also installed in the driver to reduce the heat generated by a large and continuous supply of electrical voltage to drive the motor. In the LCD Display module, the installation uses a casing made by ABS plastic to protect and tidy up the arrangement of the circuit. A potentiometer is also needed in the installation of this module to adjust the intensity of the light of the display. Installation of the LCD display is made by soldering each slot with the jumper connector head. In the input module, the 4x4 keypad installation also uses ABS plastic casing to give the impression of neatness in the design. For other input modules such as push-buttons for pendant mode and RFID scanner for RFID mode, breadboard intermediaries are needed because the circuit is quite complicated. The complete AS / RS electrical hardware design can be seen on Figure 3.
3.2. Mechanical Design

The designed AS / RS utilizes the rotational motion of three motors into linear motion in the X, Y, and Z axes to be able to retrieve, move, and store material according to certain data inputs. The motion mechanism of the X-axis and Z-axis motors use a belt pulley system, whereas the Y-axis motion mechanism uses a lead screw system. The X-axis and Z-axis movements are designed to be able to move quickly so that the belt pulley mechanism is used. For the Y-axis, the movement should be more concerned with the level of precision and strength of the load lifting rather than speed, so that the lead screw mechanism is used. The AS / RS design has dimensions of 600 x 400 x 550 mm. With that size, the AS / RS is easy to carry and does not require much space. This machine requires 12V 20A of electric energy to run properly. The results of the CAD hardware AS / RS design can be seen on Figure 4.

3.3. Software Design

AS / RS Programming is designed using Arduino IDE software because the microcontroller used is Arduino Mega. The programming in the AS / RS design is divided into two major sections that are the
setup section and the main content section. The setup section (void setup) contains libraries, input and output declarations, and program default settings. The main content section contains the contents of the program itself (void loop) that are the program to run the function of pendant mode, coordinates mode, RFID mode, and auto home mode.

The beginning of the void setup is filled with all the libraries used. Library is a collection of programming code that can be used as needed. Library writing is done by writing #include at the beginning of writing. the void setup continues to define the step where all modules used need to be defined first based on the Ramp 1.4 Shield Structure. Each module of the AS / RS programming has a different way of defining steps.

In the void setup section, all declaration names are written in the same code: ‘pinMode ()’ followed by the name of the declaration used and its role (input or output). The motor acts as the output, while the push-button acts as an input and end-stop acts as a pull-up input. LCD initialization is done by writing the sentence ‘lcd.begin ()’ followed by the size of the LCD used. Code ‘Serial.begin (9600)’ is only used to activate the serial monitor for checking. Code ‘SPI.begin ()’ is used to activate the Serial Peripheral Interaction system and code ‘rfid.init ()’ is used to enable the type of RFID MFRC522 used. Motor X-axis, Y-axis, and Z-axis are also activated first by giving a digital ‘LOW’ value.

In the void loop section, before starting the operation program, the AS / RS opening title is displayed first on the LCD. After displaying the opening title on the LCD, the contents of the program operation are made. First of all, the user needs to choose the modes from the four modes provided, namely pendant mode, coordinate mode, RFID mode, and auto home mode. After the user selects a mode, it will enter into the chosen mode. The pendant void mode contains a program to run the fork from the push-button command. There are 7 push-buttons that are clockwise and counterclockwise on the three axes and one push-button as a stop. The coordinate void mode contains a program to run the fork according to the distance of the coordinate inputting input. The RFID void mode contains a program to run the machine in accordance with the number code of the card tag that is read by the RFID scanner. The auto home void mode contains a program to run all motors back to their default position (all coordinate axes are 0). The AS / RS program design algorithm can be seen on Figure 5.

**Figure 5. AS/RS Programming Algorithm.**
3.4. Implementation and Testing
In the implementation stage, a final prototype of the designed AS / RS is made for testing and evaluating the function, the usability, and the ability to educate its users. The AS / RS design prototype for educational purposes can be seen on Figure 6.

![Figure 6. AS/RS Prototype.](image)

The cost of making the AS / RS prototype only costs around $ 230, which can be much reduced if it goes into the mass production. Thus, the costs required to produce this AS / RS will be much cheaper than buying an industrial AS / RS that has price up to thousands of dollar. In terms of space requirements, the AS / RS design only requires a small space, which is 600 x 400 x 550 mm, so that it will be easy for higher education to provide the space needed. Thus, the limited cost and space which is a problem for various educational institutions in learning the application of automation technology can be overcomed.

Most of the frames in the hardware, the shelves, and the Arduino box cases are using ABS plastic and manufactured using rapid prototyping technology (3D printing method). The AS / RS design is made open in terms of the appearance of the frame with the aim that the user can learn how the electronic circuits arranged can produce the motion mechanism that occurs. This system also makes it easier for users to learn the structure of the AS / RS to be remade by themselves. However, the Arduino circuit is wrapped in a modular ABS plastic box cases so that the position of the circuit is not easily changed and safer for the user. The microcontroller circuit and the program can be learned directly by the user and the program can be downloaded easily by the user through the Arduino device. Thus, the AS / RS electrical hardware design provides easy learning about the circuits and the AS / RS programming. The AS / RS can also improve user understanding of the motion mechanism and the algorithm of action using pendant mode, coordinate mode, and RFID mode as discussed in the previous section.

The prototype function testing was carried out by testing five potential users of the AS / RS, who are engineering students and lecturers in higher education, to carry out tasks related to the entire use of AS / RS design. Based on prior studies, five respondents are considered sufficient for a qualitative research [7]. The tasks given to the respondents were placing and retrieving materials in the unit load from and to 3 different shelves that have been determined by the researcher with pendant, coordinate, and RFID modes. Before the testing began, the respondents were given manual instructions that were made to facilitate users in operating the AS / RS. After carrying out these tasks, the respondents should have returned the fork position to the default position using the auto home menu. Based on the test conducted, all the tasks given can be carried out properly and correctly by all respondents. The AS / RS design performance also has 100% correct placement accuracy based on the user input. Thus, it can be concluded that the function and the ability of the designed AS / RS can be said to be good enough.
However, there are two notes based on tests conducted. First, the motor speed is considered too slow (X-axis speed = 89 mm/sec and Y-axis speed = 26 mm/sec). Second, some parts of the instruction manual are considered difficult to understand without images explanatory. Therefore, the motors would be replaced with NEMA 23 stepper motor that is stronger than NEMA 17 but still in accordance with their use, so that the speed of fork movement can increase up to twice.

Subsequent testing was to ensure that the designed AS / RS design successfully educates its users in terms of practices related to the working mechanism, the controller circuit, and the programming of AS / RS system. The test was held by evaluating the understanding of five industrial engineering students who have studied the AS / RS design for 120 minutes. The respondents were the students who had studied theories about automation technology in the manufacturing systems, computer programming with Java or C languages, basic electronics, and basic theories of AS / RS. The understanding evaluation was held by giving 15 essay questions on understanding the mechanism of AS / RS work and how to operate it, the AS / RS electronic circuit, and the Arduino programming. The answers of each respondent were assessed by a lecturer as well as a practitioner who is an expert in manufacturing, mechatronics, and Arduino programming. The assessment was done by giving a score of 0-100 for each respondent’s answer, where a score of 0-50 is considered very unsatisfactory, a value of 50-60 is considered unsatisfactory, a value of 60-70 is considered quite satisfactory, a value of 70-80 is considered satisfactory, and a value of 80-100 is considered very satisfactory. Based on the evaluation of students’ understanding, the average value of all respondents was 81.33. Therefore, it can be said that the AS / RS design has been able to educate students very satisfactorily. Based on the tests conducted, there are two things that need to be added to make the learning process more optimal. First, the students need the addition of a guideline book on AS / RS programming. Second, the students need a function of taking or storing material to several shelves at once in the designed AS / RS.

4. Conclusion
The AS / RS development research for educational purposes is one way to make the learning process that requires tools to be more effective and optimal, especially for some developing countries that often experience some financial and space constraints in developing their learning activities. Based on the research conducted, the designed AS / RS can be said to be successful in meeting its goal of facilitating the engineering students learning process about the AS / RS system with low procurement cost and minimum space. By using a similar methodology, subsequent research can also develop other learning practice tools with the same background and limitations. We all have already known that well-facilitated higher education can produce superior generations who can well compete in the future. Therefore, similar research can be developed with the same passion to develop the quality of humans in the industry 4.0 era which requires a good understanding of technology to well compete.

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