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Automated Library System Using SMS Based Pick and Place Robot

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Abstract: Library management system aims to automate the library processes throughout a collection of actions as book loan, catalogue, indexing, and recording. This paper goes one-step further in the automation of library systems by using the IoT and robot for more precise and reliable automation. In this proposed work, Pick and place robot has been integrated with GSM technology, Radio Frequency Identification (RFID) equipment, and sensory technology to enhance the robot functionality. The augmented robot, in this work, is used to automate the process of picking the library books and sending them to the borrower table. The user can control the robot movement inside library remotely using SMS commands. In this paper, redesigning the library ground was implemented to let the robot moves freely between the shelves. The experimental results showed the ability of robot to collect books with different thickness and weights from different shelf levels at different distances with accuracy up to 97.33%.

Keywords: Pick and Place Robot,Library Management System, Optical Reflex Sensor, IoT , GSM, RFID.

1. Introduction

Library management processes are those actions needed to facilities the library processes such as material acquisition, loan, cataloging, circulation, and return [1]. Such processes are nowadays automated throughout what is called library management systems (LMSs). LMS is the computer-based system that help the librarians to help the library customers in an efficient way. Although the great benefits of LMS in terms of managing the books records, easy access to the material, the automation is still needed to acquire, organize, and return the books. The automation is the process of deploying different technologies to accomplish the tasks with minimal human assistance [2].

Robotic is the one of the automation techniques used widely in different fields ranging from heavy industry, health sector, to smart houses. Robot is an interdisciplinary technology that comprises mechanical engineering, electronic &electrical engineering, artificial intelligence, computer vision, and other computer sciences to develop machines that mimics and substitutes the human beings [3]. Out of the popular robots is pick and place Robots, which used to expedite the process of picking stuffs up, moving them around, and placing them in new locations. Notably, Pick and place Robots is widely used to enhance the productivity with high level of accuracy, while doing backbreaking or hard to maneuver movements that may be difficult or dangerous for humans.

The popularity of pick and place robots came from their characteristics such as consistency, quality, accuracy, and repeatability, which is incomparable. Thus, pick and place robots are deployed everywhere in the industry as they are multipurpose and can be reprogrammed and tooled to provide multiple applications for consumers. Nowadays, with the advancements in technology and affordability of robots, more pick and place robots are being installed for automation applications [4].

The aim of this paper is to implement automated library system using pick and place robots to automate the daily library transactions as book borrow and return processes. In the proposed model, the pick and place robot will be equipped with optical reflex reader, RFID reader, and ultrasound sensors to be able to move around the library freely to acquire, move, and place the library objects (i.e. books). The user can send the instructions to the robot remotely from anywhere via SMS. The robot will be programmed with sets of instructions, which gives the user a full control to perform a pick and place tasks in libraries with different heights and book sizes, with the ability of the robot to avoid obstacles in case there is any. The remainder of this paper is organized as follows: section 2 discusses the related works. Section 3

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introduces the proposed methodology of this work, while section 4 presents the experimental results. Finally, the paper has been concluded in section 5.

2. RELATED WORK

Intensive research works have been done on pick and place mechanisms for different purposes and needs. The authors [4] have designed an Automated Food Delivery System to overcome the problem associated with the growing number of customers. The proposed system deploys the robots that are in synchronization with the ordering system. In the system, colored lines are drawn on the restaurant ground. These colored lines represent the paths between the kitchen and the customer's table. The robot should follow these paths to serve the customers. When customers place their order through the ordering system, the system sends the order to the kitchen. Once the dish is prepared, a signal is sent to the robot, and then the robot delivers it to the specific table, returns to the kitchen and sends a feedback signal to the ordering system as a confirmation of delivery.

Another work introduced by [5] wherein a microcontroller based on reliable and high performance robotic system for food/biscuit manufacturing line has been implemented. The proposed system aims to design a robot that is capable of picking unbaked biscuits tray and places them into furnace, and picks the biscuits tray back from the furnace after baking it. One of the limitations for this project is the payload where the robot has a low payload of 200g. Moreover, the accuracy rate of the robot is only 70%, which is also another limitation for the study.

The two aforementioned works demonstrates that food industries were having the initiative to use robots for wide range of tasks. The driving reasons are to increase efficiency, increase hygiene and reduced labor costs. However, nowadays the robot are reliable to do tougher tasks in the food industry such as handling products. The product handling is a difficult process wherein a diverse products need to be packed. These products are very poles apart and exhibit a wide range of sizes, surfaces, weights, exposures to damage, colors, and shapes. These characteristics make the products difficult to grip with traditional grippers. Although they cannot compete with humans in product packing in terms of flexibility, the robots have many advantages in food production such as hygiene and adaptability. For example, Hygiene is critical and very important when dealing with unpacked food products, Human contact with unpacked food products has a high contamination risk and possibility to transfer microorganisms and dirt which can contaminate the food, while robots can be built to be much sterilized. Besides, unlike human beings, robots are having the ability to work in an environment with diverse conditions without being affected nor being damaged by repetitive motions. Moreover, robots have the ability to work for a long time with constant quality and efficiency. To make all these advantages of robots utilized, new and innovative grippers are looked-for [6].

On the other hand, capable robots having a light duty arm with an active fingertip gripper for handling discoid objects have been proposed by [7]. The hand-arm system was designed to perform a pick-and-place task from horizontal placement to vertical placement and vice versa, therefore it can share the work space with human worker assuming that the robot will be working in a cell manufacturing system. The target task was to pick up a discoid object from the horizontal parts box and insert the object into a slot of the vertical parts box, and vice versa. The prototype gripper succeeded to perform the task with the discoid object of φ 31mm. Notably, the gripper mechanism delicately pick the object up from the vertical parts box by slowly rotating the fingertip cylinder. Gen et al. observed that the finger distance passively changed according to the relative height of the object. They also tested the same task without the passive compliance and found that the actuator current hit the limitation of the motor driver. They concluded that the passive compliance in the grasping motion is important for succeeding the task. As a result, the system successfully performed 100 times continuous pick-and-place without failure, whose cycle time is almost the same as a human worker.

The authors in [8] proposed an effective vision-based kinematic calibration method which calibrates three translational Degrees Of Freedom (DOFs) and one rotational DOF of pick-and-place robot, respectively. For the three DOFs, the vision system takes an image and finds the position of a fixed reference cross mark when it moves with pick-and-place robot, and the relationship between displacement of pick-and place robot and position parameters of the cross mark in the vision system is the key factor to adjust it. The placement accuracy is the most important factor of the pick and place robot, therefore, to improve the accuracy, the computer vision was utilized to provide correction signal. Lastly, the result of pick-and-place experiment shows that this vision-based kinematic calibration is effective for this pick-and-place robot in flip chip bonder. The findings in this quick survey motivated us in this proposed work to equip the pick and place robot with optical reflex sensor to assist the robot in how to move smoothly in the library.

A similar work work done by [9] to demonstrate the use of robots in library management systems. A robot is designed to follow a predefined line to keep track of the library book shelf arrangements. The number of the book to be taken is given to the robot as an input. Robot obtains the book data by comparing the saved RFID number with the books in the shelves. If the specific book that the robot finds matches the saved book details, the robotic sends a notification to the shelf unit. The corresponding shelf is moved forward and the book in the shelf is placed in the robot's basket. The robot returns the book to the center. The customer can therefore supply the book from the collection center.

Another work conducted [10]. It demonstrate the use of robot in library inventory management systems. A robot is designed to keep track of library book shelf arrangements using designed to keep track of library book shelf arrangements using sensor-operated motors. Robot gets the book data to be searched from the PC via Zigbee, the robot has a barcode reader that collects the barcode data from vertically arranged books and compares the decoded barcode data with the input.

A smart librarian robot with RFID technology proposed by [11]. The robot can be kept in an experimental environment based on estimates of human behavior using a laser range finder, talk to a library user with a natural language and search books depending on the user's request. When the robot explains where a book is in the library, it points to the target position using a laser spot while the body and head are turned to the target direction. However, the robot cannot always indicate the target position using the laser pointer directly. The authors in [11] therefore design three types of guidance with the laser pointer and the gestures depending on the library environment. Some experimental results show the validity and efficiency of their proposed guidance method with the laser pointer and certain gestures for their library robot.

Moreover, the authors in [12] have presented a new approach to use an intelligent system to design a robotic library. The robot works on an ARM microprocessor, a 5-degree motor driver circuit with Wi-Fi and a GPS communication protocol. RFID controls the authenticity of library books. An embedded system and ARM facilitate the proposed robotic library system.

The authors in [13] demonstrate another concept for the use of the robot in library management systems using LabView. A complete LabView test stage for the robot library association has been deliberately designed, manufactured and certified with the operational control and trademark estimation of myRIO contraction. However, their study was just a framework and there is no real robot proposed.

The authors in [14] have presents a small circularly polarized wideband patch antenna printed on low - cost FR-4 material for smart library library radio - frequency identification. The antenna consists of four sequentially rotated top-loaded patches with a phase difference of 90 cl and a double shortening to the ground. It works at 0.915 GHz center frequency. The antenna gain was about 4 dBi, and the overall dimension is reduced by ~60% in length, in comparison with that of the conventional sequential patch antenna.

Literature has shown that libraries in developed countries are rapidly increasing early adopters of RFID technology. Another sector of early adopters are distributors that primarily use the technology in the supply chain. The literature abounds with studies on perceived and expected RFID problems in the supply chain, but is sparse in terms of technology performance and reliability in library environments. This has led researchers to suggest that RFID research is needed in library environments.

3. METHODOLOGY

In this paper, the proposed methodology is divided into multiple stages, as depicted in Figure 1, which demonstrate the detailed design.

This proposed system operates according to SMS commands as it is shown in the signal flow (Figure 2). The system consists of command receiving region, command processing region, scanning operation to find the object, picking the object, scanning for placement area, place object on target, sending a status clarification message and task termination regions, respectively.

First, the user will send SMS containing the command to GSM module, which is connected to the robot and is having an active SIM card number. Once the user sends a command, GSM module transfers the instruction through MAX232 circuit to Arduino board for processing purpose. The validity of instructions will be checked before further processing. If the sent command is invalid, a reply SMS will be sent to the mobile number informing the user to check the command. Otherwise, the microcontroller will start processing the command to read the location of book (e.g. section, and height). Based on the extracted information, microcontroller will send signal to activate the power window motor to lift the gripper to the desired level height. Next, Arduino will decide the appropriate path to reach the target, and then the robot will start moving by following the path until it reaches the right section. The robot will keep moving until the optical reflex reader detects the needed section. When the robot reaches the target section, a signal will be sent to the RFID reader to start scanning for different tags.

The moment that RFID identifies the serial number of the tag that is matching the serial number sent to Arduino, Arduino will send signals to the DC motor of the robot to stop moving, then will send signal to the gripper motors to grip the book. After picking the book up, the robot will reverse its movement direction to go back and deliver the requested book.

Figure 2 shows the entire process of the working principle of the pick and place robot. The flowchart is showing how the desired books are collected from the different shelves.

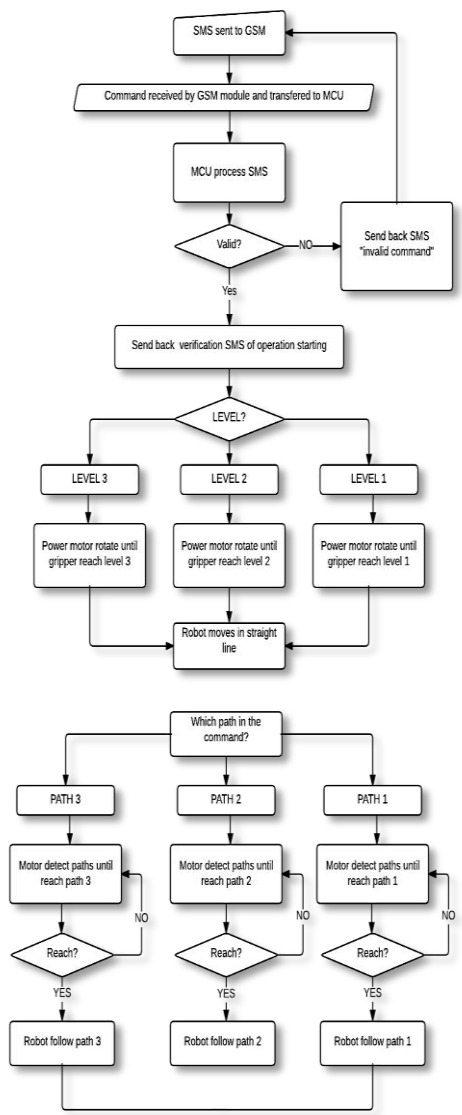

Figure 1 (a). Flowchart of the proposed system

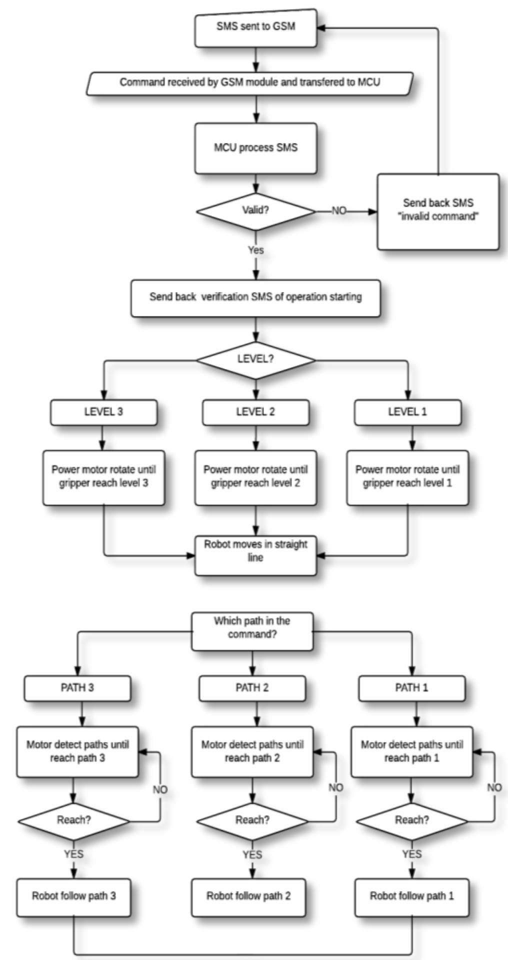

Figure 1 (b). Flowchart of the proposed system

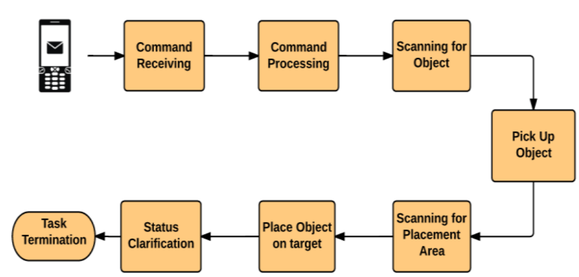

Figure 2. Signal flow for the Proposed System

A. Proposed circuit design

The proposed SMS based pick and place robot consists of three circuits, each one has specific role to do. The first circuit is the GSM MODULE circuit; this circuit contains the GSM Modem, which receives the SMS commands, and the RS232 serial communication port. RS232 is an asynchronous communication protocol that helps to transfer data between electronic devices. In the proposed circuit, the data is being transferred between the GSM modem and the MAX232.

The second circuit is the Control Board Circuit. The Control Board Circuit consists of the Microcontroller unit and the MAX232 IC. The microcontroller unit is basically the PIC16F887A IC that is connected by the pins TX and RX with the MAX232 IC T1IN and R1OUT pins.

Particularly, Control Board is the main circuitry in the proposed system that works as the brain of the robot. Control Board processes the SMS commands that are received from the GSM Module, processes the data from the Ultrasonic Sensors, and gives signals to the gripper, as well as, to the 2-DC motors wheels to rotate in certain directions and speeds accordingly to accomplish the tasks.

The third circuitry is the motor driver board, it consist of LM298 motor control circuit and used to control the speed and direction of the DC motors. The circuit design for the proposed pick and place robot shown in Figure 3.

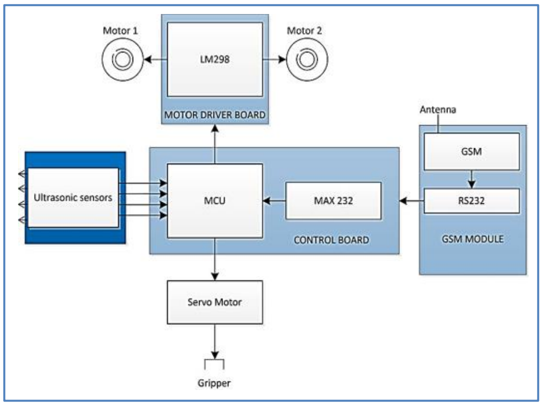

Figure 3. Proposed Circuit Design for the SMS based Pick and Place

B. *Robot design & weight*

When designing mechanical structures with lifting weights applications, the weight of the machine must be within calculated limits in order to avoid losing the equilibrium when under usage. In this part, Figure 4 shows the forces that affect the robot structure and we calculated the robot total weight as follows.

Desired book weight = 500g (Maximum weight)

Desired manipulator arm length = 30cm (Maximum arm length)

Since F = m×a (Force = mass × acceleration) [15].

$$\therefore \quad F_b = \left(\frac{500}{1000} \times 9.81\right) = 4.905\ N$$

To find overturning equilibrium at point A:

Firstly, find the overturning moment:

$$OT = F_b \times L_a \tag{1}$$

Where,

OT: Over turning moment

F_b: Book force

L_a: Manipulator arm length

$$OT = 4.905\ N \times 0.3\ m$$
$$= 1.4715\ \mathrm{N.m}$$

Secondly, Find the resisting moment:

$$Rm = \frac{Robot\ Mass\ (M_R) \times acceleration(a)}{2} \times Robot\ length\ (L_C)$$

Where,

Rm: Resisting moment

$$R_m = \frac{M_R \times a}{2} \times L_C \tag{2}$$

Assume $L_C = 0.5\ m$ (required for the robot components to fit) [16].

Equilibrium at point A

$\Sigma m_A = 0$

(3)

$$(F_b \times L_a) - \left(\frac{M_R \times a}{2} \times L_C\right) = 0$$

$$(4.905 \times 0.3) - \left(\frac{M_R \times 9.81 \times 0.5}{2}\right) = 0$$

$M_R = 0.6$ Kg (Minimum required robot mass)

Overturning factor of safety = 3

$$Robot\ mass\ (M_R) = 0.6 \times 3 = 1.8\ kg$$

As shown in the above calculations, the mass of the body of the robot must not be less than 0.6 kg. However, to increase the stability and safety of the robot, the total mass of the robot was amplified by multiplying it by 3, as safety factor. Therefore, the total mass of the SMS based pick and place robot will not be less than 1.8 kg in order to protect the robot from overturning motion.

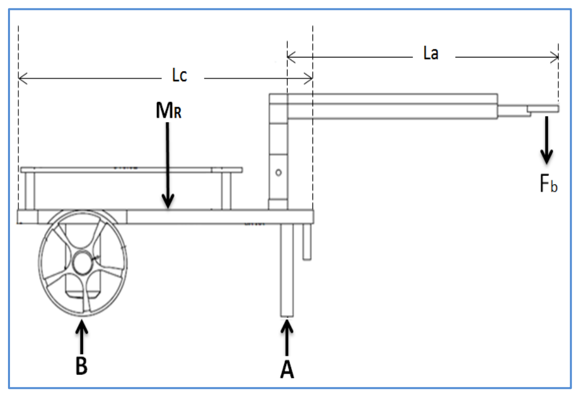

Figure 4. Forces that affect the robot structure.

C. *The General Design of the Library*

The process of picking the right book among hundreds or thousands of books is a very delicate. Therefore, the library environment for this study must be carefully designed including the distance between the shelves and the shelf's dimensions. Designing the shelf's dimensions is important to make it fit with the robots ability as the robot is moving between the shelves and picking the books in a different mechanism than human beings.

The entire area of the designed library is divided into two parts; the first part is where the robot will operate in. and the second part is where the people can sit on tables to read books or do their activities and nobody is allowed to enter the first part where the robot will operate except for the librarians.

The first part where the robot will operate was designed based on the most suitable arrangement for books, as well as, robot's dimensions. For the demonstration purposes, the heights of the shelves were designed to be not more than (1.1 meters) height since the robot's height is (1.1 meters). But when this study is implemented in a real life library, the height of the shelves can be extended higher, since the robot height can also be extended as well. Also, black lines were added to the library's floor in order to guide the robot among the different shelves and sections using line follower sensors. Also, this part of the library has a wooden disk with a glass book rack on top of it at the "final destination" for the robot to put the picked book in it.

The second part is where the readers will sit. It is consisting of chairs and tables and also a PC must be provided with a search engine connected to the database of the library so the reader can use it to get the SMS codes for the books they want to read.

The following design for the library was implemented. Based on this design, the programming for the Arduino was done. The library design was done using Sketchup software, and depicted in Figures 5.

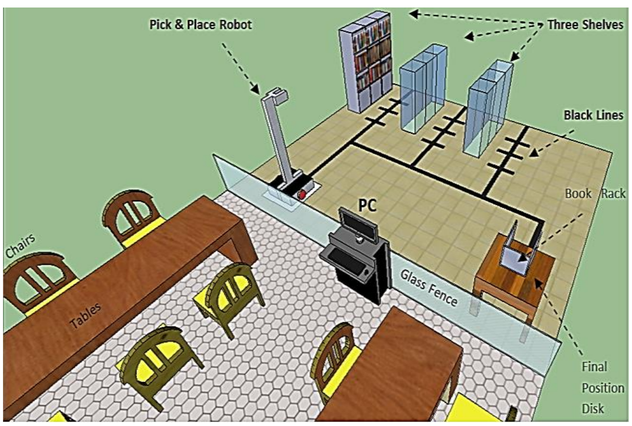

Figure 5. General Design of the proposed Library Environment.

The Shelf Design:

Each shelf consists of three sections A, B and C, while each section consists of three levels 1, 2, and 3. Each level has a height of (25cm) and the total height of the shelf is (1.05m). Each section is (30cm) in width and the total width for the 3 sections is (90cm). The design of the shelf is shown in the Figure 7.

Finally, when the robot receives a signal, the navigation process will start to navigate among the shelves from a defined area. This area is referred to as "initial position ". After the desired book is picked, the robot will come back to another defined area which referred to as "final position" and will drop the book on a disk where the readers can collect their book from the book rack.

D. Simulation and hardware results

1. Optical reflex sensor circuit implementation:

The circuit was constructed and connected to comparator dual op amp IC, as shown in Figure 8, and then it was connected to the Arduino.

2. Circuitry of the robot implementation:

The circuit components were constructed as depicted in Figure8. All the components of electrical implementation were connected to power source to check the circuit functionality. The final design of the proposed system including the mechanical and electrical circuitry is shown in Figure 9. Also, the RFID Tag and reader with an example of gripped book shown in Figure 10.

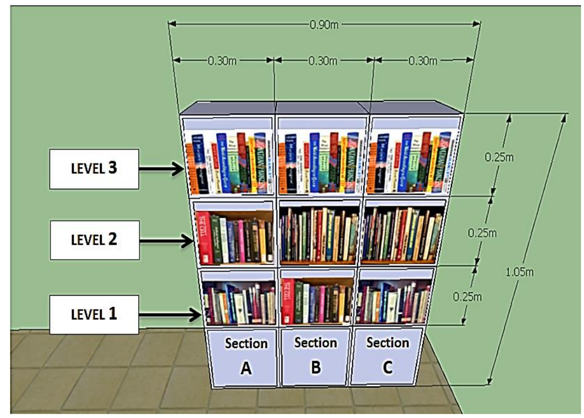

Figure 6. Design of the Shelf.

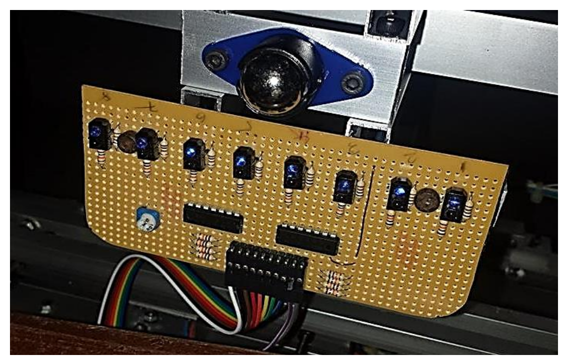

Figure 7. Implementation of the optical reflex sensor circuitry

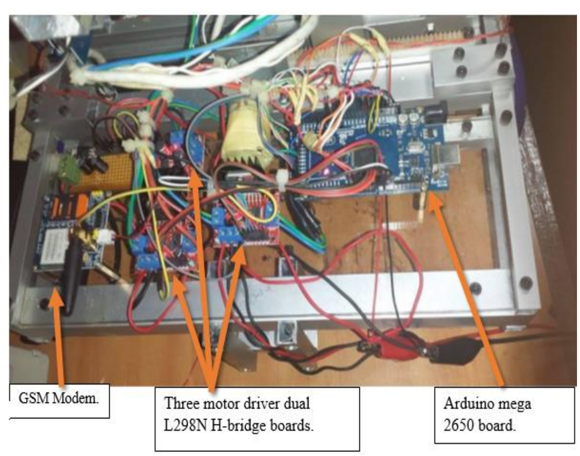

Figure 8. Implementation of the optical reflex sensor circuitry

An SMS command "A-1-C" was sent to the GSM modem and as seen in the Figure 11, the phone number of the SMS message is extracted. Then it will go to the

desired shelf and collect the book by scanning the IDs of the RFID tag of each book.
In Figure 12, the optical sensors check for black lines and if it find on then it will show the number 1 on the screen. Otherwise it, will show 0.

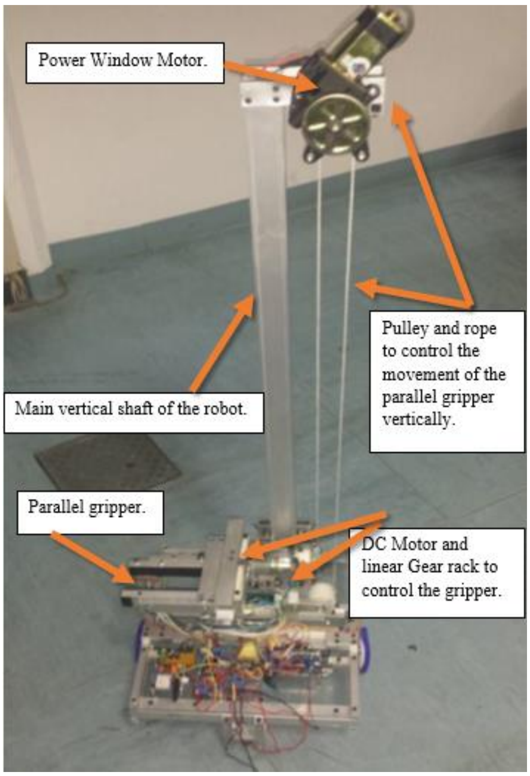

Figure 9. Implementation of the mechanical and electrical design for the robot

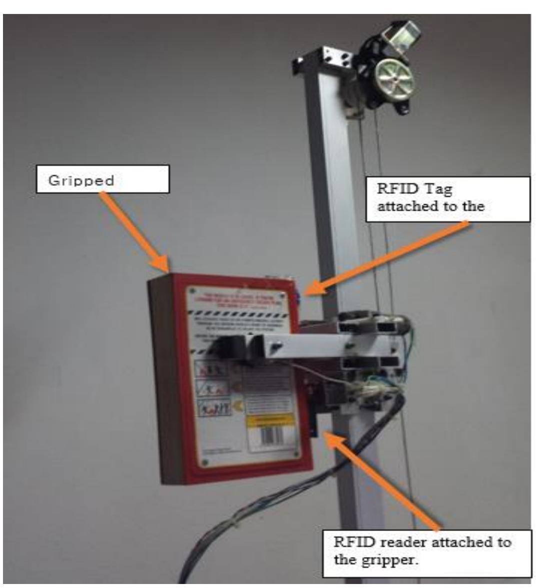

Figure 10. An example of the RFID tag and reader with gripped book.

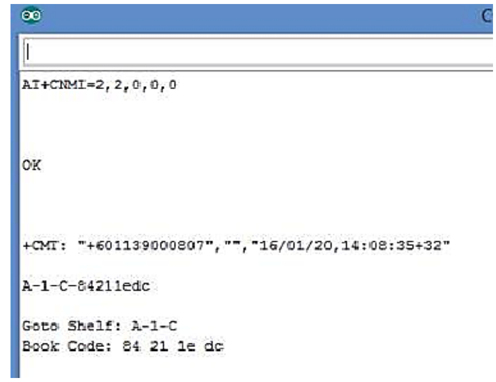

Figure 11. GSM modem extraction of phone number and executing SMS commands.

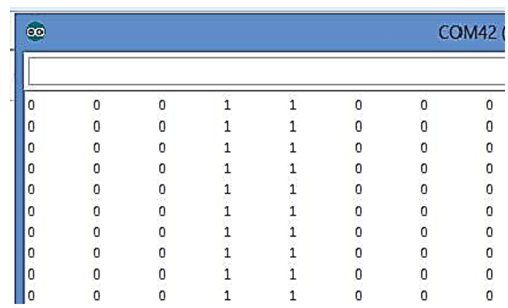

Figure 12. Optical reflex sensor simulation

Two SMS commands were sent to the system, to test the feedback messages, the first command was fault command, therefore an SMS sent back with the phrase "The book code requested is not available!". However, when a correct command was sent to the GSM module and SMS sent back with the phrase "Request is received successfully. The book will be delivered to you shortly". This means the system was able to communicate with the sender

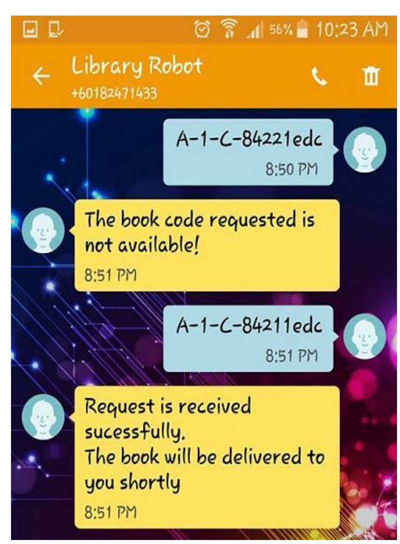

Figure 13. Optical reflex sensor simulation

4. EXPERIMENTAL RESULT

In this study, four tests conducted to evaluate the system performance. The first test is about the potentiometer accuracy that is attached to the power window motor to detect the accuracy of reaching the desired height for the robot. The second test is about the gripper ability to hold different book thicknesses, a different book thickness will be tested to see whether the gripper could hold them or not. The third test is about the gripper ability to hold different book weights, a different book weights will be tested to see whether the gripper could hold them or not. The forth test is about the accuracy of picking a book relative to its distance from other books. Four different tests will be implemented to the design and data will be analyzed to evaluate the overall performance of the system.

Test 1: Level shelf testing and potentiometer accuracy

This test carried out based on few steps. Firstly, the Arduino software has been set and upload the codes to the Arduino board for the multilevel test. Then, connect the power source to the robot and define the height of the shelves measurement. After that, place the robot on the track of movement and send the SMS command to the GSM modem whenever there is any book requested. Table 1 and Figure 14 illustrates the Percentage of successfully reaching levels 1, 2 and 3. In most of the runs, the desired accuracy for the system was achieved. The data shows that the potentiometer average accuracy was 97.33% which is an acceptable percentage for the system.

TABLE I. DATA COLLECTED OF THE ACCURACY OF THE POTENTIOMETER.

Number of run	No. of Level	Command	Percentage of Success %	Average Percentage of Each Level %
1	level 1	1-A-1-xxxxx	100%	96.00%
2		1-A-1-xxxxx	80%	
3		1-A-1-xxxxx	100%	
4		1-A-1-xxxxx	100%	
5		1-A-1-xxxxx	100%	
1	level 2	1-A-2-xxxxx	100%	100.00%
2		1-A-2-xxxxx	100%	
3		1-A-2-xxxxx	100%	
4		1-A-2-xxxxx	100%	
5		1-A-2-xxxxx	100%	
1	level 3	1-A-3-xxxxx	100%	96.00%
2		1-A-3-xxxxx	100%	
3		1-A-3-xxxxx	100%	
4		1-A-3-xxxxx	80%	
5		1-A-3-xxxxx	100%	
			Average Percentage	97.33%

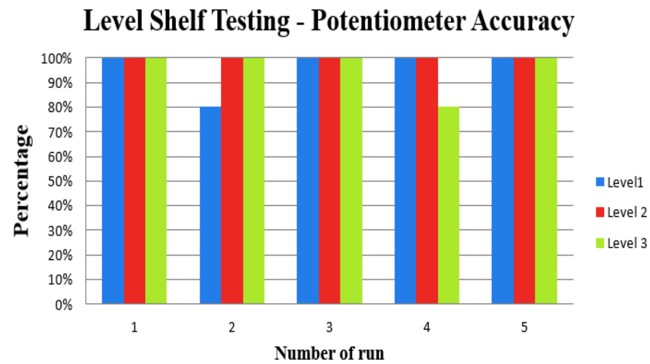

Figure 14. Percentage of successfully reaching levels 1, 2 and 3.

Test 2: gripper ability to hold different book thickness

The results from this experiment show that when the book thickness is 1cm- 2cm, the accuracy is at optimum. However, the system efficiency decreases with the increase of the book thickness. The thicker the book is, the less efficient the system gets. Figure 15 represents the results of the robot handling books in different thickness.

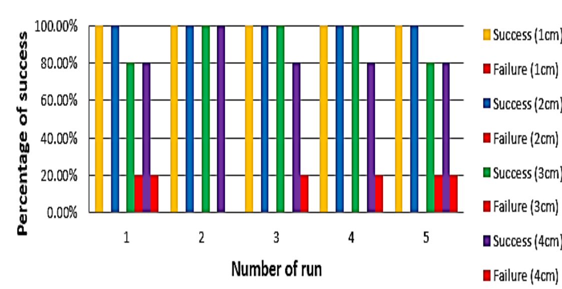

Figure 15. Successfully and failed collected books with respect to book thickness.

Test 3: Gripper ability to hold different book weights

The results from this experiment show that the system ability to grip books of 250grams to 500grams is 98%, however when the book weight increases, the efficiency of the system decreases. The results show that the percentage of successfully collected books with 750 grams is 92% and for 1000 grams is 80%.

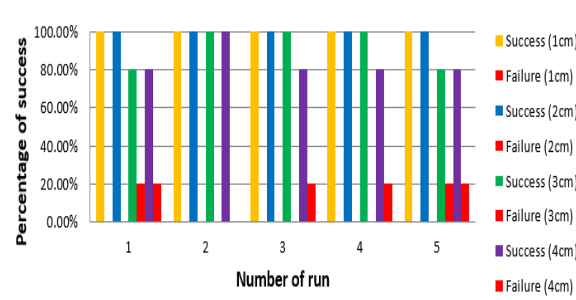

Figure 16. Successfully and failed collected books with respect to book weight.

Test 4: Accuracy of picking a book relative to its distance from other books.

The data was collected from this experiment and then analyzed. The results show that the accuracy of picking a book is relative to the distance from other books, the more the distance, the accurate the gripping. Table 1 and Figure 17 represent the data collection for the accuracy of picking a book relative to its distance from other books.

TABLE II. DATA COLLECTION FOR THE ACCURACY OF PICKING A BOOK RELATIVE TO ITS DISTANCE FROM OTHER BOOKS.

Number Of Run	Successful Picked Books				Failed Picked Books			
	3cm	4cm	5cm	6cm	3cm	4cm	5cm	6cm
1	80%	80%	100%	100%	20%	20.00%	0.00%	0.00%
2	60%	100%	80%	100%	40%	0.00%	20.00%	0.00%
3	80%	80%	100%	100%	20%	20.00%	0.00%	0.00%
4	100%	80%	100%	100%	0.00%	20.00%	0.00%	0.00%
5	80%	80%	80%	80%	20%	20.00%	20.00%	20.00%
percentage	80%	84%	92.00%	96.00%	20.00%	16.00%	8.00%	4.00%
Average Percentage	88.00%				12.00%			

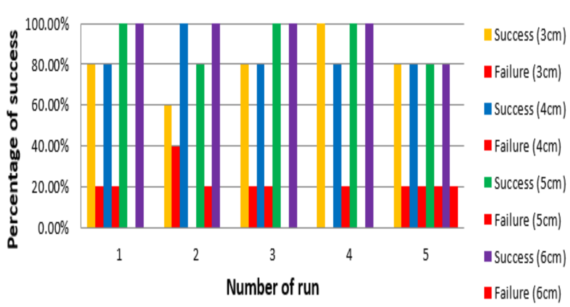

Figure 17. The accuracy of picking a book relative to its distance from other books.

5. CONCLUSION

To sum it up, Pick and place Robots speed up the process of picking parts up and placing them in new locations with reasonable production rates. In this paper, pick and place robot has been used to automate the process of picking the library books and send them to the borrower table. In this paper, the proposed system integrated pick and place robot with GSM technology, RFID equipment, and sensory technology. Redesigning the library ground was needed to let the robot move freely between the shelves. To analyze the system performance, different tests were conducted. The experimental results showed the ability of robot to collect books with different thickness and weights from different shelf levels at different distances with accuracy up to 97.33%. However, the proposed system has some limitations as using GSM SMS to control the system, using the potentiometer for the shelves identification. As known, the range of rotation for the potentiometer is limited so the range of output values is limited as well, which limits the number of shelves used. Therefore, some enhancements are needed as future work for this system. There might be better solutions to control, instruct and monitor the robot such as implementing the Bluetooth technology if the range is less than 10 meters, or implementing wireless communications if the library has a larger space. Also, for future work, a better solution to identify the shelf level is to exclude the potentiometer detection method and to replace it with level detectors like optical reflex sensors at the gripper's tip and place colored lines on every level shelf, so when the gripper is moving up, it gets readings from the sensor that indicate the level height. For instance, the accuracy of proposed system can be improved by using shape features extraction techniques.

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