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DESIGN AND IMPLEMENTATION OF A PROTOTYPE REMOTE-CONTROLLED PICK AND PLACE ROBOT

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ABSTRACT

There are several mundane and repetitive tasks in recent times that call for the development of effective and efficient robots that can be remotely controlled for safety, accuracy and flexibility. In the work reported here, a versatile and low cost "Pick and Place Robot" that can be remotely controlled is developed. The robot uses two Arduino microcontrollers connected in a master/slave configuration. The master controls the robotic arm while the slave controls the robotic base. The arm utilizes servomotors to provide motion in the required axis. The base consists of dc geared motors and tracked wheels for transporting the robotic arm with the griper. The result of this project is a miniature robot that provides pick and place functions that can be used in several applications by changing the program of controller. The structure is designed to lift light loads. The applications of this system include warehousing, performing tasks in factory lines and even it can be employed as a personal helper for people with disabilities

Keywords: Joint actuator, kinematic, microcontroller, pick and place, robot manipulator.

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1. INTRODUCTION

A robot is a machine that can carry out a series of functions automatically and is guided or controlled using programming and electronic circuitry. An alternative definition of a robot is that it is a mechanical or electromechanical device that is programmable and can interact with the environment, carry out tasks and perform various functions without human intervention [1]. The first programmable robot was invented and patented by George David in the early 1950s and up to date, numerous advances in robotics have occurred [2]. The rapid growth in the field of robotics has led to technological advancements such that numerous researches and developments have been witnessed [3, 4, 5, 6,]. Robots are used in industries, warehouses, customer services, agriculture and in a vast number of fields. Robots have increased in popularity due to a wide range of factors. These factors include better quality of products, cost reduction, ability to perform repetitive tasks, ability to perform dangerous task or work with hazardous materials and so on [7, 8, 9].

The Pick and place robots are designed to pick up a specified object and place it in a desired location. It could be used in an industrial application for package delivery and also for placing different parts where they are needed. Moreover, the pick and place operation can be done in a wide number of ways depending on the application of the robot. For instance, O. Altuzarra et al. [9] proposed two design methods for a mechanical drive which could yield an increased end-effector angular range to obtain effective pick and-place operation; other area of application may be to improve the operational velocity and accuracy for pick-and place of robot manipulator [10]. S. L. Narayan et al. [11] carried out a study on position control of pick and place robotic arm, a five-Degree of Freedom (DOF) articulated robot arm for real-time molding machine operation. B. Lian et al. [12] also verified the optimization of the dimensional parameters of a two-degree-of-freedom parallel manipulator to realize high-performance pick-and-place operation;

In this work, a prototype remote-controlled mobile robot with five-degree-of-freedom revolute robot manipulator is designed and developed. The pick-and-place task in the study requires that the manipulator positions itself to grab the object with gripper, applies the necessary joint torque to lift the object and then transverses a distance before releasing the object to an exact position. The details of the work are divides into mechanical design such as robot manipulator that deals with physical construction and range of motion of each joint, wheels, gears and the kinematics model that calculate the position and orientation of each joint in the arm and orientation of the gripper [13]; the Denanvit-Hartengerg’s [14,15] conversion and methodology are used to derive the forward kinematic [16], and the moment arm calculation for servo mechanism. The electrical components are the hardware necessary to control and power the system, actuators, and the devices to send command signal to them. The software design includes the programming methods. This directs and coordinates the entire robot operation when the operator issues a command from the remote control, signals are sent to the device’s processor which executes the command. An android application on a smartphone device served as the transmitter that acts as a remote control with the added advantage of adequate range. Thus, remote operation was achieved via a smart-phone or tablet etc., with Android OS [17]. This mobile system was used to control the microcontroller wirelessly using RF module [18,19]. The developed structure of robot is a low cost and simple, to facilitate easy adaptation and future upgrading.

2. SYSTEM ANALYSIS AND DESIGN

In the development of a remotely controlled pick and place robot, various units and the algorithms used that are very fundamental to an effective description of the system are explored. The design has been divided into two parts: the hardware design, namely, the mechanical and electrical parts and the software design.

The mechanical design highlights the components that constitute the mechanism of the robot and these include the dynamic and kinematic of the manipulator, actuator, gripper, base and arm manipulator. The electrical design constitutes the electrical and electronic components such as microcontroller unit and external power source. All these make up the prototype. The software design includes the flowchart and algorithm used to perform all the necessary tasks as commanded. The bottom-up approach of design has been adopted for this system. The outline of the various components for the design is shown in Fig. 1

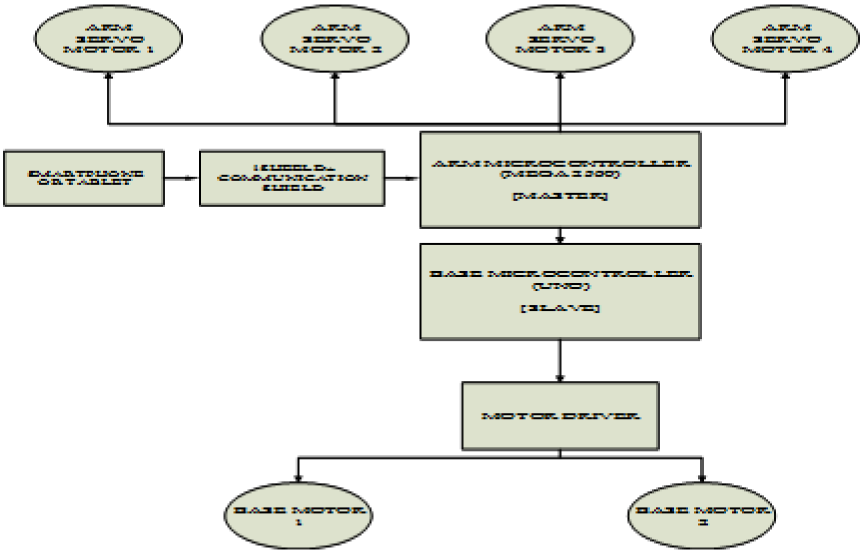

Figure 1 Block diagram of the System.

2.1. Mechanical Design

The mechanical parts are the components or mechanism of the robot that are responsible for the motion of the system. The mechanical design includes the mechanical structure of the pick and place robot. The mechanical design is subdivided into the design of the arm and the design of the base. The different mechanical parts considered in the design of place and pick robot manipulator are analysed below.

2.1.1. Kinematic Analysis of Robot Arm Design

In this design work, the robot arm manipulates the gripper's position and orientation and the joint rotational and translational displacements. The mechanical design is a five degree-of-freedom (DOF) revolute arm. The arm parts are fabricated from acrylic glass (Poly methyl methacrylate); a shatterproof, lightweight, tough, transparent and high aesthetic value material. The detailed design of the robot arm is based upon the preparatory sketch shown in Fig. 2.

The method of Denavid-Hartenberg (DH) is employed here to solve the kinematic problem of robot arm. Using the schematic diagram of Fig. 2, the DH parameters are determined as shown in Table I.

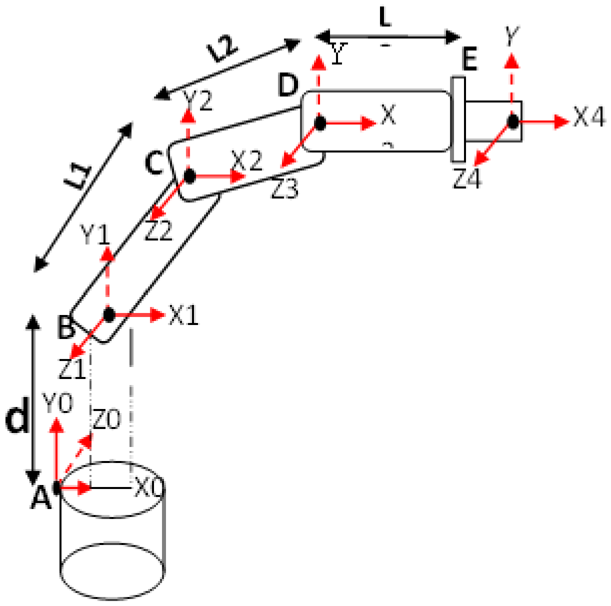

Figure 2 Robot manipulator (arm) with link frames and parameters

Table 1 DH parameter values

Link No	θ_i	d_i	a_i	α_i
1	θ_1	d	0	90^0
2	θ_2	0	L_1	0
3	θ_3	0	L_2	0
4	θ_4	0	L_3	-90
5	θ_5	0	0	90

The above four distinct parameters define the transformation matrix between the end-effector frame to the base frame which is used to calculate the position and orientation of the 5 DOF shown in Fig. 2. Therefore, the transformation matrices between successive frames (A-E), expressed in terms of corresponding parameters from Table I, are given as shown in equations (1) to (5).

$$T_A = \begin{bmatrix} \cos(\theta_1) & -\sin(\theta_1)\cos(\alpha_1) & \sin(\theta_1)\sin(\alpha_1) & a_1\cos(\theta_1) \\ \sin(\theta_1) & \cos(\theta_1)\cos(\alpha_1) & -\cos(\theta_1)\sin(\alpha_1) & a_1\sin(\theta_1) \\ 0 & \sin(\alpha_1) & \cos(\alpha_1) & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$T_B = \begin{bmatrix} \cos(\theta_2) & -\sin(\theta_2)\cos(\alpha_2) & \sin(\theta_2)\sin(\alpha_2) & a_2\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2)\cos(\alpha_2) & -\cos(\theta_2)\sin(\alpha_2) & a_2\cos(\theta_2) \\ 0 & \sin(\alpha_2) & \cos(\alpha_2) & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$T_C = \begin{bmatrix} \cos(\theta_3) & -\sin(\theta_3)\cos(\alpha_3) & \sin(\theta_3)\sin(\alpha_3) & a_3\cos(\theta_3) \\ \sin(\theta_3) & \cos(\theta_3)\cos(\alpha_3) & -\cos(\theta_3)\sin(\alpha_3) & a_3\sin(\theta_3) \\ 0 & \sin(\alpha_3) & \cos(\alpha_3) & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$T_D = \begin{bmatrix} \cos(\theta_4) & -\sin(\theta_4)\cos(\alpha_4) & \sin(\theta_4)\sin(\alpha_4) & a_4\cos(\theta_4) \\ \sin(\theta_4) & \cos(\theta_4)\cos(\alpha_4) & -\cos(\theta_4)\sin(\alpha_4) & a_4\sin(\theta_4) \\ 0 & \sin(\alpha_4) & \cos(\alpha_4) & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$T_E = \begin{bmatrix} \cos(\theta_5) & -\sin(\theta_5)\cos(\alpha_5) & \sin(\theta_5)\sin(\alpha_5) & a_5\cos(\theta_5) \\ \sin(\theta_5) & \cos(\theta_5)\cos(\alpha_5) & -\cos(\theta_5)\sin(\alpha_5) & a_5\cos(\theta_5) \\ 0 & \sin(\alpha_5) & \cos(\alpha_5) & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

Where

Each joint angle; $\theta_{1,}\theta_2, \theta_3, \theta_4, \theta_5$ = measured angle in degrees or $\frac{\pi}{180} \times$ joint angle in radians

Link lengths (meters); $a_1 = 0,\ a_2 = L_{1,}\ a_3 = L_2,\ a_4 = L_3,\ a_5 = 0$

Joint offsets (meter); $d_1, = d,\ d_2 = 0,\ d_3 = 0, d_4 = 0,\ d_5 = 0$ and twist angle between successive joints; $\alpha_1 = {}^{\pi}/_{90_{,}},\ \alpha_2 = 0, \alpha_3 = 0, \alpha_4 = -{}^{\pi}/_{90},\ \alpha_5 = {}^{\pi}/_{90}$

Therefore, the overall transmission matrix equation expressed between each successive frame (A-E) is given as presented in equation (6).

$$T_{A-E} = T_A \times T_B \times T_C \times T_D \times T_E \quad (6)$$

2.1.2. Torque Calculation of Robot Arm

This aspect provides moment arm calculation to establish the required servo mechanism that meets the specification of this work. The torque diagram of the robot manipulator showing the weight of links and servo motors is as presented in Fig. 3.

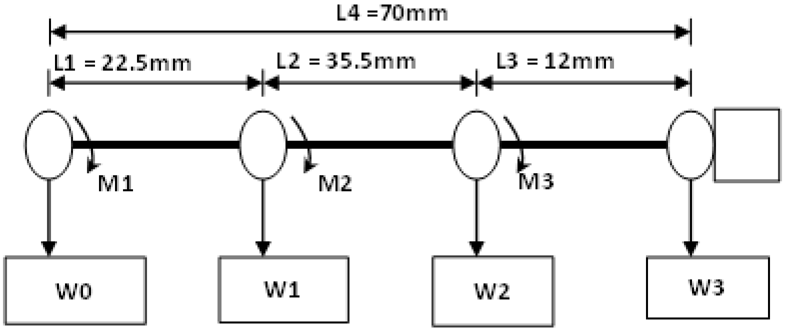

Figure 3 Force moment calculation on each servo.

where

M1 is the moment sustained at the shoulder and it is calculated as

$$\text{M1} = W_3 \times L_4 + W_2 \times (L_1 + L_2) + W_1 \times L_1 \quad (7)$$

M2 is the moment sustained at the elbow and calculated as

$$\text{M2} = W_2 \times L_2 + W_3 \times (L_2 + L_3) \tag{8}$$

M3 is the moment sustained at the elbow and calculated as

$$\text{M3} = W_3 \times L_3 \tag{9}$$

Thus, excess torque = Actual servo torque − Calculated torque. (10)

If the weight of material is negligible compare to the servo specification, then $W_0 = W_1 = W_2 = W_3 = 13.4g$.

Applying equations (7) – (10), the calculated maximum moments around MI, M2 and M3 are respectively 1.79Kg cm, 1.89Kg cm and 1.84Kg cm to select the appropriate motor. This prototype employs four Tower Pro MG90S micro servo motors for the robotic arm. The specifications are as indicated in the Table II.

Table II Specification for servo motor

Weight	**13.4 g**
Dimension	22.5 x 12 x 35.5mm
Operating speed	0.1 s/60 degree (4.8 V), 0.08 s/60 degree (6 V)
Stall torque:	1.8 Kg-cm (4.8V), 2.2 Kg-cm (6 V)
Operating voltage	4.8 V - 6V
Dead band width	5 µs

2.1.3. The Base Design

The robotic base uses two brushed d.c geared-motors, designed to produce high torque while maintaining a low output that drives the sprockets of the track and wheel set for motion. The 203:1 configuration is used for this design and presented as shown in Fig. 4. The basic designed specification is as listed in the Table III.

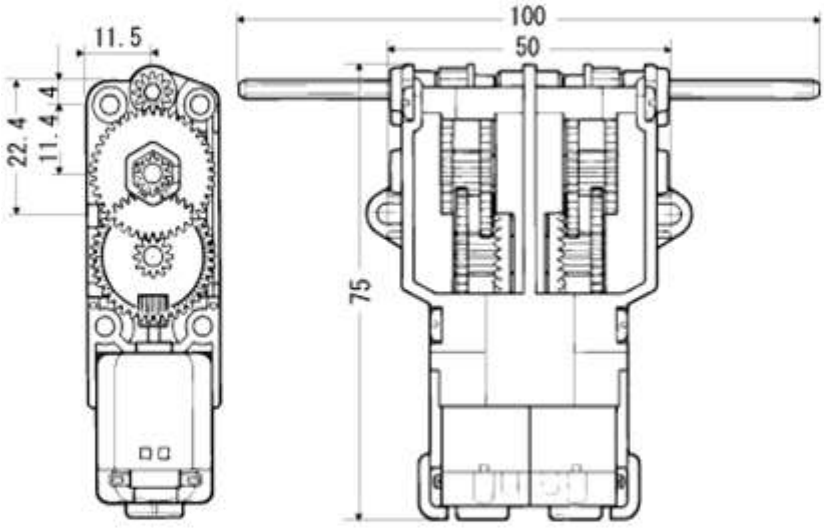

Figure 4 Structural design of the gearbox

Table III Specification of the gearbox

Motor voltage	**1.5-3V (1.5V recommended)**
Motor stall current	2.1A
Free-run current	0.15A
Motor stall Torque	35 g-cm or 0.5oz.in
Gear ratios	58:1; 203:1
Motor RPM	12300 (9710Max. Efficiency)

2.2. Electrical Hardware

This design aspect deals with the electrical and electronic components that make up the circuit as shown in Fig. 5. The circuit includes the power supply unit, actuating unit, microcontroller for arm and base circuit and the unit for interfacing the robot with computer. The brief discussion of each circuit design is given below.

2.2.1 Power Supply Circuit

The whole system is powered using a 5-V DC power bank. This source supplies the four servo motors in the arm, the two motors in the base and the microcontroller boards for the arm and the base.

2.2.2. Actuating Unit

Each of the four motors used is connected directly to the power supply. The method of control for servo motors is Pulse Width Modulation (PWM) that varies the high/low time in an analogue manner. The servo motor is designed to update at every 20ms with a pulse between 1ms and 2ms. This implies that the duty cycle, which is the amount of time the signal is “on”, is between 5 and 10% on a 50-Hz waveform.

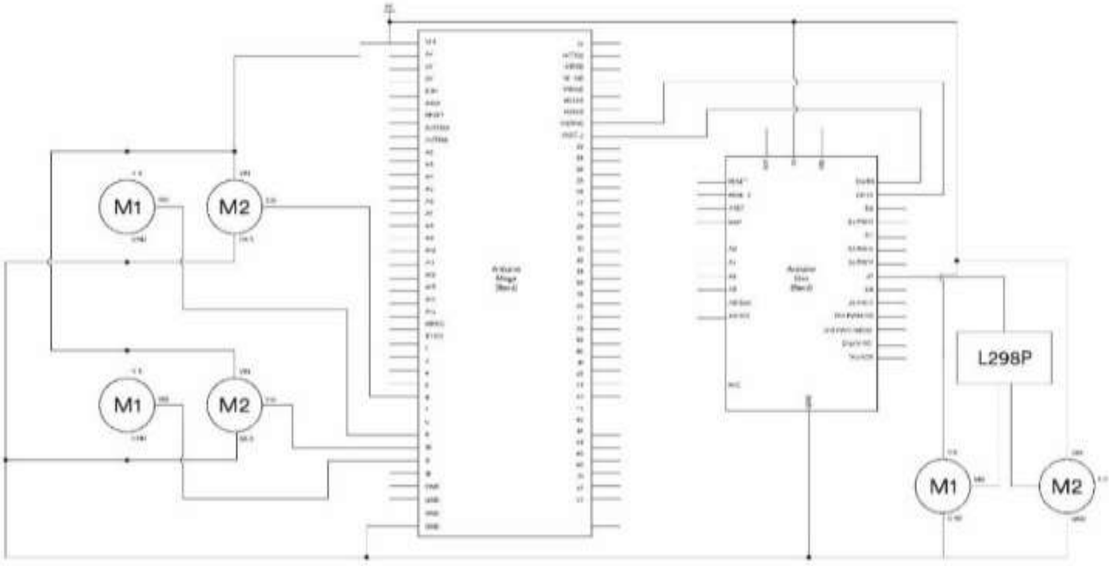

Figure 5 Electrical circuit diagram

2.2.3. Microcontroller for the Robot Arm

The microcontroller used for the robotic arm is the Arduino Mega 2560 board based on the ATmega2560 with 54 digital input/output pins. 15 of these pins are used as PWM outputs that control the motion of the servo motors and relays' commands from the smartphone to the four servo motors. It also possesses 16 analogue inputs, 4 UARTs (hardware serial ports), a 16 - MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The board can be powered via a computer with a USB cable, an AC-to-DC adapter or a battery. The components in the arm received power from a 5-V power bank via the 2.2-A outlet with operating voltage of 5V for this board. The recommended input voltage range lies between 7 and 12V. The flash memory is 256 KB of which 8 KB is used by bootloader. The SRAM and EEPROM are 8KB and 4KB respectively. The Mega 2560 board is compatible with most shields designed for the Uno. For instance, the1Sheeld+ Arduino shield is designed with Arduino PCB to turn a smartphone into different shields. The length and width of the board are respectively 101.52mm and 53.3mm. The weight of the board is 37g. Fig. 6 shows an Arduino Mega Board.

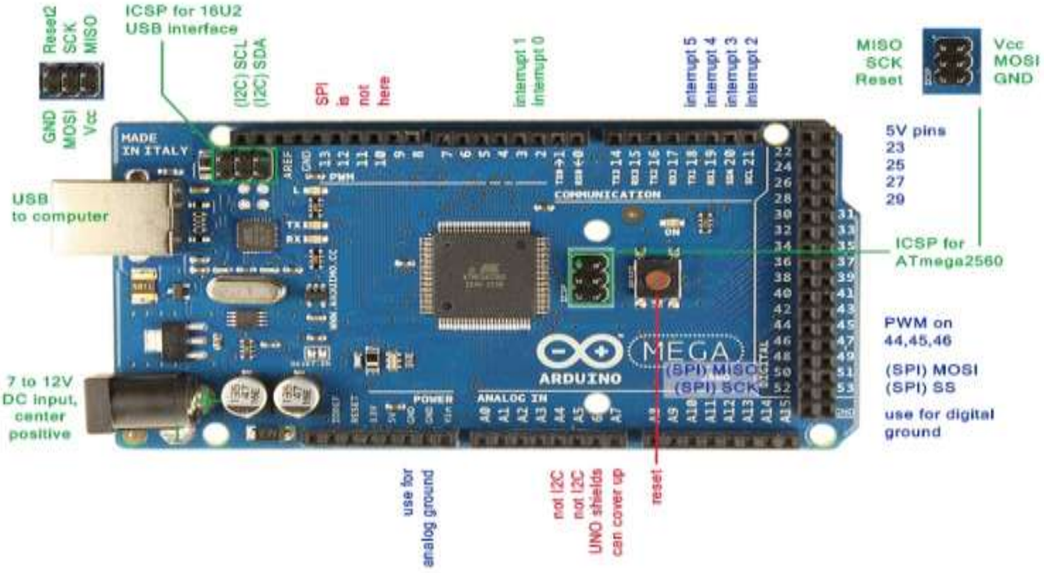

Figure 6 Arduino mega with pins labelled

2.2.4. Microcontroller for Base Design

The microcontroller board used for the base is produced as part of the DFRobotShop Rover Series. The microcontroller sends commands to the rover (robotic base) to control its motion. The PCB design is based on the Arduino microcontroller and has a built-in Arduino Uno module. The board integrates an Arduino Uno, L298P motor driver, voltage regulator and a prototyping area. The Arduino Uno uses a surface mount ATMega328 Chip. The motor driver allows bi-directional control of the motor. The voltage regulator allows the board to be powered using 3.7-9V. Fig. 6 really shows the PCB of the robot base.

2.2.5. Motor Driver

The motor driver acts as an interface between the batteries, the microcontroller and the servo motors. The motor driver used for the rover base is a dual H-bridge driver capable of driving inductive loads like DC motors and solenoids. The device provides bidirectional control of the motors. Maximum operating voltage is 46V and the DC current is up to 4A. This motor driver is embedded on the PCB of the rover as presented in Fig. 6. The DC motors are then connected to the motor driver.

2.3. Controller Software Design

The robot uses two Arduino microcontrollers connected in a master/slave configuration. The master controls the robotic arm while the slave controls the robotic base. The robot software directs and coordinates the entire robot operation when the operator issues a command from the remote control which send signals to the microcontrollers. The code is written within two software, namely, Arduino IDE and Isheeld + APP software. Figures 7 and 8 are flowcharts that describe the software algorithm for the arm and the base.

2.3.1. Arduino IDE

This is the software that runs on a computer and is used to write, edit and upload code to the physical Arduino board. The software can run on Windows, Linux and Mac OS X. This environment was written using java and is an open source. The program for the up and down, forward and backward, side to side motion of the arm as well as the opening and closing of the claw (gripper) is fully implemented in the design of this prototype robot.

2.3.2. 1Sheeld + APP

This is the other part of the1Sheeld + package. This is the software platform that oversees the communication between a smartphone device and the 1Sheeld+ shield. The communication shield (1Sheeld+) was stacked on the Arduino Mega. The APP enables the user to select between a variety of shields and makes the capabilities and sensors of the smartphone accessible to the robot

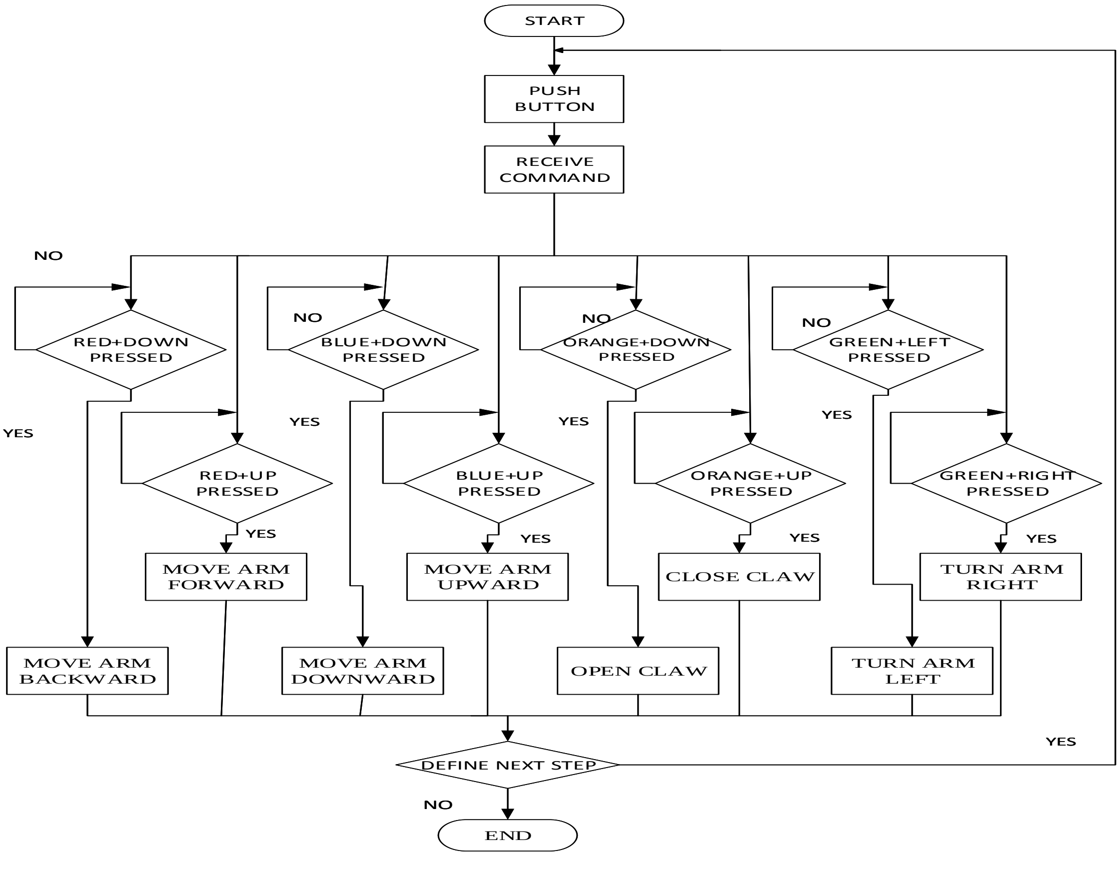

Figure 7 Flowchart for the robot arm

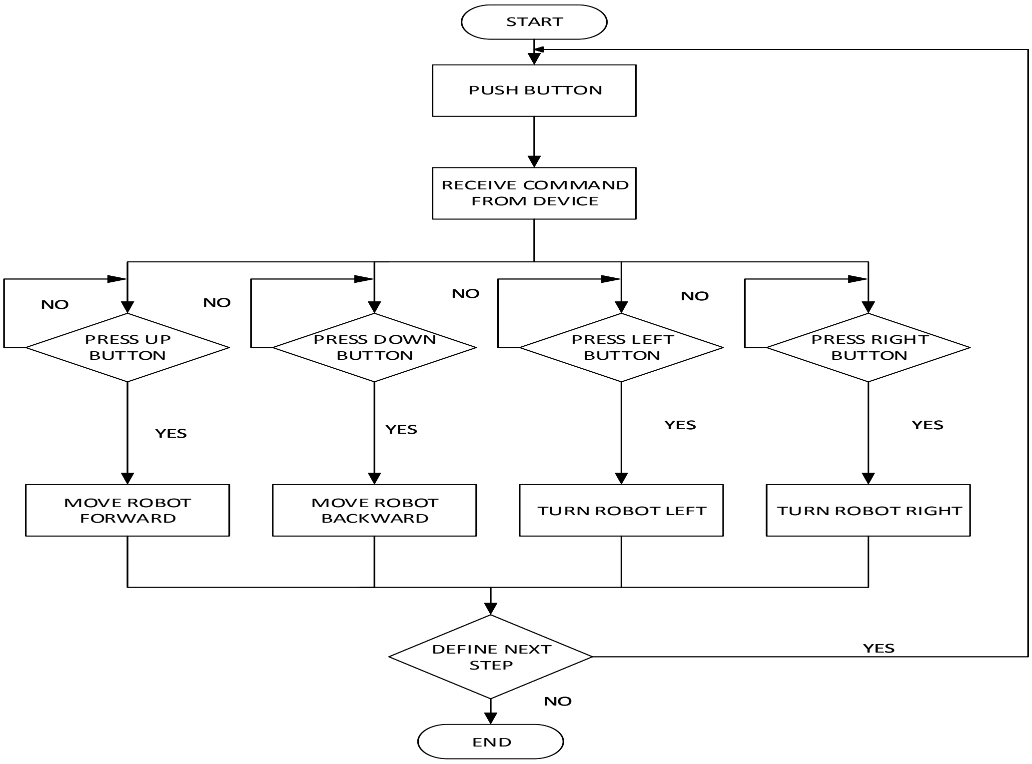

Figure 8 Flowchart for the base

3. SYSTEM TESTING AND OBSERVATION

The bottom up approach was taken towards the testing of the system. This implies that the subsystems were individually tested before the system was tested. The process of testing led to various adjustments for optimal performance of the system. The arm was the foremost subsystem to be tested by using a DC voltage generator to power the four servo motors while the Arduino Mega board was powered via a USB connection. The smartphone was connected to the arm through the 1Sheeld+ application. The gamepad controls for the arm were tested individually. The left, middle, right and claw motors performed as expected.

The next phase of testing was carried out on the robotic base as shown in Fig. 9. The base PCB was powered via a USB connection to a computer. The commands were sent to the robot from a PC through a serial link. The forward and backward movements of the rover were tested. However, the delay in the code was adjusted so the rover could move faster. The left and right movements of the rover were also tested satisfactorily. Fig. 10 shows the complete assembly of the manipulator. The robot works satisfactorily well when tested. The robot was tested to carry an empty Schweppes bottle from one point to another as illustrated in the Fig. 10 below.

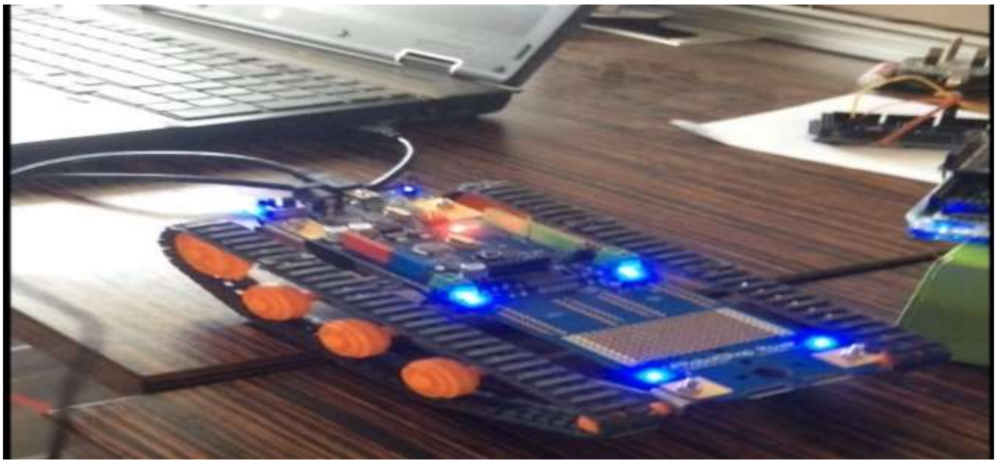

Figure 9 Testing of the robot base

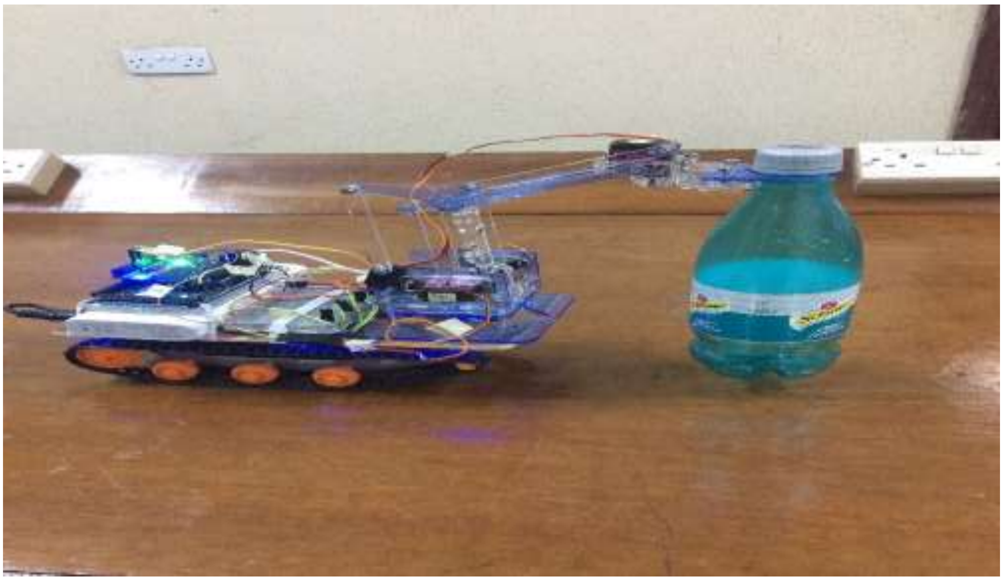

Figure 10 Pick and place robot carrying an empty bottle

4. CONCLUSION

On a final note, the design and development of the mobile pick and place robot for multiple applications were completed and the prototype confirmed functional. This robot can take commands from a remote smartphone device and move objects to desired locations. The weight of the robot is 3kg and its base motors are run on a 100% duty cycle. The maximum weight it can safely carry is 75g. This concept can be redesigned and specialised for various applications and industries.

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