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A Project Report on

"COLOUR SENSING ROBOT"

Project Report submitted in partial fulfillment of the requirement for the award of the degree of

Bachelor of Engineering

In

Electrical & Electronics Engineering

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Certificate

Certified that the project work entitled **"Colour Sensing Robot"** carried out by Ms. Aishwarya S, USN 1CR16EE004; Ms. Dhanya S Naik, USN 1CR16EE023; Mr. Kumar Satyam, USN 1CR16EE036; are bonafied students of CMR Institute of Technology, Bengaluru, in partial fulfillment for the award of Bachelor of Engineering in Electrical & Electronics Engineering of the Visvesvaraya Technological University, Belgaum, during the year 2019-2020. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library.

The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

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DECLARATION

We, [Ms. **Aishwarya S (1CR16EE004),** Ms. **Dhanya S Naik (1CR16EE023),** Mr. **Kumar Satyam (1CR16EE036)],** hereby declare that the report entitled **"Colour Sensing Robot"** has been carried out by us under the guidance of **Mr. Kodandapani D,** Assistant Professor, Department of Electrical & Electronics Engineering, CMR Institute of Technology, Bengaluru, in partial fulfillment of the requirement for the degree of **BACHELOR OF ENGINEERING in ELECTRICAL & ELECTRONICS ENGINEERING**, of Visveswaraya Technological University, Belgaum during the academic year 2019-20. The work done in this report is original and it has not been submitted for any other degree in any university.

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Abstract

Though on global scale, life expectancy has increased and death rate is declining, poor countries, mainly in Africa, record life expectance of 55 years or less. Death rates in Africa countries are of high magnitudes. In Nigeria for example, crude death rate is 12.9 deaths per 1,000 people, meaning that around 2.1 million people die annually. Though during processing of food products like grains in agro processing industries, complex sorting machines are used, total separation of impurities is still not guaranteed. So, system that can guarantee high level sorting accuracy is of high demand. Robotics system is being used by packaging industries for product sorting and high sorting accuracy has so far been observed. Increase in efficiency is also observed. Adoption of robot that can be used by agro processing industries for separation of impurities from food grains (like rice and beans) will go a long way in assuring high sorting accuracy, consumption safety, production efficiency and low cost of production. This document explains the design and development of robotic arm capable of sorting objects. The model of categorization was based on physical property of the object, colour, relatively to white light. This robot was equipped with color sensor, power unit, actuators (DC servo motors), end-effector (impactive gripper) and Atmega microcontroller (to control DC servo motors and sensor). Color sensor (that was integrated) performed the task of colour identification. The arm (developed) read in respective angles of joints and move the actuators in other to pick targeted object. The robotic arm performed object sorting based on colour code returned by colour sensor attached to the end-effector.

The project deals with an automatic material handling. It coordinates the movement of robotic arm pick the items moving on the conveyor belts. It aims in organizing the coloured objects which are approaching on the conveyor by picking and placing the objects in its separate located place. There by reducing the tedious work done by human, accomplishing accuracy and rapidity in the work. The project includes color sensors that senses the items color and lead the signal to the controller. The microcontroller guides signal to the motor driving circuit which drives the different motors of the robotic arm to grasp the object and place it in the correct location. Depending upon the color sensed the robotic arm goes to the correct location to releases the object and comes back to the normal potion.

Acknowledgement

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CHAPTER 1

INTRODUCTION

1.1 Background

The word “Robot” was coined from “Rabata”, which is Czech translation for “Slave”. The definition of robot is dynamic, depending on technological advancement. However, the Robotic Institute of America (1979) provided a definition that received general acceptance. Robotic Institute of America (RIA) defines a robot as a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks.” A robot is a virtual or mechanical artificial agent. In practice, it is usually an electromechanical machine which is guided by computer or electronic programming, and is thus able to do tasks on its own. Another common characteristic is that by its appearance or movements, a robot often conveys a sense that it has intent or agency of its own. Although the appearance and capabilities of robot vary vastly, all robots share the feature of a mechanical movable structure under some form of control. This control of robot involves three distinct phases: perception, processing and action. In common the preceptors are sensors mounted on the robot. Processing is done by onboard microcontroller or processor and action (task) is performed using motor or with some other actuators.

Robot is multi-disciplinary machine as its applications are not just limited to one field. In space industry, robots (in form of space probes) are used in space exploration; in defense department, robots are used as bomb discarding, and surveillance drones; in medial field, assistive robots are used during surgical operation.

1.2 Classification of Robots

Though there are numerous classifications of robots, the followings are of utmost importance from the subject point of view if this project:

(i) Classification based on coordinate frame. (ii) Classification based on locomotion method (iii) Classification based on applications

1.2.1 Classification based on coordinate frame

Based on this mode of classification, the three types of robots are Cartesian, Spherical and Cylindrical robots. Cartesian robots are used for picking and placing objects, applying sealant, handling machine tools and arc welding. It's a robot whose arm has three prismatic joints, whose axes are coincidental with the Cartesian coordinators. Some of applications of Cartesian robots are:

- Application of Adhesive - this robot is being used to apply adhesive to a pane of glass and it is capable of handling large sized work pieces.

- Pallet transfer - this orientation of a Cartesian robot transfers Integrated Circuits (ICs) from a pallet and transfers the part to a specific place.

- Product inspection - companies need to monitor their products to ensure high quality. Due to its construction, the robot can move along with the moving conveyor and focus on a product at once.

- Transfer and stacking - owing to its linear movement, the Cartesian robot is ideal for the transfer and stacking of sheet metal or timber sheets. It can feed sheets into processing machines or draw them away as finished products. Cylinder robots are used in assembly operations, handling of machine tools, spot welding and handling at die cast machines. They also have many uses in medical testing. A Cylindrical robot is able to rotate along its main axes forming a cylindrical shape.

- Medical testing - medical robot is used in numerous medical applications, for DNA screening, forensic science, drug development and toxicology. These robots are suitable in medical research where hundreds of samples must be tested and the same repetitive tasks performed many times. The robot eliminates human error providing more repeatable yields and consistent results. Spherical or Polar Robots combine rotational movements with single linear movements of the arm. The polar robot is sometimes referred to as the gun turret configuration. They are generally used in many welding applications mainly spot, gas and arc. Polar robots are extremely suitable for reaching into horizontal or inclined tunnels. Aside from welding applications, spherical robot also features in car assembling.

1.2.2 Classification based on locomotion method

Another mode of classifying robots is classification based on locomotion or kinematics method. Two major types of robots featuring here are **stationary** and **mobile robots**.

Mobile robots can be further classified as wheeled robots, tracked robots, legged robots, swimming robots and flying robots.

1.2.3 Classification based on applications

Robots could also be classified based on their uses or applications. Based on this mode of classification, robots could be classified as:

- **Industrial robots** – robots employed in an industrialized manufacturing atmosphere. Typically, they are robotic arms particularly created for applications like material handling, painting and welding.

- **Medical robots** – robots employed in medicine and medicinal institutes. A typical example is the da Vinci Surgical System - a robotic surgical system.

- **Service robots** – robots which operate semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. Examples include lawn mowing robots, vacuum cleaning robots and sewer robots.

- **Military robots** – robots brought into play in military and armed forces. They consist of bomb discarding robots, shipping robots and exploration drones.

- **Entertainment robots** – robots employed for entertainment. They include model robots such as Robosapiens or the running photo frames as well as articulated robotic arms employed as movement simulators.

- **Space robots** – robots employed in space exploration and other space activities A Common example is the mars exploration rover (International Federation of Robotics, 2003). A manipulator, in general is a mechanical system aimed at manipulating objects. Manipulating, in turn, means to move something with one's hands, as the word is derived from the Latin word 'manus', meaning hand. The basic idea behind the foregoing concept is that hands are among the organs that the human brain can control mechanically with the highest accuracy as the work of an accomplished guitar player or a surgeon can attest.

1.3 Objective of the Thesis

This project was aimed at designing and development a colour sensing based object sorting robotic arm that could be used in agro based multi-product packaging industries.

Project Objectives

Listed below are the objectives of the project:

1. to design and fabricate object sorting robotic arm based on colour sensing (using suitable materials).

2. to model object sorting robotic arm and simulate its movement and object detection capability.

3. to integrate color sensing and develop suitable algorithm to implement the forward kinematics of the robotic arm, making it possible to position the robot end-effector by specifying desired joints angles.

The positive impact of robotics in the advancement of medical field, manufacturing industry, entertainment industry, space industry, and defense department are definitely huge and indispensable. Availability of robotic arm that can be used in agro based multi-product packaging industries will go a long way in assuring high sorting accuracy, consumption safety, high production efficiency and low cost of production.

1.4 Scope of the Thesis

The positive impact of robotics in the advancement of medical field, manufacturing industry, entertainment industry, space industry, and defense department are definitely huge and indispensable. Availability of robotic arm that can be used in agro based multi-product packaging industries will go a long way in assuring high sorting accuracy, consumption safety, high production efficiency and low cost of production. This thesis covered design, and development of robotic arm with object sorting capability based on color sensing. It also covered the implementation of the kinematics of the arm but does not consider the details of the derivation of the kinematic equatio

CHAPTER 2

LITERATURE REVIEW

2.1 Robotics

According to Merriam-Webster Dictionary (2016), robotics is defined as branch of technology dealing with the design, construction, and operation of robots in automation. The same source also defined robotics as technology that is use to design, build, and operate robots. Accepted technical definition was put forward in literature authored by Craig (2005). He described robotics as a field that concerns itself with the desire to synthesize some aspects of human function by use of mechanism, sensors, actuators and computers. Robotics, like other fields of study, is wide and a superset of many disciplines. The four major robotics disciplines are:

(i) Artificial intelligence,

(ii) Computer vision,

(iii) Locomotion, and

(iv) Mechanical manipulation disciplines.

Artificial intelligence deals with development of robots capable of perceiving their environment and take actions that maximize chance of success at some goals. Robots mimic cognitive functions like learning. Computer vision deals with how computers can be made to gain high-level understanding from digital images or videos. Though, the output of robotics fields is robot but its development integrates contributions from mechanical engineering mathematics, control field, and electrical & electronic engineering; electrical and electronic engineering techniques are brought to bear in the design of sensors and interfaces for industrial robots, computer science knowledge is used to develop program (i.e. lines of code) that helps the robot perform a desired task. The tools for designing and evaluation algorithms to realize desired motion or force application are provided by control field. The description of spatial motions and other attributes of robots is supplied by field of mathematics. Field of mechanical engineering contributes methodologies needed for the study of kinematic and dynamics of the robot.

2.2 Robots

The term robot coined from Czech and means ‘forced labor’. The term in its present interpretation was invented by the Czech writer Kanel Capek in his 1921 RUR, which stands for Rossum’s Universal Robots. Although Capek’s robots look like people, they work twice as hard as human beings. Design and development of artificial creators is not 21st century technology but has been in existence for long time. The medieval legend of Goleen is a common historical example. First patent on robot was granted in 1961 to George C. Devol after he requested for protection over his intellectual work. Devol’s robot was the first industrial robot, which was designed to pick and place objects in factory environment. At this juncture, it is important to explain industrial robot. Industrial robot, as other modern manufacturing systems, is advance automotive system that utilize computer as an integral part of its control: Computers are now vital part of industrial automation. They run production lines and control stand-alone manufacturing systems; such as various machines tools, inspection systems and laser-beam cutter. In modern day, advance robots feature in market and in industries. A revolutionary change in factory production techniques and management is predicted through 21st century. Every operation in future factories, from design to manufacturing, assembling, and product inspection would be monitored and controlled by computers and performed by industrial robots and intelligent systems. Timothy et al., simulated a climbing robot in natural terrain. The Three-limbed robot is capable of moving on natural surfaces. The technology will be employed in terrestrial applications like search-and-rescue mission, cave exploration, human assistance for rock and mountain climbing, and tactical urban missions. Space applications are not left out as the industry has high potential of benefitting from this aggressive robotic system. For example, site on mars with potential high science value being identified on cliff faces. Climbing, descending or traversing steep slopes and braking terrain involve considerable human risk, but with climbing robot employed, human risk is approximately or completely eliminated.

Honda Asimo, a humanoid robot with thirty-four degrees of freedom, is the world first modern advance humanoid robot. Thirty-four degrees of freedom featured by this robot enables it to perform tasks like opening of doors, switching of light, and object carriage. It also has ability to recognize moving objects, postures, gestures, surrounding environment, sounds and faces, which enable it to interact with humans. The robot features intelligent real-time flexible walking as well as environmental recognition technologies which help in executing complex tasks such as ascending and descending stairs, slope navigation.

2.3 Robotic arm

Robotic arm is a robotic manipulator, usually programmed, with similar functions to a human arm. Human beings pick things up without having to think about the steps involved. For robotic arm to execute actions in a particular order, from moving the arm, rotating the 'wrist' to opening and closing the 'hand' or 'fingers'; it has to think (i.e. someone has to control it). In 1954, George Devol received patent on robotics. First robotics arm was invented by him. The industrial robotic arm was made up of a mechanical arm with gripper as end-effector (mounted on tracks). Rotating drum served as storage for sequence of motions encoded in form of magnetic patterns. Devol initially named the device as "universal automation', but later shortened it to 'unimation'. Devol's unimation was designed to pick and place objects in factory settings.

In a paper that featured in International Journal of Engineering and innovative Technology, developed a 3-joint automatic arm which could be used in industries to do repetitive tasks like moving components from conveyor to another place. In this project, three geared DC motors were used, each of which was controlled by L293D motor driver. Two reference positions were chosen, the first was location where the arm has to pick object in consideration and second position was the place where the arm has to place the targeted object. The microcontroller used, ATmega 5, was programmed to signal to third motor via driver circuit to make the rotation of the arm to the desired direction. Second motor was then driven by signal redirected to the

driver circuit from the microcontroller. This enabled the robotic arm's up and down movement. First motor that controlled the gripper was actuated. The third motor was again actuated to turn to destination direction, motor was then actuated to make the down movement of arm finally. Gripper motor was activated to release the object. Obstacle sensor was integrated into the robotic arm. The sensor senses presence of obstacle in the path of the robotic arm and notify industry personnel to clear the obstacles. Capitol University developed a pick and place robotic arm with pneumatic components. The project was aimed at developing an arm utilizing an electropneumatic robotic pick and place system that mimics programmable logic controller (PLC). This type of robot falls under close-loop control system, the electro-pneumatic robotic arm pick and place powered by compressed air and controlled by programmed or machine language. The objectives of the projects are to build a photo-type robotic arm pick and place system, verify the relationship between electro-pneumatic components PLC and come up with a program with the system's proper motion sequence using a programmable logic controller (PLC).

The design of the mechanical arm was based upon the availability of pneumatic cylinders, considering the exact movement of the actuators. The robotic arm could be operated pneumatically via programmable logic controller.

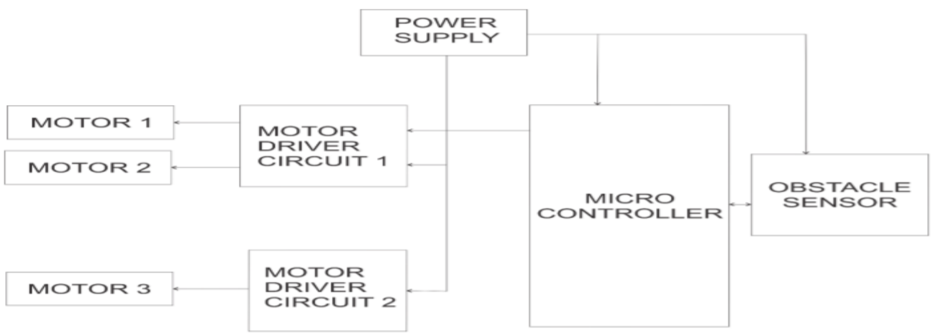

Fig 2.1. Block diagram of a robotic arm

Five pneumatic cylinders were integrated into the robotic arm. One compact cylinder for upward and downward motion, one rotatory cylinder for left and right motion, one linear cylinder for the forward and backward motion, and two spring cylinders for the gripper. The movement of the cylinders were controlled by directional values. The air compressor used compressed atmospheric air of 14.7psi to the power directional valve, double acting cylinders and spring return cylinders. Directional valves were powered by electric current from 24volts DC solenoid coil. The two sensors used for object sensing were inductive and capacitive sensors. Metallic objects were detected by inductive sensor while detection of any other material was done by capacitive sensor. Subsequent figures show conceptual framework of the robotic arm pick and place system, operational block diagram.

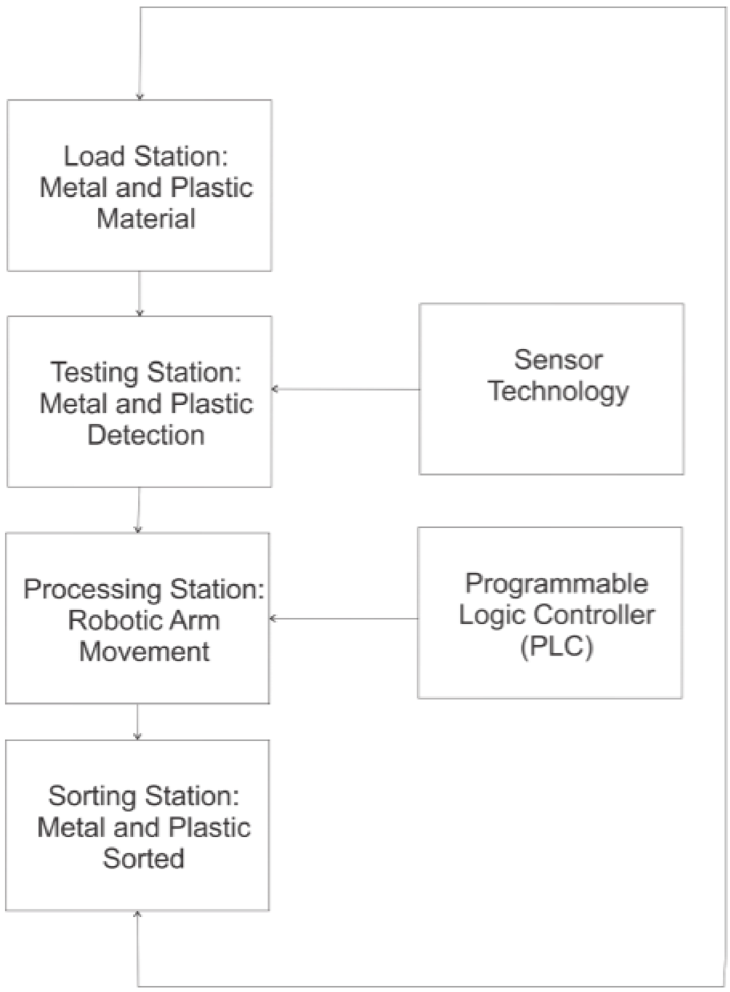

Fig 2.2. Schematic diagram of conceptual framework for the robotic arm pick and place system

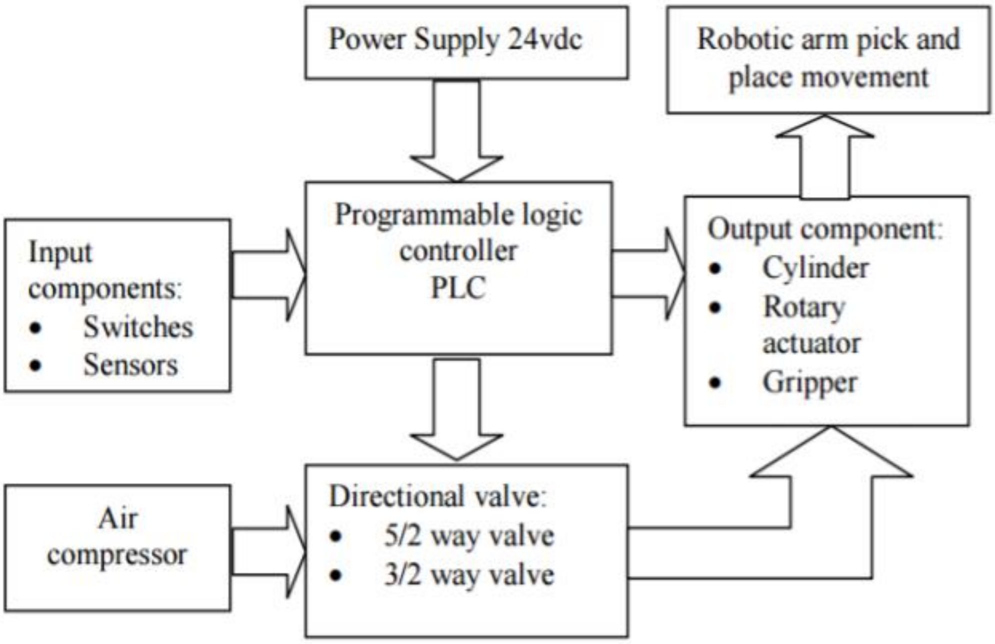

Fig 2.3. Operational Block Diagram of the Project

A professor from Taif University, published a paper in the Modern Mechanical Engineering Journal. The aim of the paper was to design, develop and implement a comparative robotic arm with enhance control and stumpy cost. The arm was designed with four degrees of freedom and talented to accomplish accurately simple tasks such as light material handling, which could be integrated into a mobile platform that serves as assistant for industrial workforce. Servo motors, 4, present in the system did link between arms and pre-defined arm movement. LabVIEW software package was employed to perform inverse kinematic calculations and communicated the proper angles serially to Atmega 368 microcontroller that powered the servo motors. The system had unique characteristics that allowed flexibility programming and controlling method which was implemented using inverse kinematic. Besides, it could also be implemented in a full manual mode. The robotic arm in contrast to others is cheaper than available robotic arm. Results obtained from series of testing operations showed that the robotic arm was trustful. Postgraduate and undergraduate students of many universities in Nigeria have also contributed to the advancement of robotics field through their research works. These research works are discussed below: Okedeyi (1998), of the Department of Mechanical Engineering, Obafemi Awolowo University in his B.Sc. final year project came up with a serial algorithm for dynamic simulation of a two-link constrained robotic manipulator. Four assumptions were made, they were: End-effector of the manipulator was in contact with some rigid body in its environment so as to form closed kinematic chain configuration; effects of actuators dynamics, elasticity and backlash were neglected; the robotic manipulator was developed with rigid bodies with ideal revolute joints and powered by ideal actuators; the manipulator was non-redundant. The motions of the manipulators were described by complex mathematical equations derived from euler-lagrangian formulae. Equations derived created relationship among torque acting on the joints, centripetal effects, gravitational effect, inertial force, and velocities of the links. With availability of torque surrounding the joints, accelerations were then solved. Though FORTRAN (Formula Translator) 77 is now obsolete, it was employed by Okedeyi to develop computer program for the simulation. Two-link manipulator was used as a case study for the simulation. The report revealed that the algorithm derived was practical and result-oriented. The approach employed for simulation is however only efficient for few links but computationally intense for manipulator with higher number of links such as five and more. From the Department of Mechanical Engineering, Obafemi Awolowo University in his B.Sc. thesis developed a control for robotic arm applying fuzzy control system. The controller was designed for two degrees of freedom arm. A two degrees of freedom robot is restricted to planner motion (i.e. motion in a plane). Unlike binary system, fuzzy logic recognizes more than simple 0 and 1 Boolean values (i.e. false and true). Its logical variables may have a truth value that ranges in degrees between 0 and 1. The objective of the controller development was to implement collision detection and avoidance during incorporation of fuzzy control into the robotic arm. Sensors were used to enable the determination of relative distance between the robotic arm, object it was transporting and obstacles in environment. The design was based on the model approach. Objective information was represented using mathematical models while subjective information was represented by linguistic statements that were converted to values that were then quantized using fuzzy logic. The sensor used also had capability of sensing and forwarding (as input variable) the relative distance between obstacles and robot. The input variables were used to generate sixteen linguistic rules to implement control of the robotic arm. The linguistic rules were used to instruct the motors to rotate at a certain speed and in a direction based on the conditions of the environment of the robotic arm.

	Distances				Motor Speeds	
	Left	Front	Right	Back	Forward-Backward Motor	Left-Right Motor
Rule 1	Big	Big	Big	Big	PM	Stop
Rule 2	Big	Big	Small	Big	PS	PS
Rule 3	Small	Big	Big	Big	PS	NS
Rule 4	Small	Big	Small	Big	PM	Stop
Rule 5	Big	Big	Big	Small	PM	Stop
Rule 6	Big	Big	Small	Small	PF	PF
Rule 7	Small	Big	Big	Small	PF	NF
Rule 8	Small	Big	Small	Small	PM	Stop
Rule 9	Big	Small	Big	Big	NS	PM
Rule 10	Big	Small	Small	Big	NF	PS
Rule 11	Small	Small	Big	Big	NF	NS
Rule 12	Small	Small	Small	Big	NM	Stop
Rule 13	Big	Small	Big	Small	Stop	NM
Rule 14	Big	Small	Small	Small	Stop	PM
Rule 15	Small	Small	Big	Small	Stop	NM
Rule 16	Small	Small	Small	Small	Stop	Stop

Table 1. Linguistic rules for fuzzy logic control of robotic arm

S/N	ACRONYM	MEANING
1	PF	Positive Fast
2	PM	Positive Medium
3	PS	Positive Slow
4	NS	Negative Slow
5	NM	Negative Medium
6	NF	Negative Fast

Table 2. Acronyms representing speed and direction of motors

The six acronyms used to represent speed and direction of motors are presented in tabular form in previous page. The controller developed needs further improvement. Number of sensors integrated can be increased. Also, sensors with higher sensitivity values should be used. A professor of the Department of Mechanical Engineering, Obafemi Awolowo University designed an improved robotic arm. The system was implemented using improvised materials while software was developed using C# (C Sharp) programming language. He fabricated two models, A and B, evaluated and compared their results. Test results showed that model B was fully functional having all of its joints (apart from gripper) capable of 360-degree movement. Model A failed due to inability of its electronics circuit to supply the power required by its motors. He used motors obtained from old antennas and from children toys. Perspex was used for each link and gripper of the successful; model. Since the movement of each link was controlled fully manually by human eye, result of inverse kinematics analysis was integrated. No microcontroller was used. Supposing the student controlling the robot wanted the gripper to move from position A to B, he would move each link until gripper reach position B. In conclusion, the studies revealed successfully that an educational instructional robotic arm made using local material was feasible and viable for teaching robotics especially at earlier stages.

An autonomous robotic is a programmed mechanical arm with similar functions as a human arm. It may be the sum total of the mechanism or may be part of a more complex robot.

Eye-bot is a typical model used to pick and place the desired color objects from one location to another. This robot is used in sorting the objects in a mixture of different color objects.

The following components make up a typical object sorting robotic arm:

I. Links and joints

II. Actuators

III. Controller

IV. End-effector 7

V. Sensor (not present in some robots)

I. Links and joints

In a robot, the connection of different manipulator joints is known as Robot Links, and the integration of two or more links is called as Robot Joints. A robot link will be in the form of solid material and it can be classified into two key types: input link and output link. The movement of the input link allows the output link to move at various motions. An input link will be located nearer.

Robot Joint is the important element in a robot. It helps links to travel in different kind of movements. There are five major types of joints:

- Rotational joint
- Linear joint
- Twisting joint
- Orthogonal joint
- Revolving joint

II. Actuators

Actuator is a physical device that transform electrical, chemical, or thermal energy into mechanical energy. Actuators play the same role the muscles play in the human arm - they convert stored energy into motion. Actuators are used to move joints of robotic manipulator. The three basic types of actuators currently used in contemporary robots are pneumatic, hydraulic, and electrical actuators. (Angelo, 2007). An electric actuator is powered by a motor that converts electrical energy into mechanical torque. There are different types of motors:

- Direct Current (DC) motors
- Alternating Current (AC) motors
- Inductive motors

Motors can be controlled in different ways– increasing or decreasing the voltage (stepper motors), slowing or speeding up the motor using a feedback loop (servo motors). Electric actuator is one of the cleanest and most readily available forms of actuator.

In Pneumatic actuators, manipulator’s joint moves through the use of pressurized gas. Though pneumatic actuators are economical, there are rarely used because movement precision is low. Hydraulic actuators, on the other hand, employ a pressurized liquid (typically oil) to move the manipulator joint. They are quite common and offer very large force capability as well as high power-to-weight ratios.

III. Controller

The controller is the main device that processes information and carries out instructions in a robot. It is the robot's 'brain' and controls the robot's movements. It is usually a computer of some type used to store information about the robot and the work environment and to store and execute programs which operate the robot. It contains programs, data algorithms, logic analysis and various other processing activities which enable the robot to perform its intended function.

Most robots incorporate computer or microprocessor-based controllers. These controllers perform computational functions and interface with and control sensors, grippers, tooling, and other peripheral equipment.

Most modern servomotor actuators are designed and supplied around a dedicated controller module from the same manufacturer. Such controllers are usually developed around microcontrollers and common examples are the Pololu Mini Maestro 12-channel USB Servo Controller and Lynxmotion's SSC-32 servo controller.

IV. End-effector

In robotics, an end-effector is the device at the end of a robotic arm, designed to interact with the environment. The exact nature of this device depends on the application of the robot. In the strict definition, which originates from serial robotic manipulators, the end effector means the last link (or end) of the robot. At this endpoint, the tools are attached. In a wider sense, an end effector can be seen as the part of a robot that interacts with the work environment. This does not refer to the wheels of a mobile robot or the feet of a humanoid robot which are also not end-effectors—they are part of the robot's mobility.

The major types of robot end-effectors are:

• Grippers - Grippers are the most common type of end-effectors. They can use different gripping methods (such as vacuum or use of fingers).

• Material removal tools - These include cutting, drilling and deburring tools installed as robot tools.

• Welding torches - Welding is a very popular robotic application. Welding torches have thus become very efficient end-effectors that can be controlled in a sophisticated way for optimized welding.

• Tool changers - Tool changers are used when many different end effectors need to be used in sequence by one robot. They are used to standardize the interface between the robot flange and the base of the tool. They can be manual or automatic.

V. Sensor

Sensors are physical devices that enable a robot to perceive its physical environment in order to get information about itself and its surroundings. They allow the robotic arm to receive feedback about its environment. They can give the robot a limited sense of sight and sound. The sensor collects information and sends it (electronically) to the robot's controller. Color sensor is used in this project.

The color sensor identifies color and gives serial output of RBG value. It can identify 16.7 million color shades giving RGB value for the detected color. The detected color is identified as amount of three primary color values namely Red, Green & Blue with 8 bit accuracy for each primary color. Any color can be separated or combined into three primary colors Red, Green and Blue using the RGB values.

CHAPTER 3

PROPOSED MODEL

3.1 Theoretical background

Based on a survey conducted in a helmet manufacturing company, there was a problem regarding the count of the total manufactured products and also, there were various assembly lines for every different colored helmet. The main idea was to provide a single conveyor for all the different colored products which would decrease the work space and labor cost but also provides the basic function of segregating different colored objects into its respective boxes. Also, the accurate count of the manufactured products could be centralized using wireless communication.

In a food packaging industry huge amount of time and labor was invested in segregating raw and ripened tomatoes. An object sorting robot would decrease the time, workspace and labor cost while providing the basic function.

To decrease human works in operating the mechanical machines, different functionality robotic arms are established. Different functionality arms that are used in robotics are designed and developed to handle the jobs that are repeated. Different considerations are taken care of to design the automation system. To design a high strength mechanical structure, these are the important parameters to be considered i.e. load bearing capacity, optimum weight, degree of rotation and speed of movement. In the form of designing an electronics system, the specifications of the used electronics devices are to be considered.

Alsahafi and Almaleky (2014), both of School of Engineering, University of Bridgeport designed and implemented a metallic waste collection robotic arm. Zen robotic recycling is a waste metallic collection system but it is expensive and restricted to industrial applications. Alsahafi and Almaleky then decided to develop a low-cost, compact and flexible waste collection robotic arm. The aim of this project was to detect metallic object in a specific area and pick them. Though numerous microcontrollers were available in the market, Arduino microcontroller was chosen because of its well-structured programming language. To meet the objective of the project, several sensors such as ultrasonic sensor and IR sensors were integrated. An electromagnetism-based metal detector was incorporated for metal detection. Building a robotic arm was not the aim of this project, so already built lynx5 robotic arm with IR distance sensor mounted on top of bulldozer is used, it featured servo motors that controlled the movement of the robotic arm. DC motors were employed in this project. A non-convectional servo motor driver called 'Arduino moto shield" allowed the microcontroller to drive the two channel DC motors. Speed control was accomplished through convectional PVM pins. The project was separated into four units: the locomotion, detection, pick up and control units. Locomotion unit was equipped with transport device for transporting the robotic vehicle from a start location to a target location. Locomotion unit depends on the detection unit in moving and stopping. Pickup unit depends on control unit to determine and define target location by the data. 37 The robot system with components installed was mounted on 4-wheel drive rover. In addition, bulldozer was designed and installed at the front of the rover to give enough support during execution of object collect task. 4-wheel rover was chosen because of its robust, modifiable nature and availability of expandable chassis. "Ultrasonic" sensor installed at the front of the chassis changes the path of vehicle when obstacle is sensed. Though the aim of the project was achieved, the project can still be subjected to improvement. This modular system can be extended to handle different types of waste.

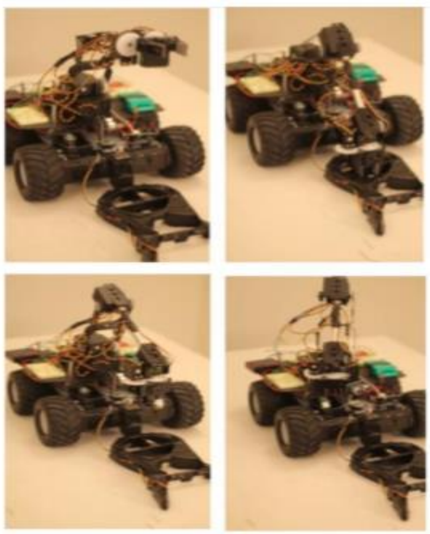

Fig 3.1. Metallic waste collection robotic arm

3.2 Object sorting robotic arm

In this project, we have developed a color sensor-based object sorting robot using embedded system. The developed robot picked different coloured cubes and performed sorting operation by placing them in different cups. The detection of a particular colour was done by a light intensity to frequency converter (photodiode based). The “brain” of the robot was a microcontroller-based system which controlled DC servo motors through servo driver. The robot’s end effector was able to pick and place both wet and dry objects. Photodiode based colour sensor was attached to the system to detect colour of object. Colour sensor returned signal in RGB format to the microcontroller. In this project, the microcontroller (used) turned sensor output signal to its input variable and used it (with the help of embedded program) to control all functions of the whole system. Microcontroller controlled the gripper motor on the robotic arm to pick targeted object and having interpreted the color of the held object, placed it in specified box. Servo motors used required voltage higher than value microcontroller could supply, motor interface served as third-party element between microcontroller and the servo motors. The interface received low level logical signal from controller and provided necessary voltage and current excitation to the motors. Logical signal from controller has measured voltage of 5 volts. LCD display was used for displaying the status of the system. LCD stands for Liquid Crystal Display. It can display alphanumeric, Kana (Japanese character) and symbols. The aim of the project was to develop a fully functional robotic arm which could sort different coloured objects. The aim was achieved. High level colour sensor and microcontroller can be integrated to speed up the response time of the system.

3.3 Design and Block Diagram

In the process of designing the module for our requirements, first list out our requirements and choose efficient components for our requirement to be fulfilled. Those components should be connected in a different way to work accordingly to our method. The connection between all those components in a systematic manner is called block diagram and the block diagram of our design is shown below.

In the working process, it has two different areas of work, one for working with the colored objects and the other is for controlling the first area.

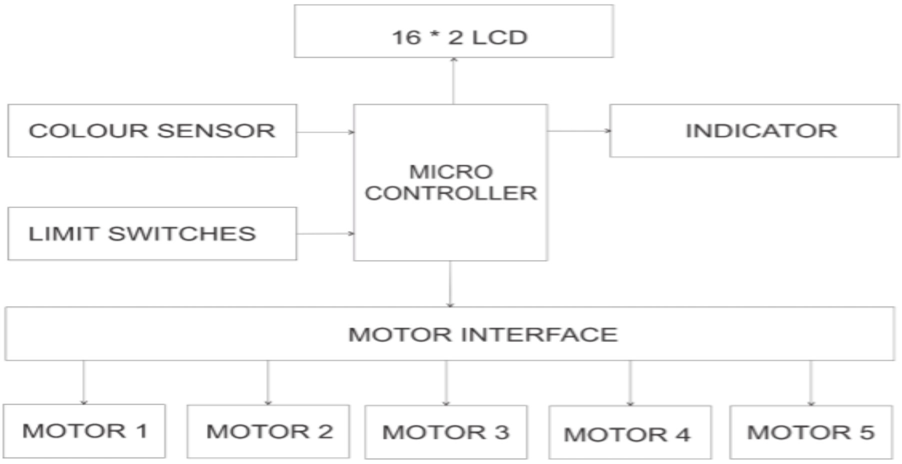

Fig 3.2. Block diagram of the robotic area

In the robotic area, the conveyor motors receive power from the power supply. The pulley conveyor belt with a circular loop of materials that rotates about them. Forward movement of the belt brings the materials near the sensor unit, when materials sensed by the sensors the conveyor belts stops for the identification of the color of the material with the help of the color sensor, then the signal of the particular material color is fed to the control unit for further operation, then the control unit sends the signal to the robotic arm that picks the material and places the material in the prescribed area, after placing them material the arm of the robot comes back to the normal place and waits for the next material to arrive. Then the controller starts the conveyor and brings the next material to the sensor unit and the process continues.

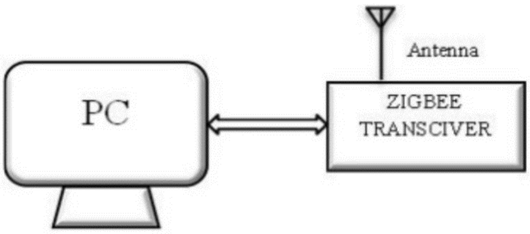

Fig 3.3. Block diagram of the control unit

This block is the main clock for working out or controlling the operation of the robotic area and this is operated by a known user. It maintains record of the objects in a systematic manner for our observation and future use.

3.4 Working principle

After material production, materials will be kept on conveyer, and that conveyer will bring the materials into the packing area. In the packing area, the IR sensor is used to detect material arrival and the conveyer will stop when material arrives at the packing area and the color sensor is used at the packing area to sort out the materials based on the color of the material. After identification of the color of the material, the same colored is placed in the prescribed bins, and those bins are kept at the packing junction. Here the picking and placing of the material is done using the robotic arm.

The admin can change the bin configuration from the central PC using Zigbee technology. If admin needs material count, he can take the counts from the central system and control the action of the whole system in the central action.

CHAPTER 4

METHODOLOGY AND DESIGN PROCESS

4.1 Introduction

Embedded in this chapter are the methods used for construction of object sorting robotic arm based on colour sensing. Also, the materials used, the scientific and engineering characteristic properties that made those materials suitable, are explained in detail.

4.2 Material Selection

Building a robotic manipulator from scratch requires selection of material suitable for the job, and a suitable material is one that meets some design requirements. For this project, design requirements were: (i) Ease of machining (ii) Ease of shaping (iii) Durability (iv) Strength (v) Lightness (vi) Availability To prevent failure of each link of the arm when load is imposed, material with sufficient strength was used. Durability characteristic increases life span of robotic material. One-way cost minimization was achieved was by reducing torque requirement of the robot actuators through the use of light material. The material was also carefully selected to ensure ease of shaping because some components of the robotic arm required cutting of intricate shapes. Deep research shows that Perspex (polymethyl methacrylate or PMPA plastic) sheet features the above listed requirements as characteristics, so, the sheet was used for this project. Perspex sheet is easy to machine, of outstanding strength, cheap, and readily available. Density of Perspex is 1180kg/m3.

4.3 Implementation Plan Representation

Figures 4.1 and 4.2 below are block flow diagram (representing the entire implementation plan for the object sorting robotic arm) and circuit schematic diagram for the robot setup.

4.4 Modelling

Computer modelling is of great importance because it aids better understanding of a particular system and communicate ideas behind the system clearly. It helps visualize a system as it is, permits the specification of the structure and behavior of a system, and serves as template that direct the construction of system's prototype. Computer modelling also helps document decisions. As earlier mentioned in the introductory section of this report, the object sorting robotic arm has five degrees of freedom. A CAD model of the arm was designed with Autodesk® Inventor®. The modelling was sectioned into part modelling, assembly modelling and annotated drawing. During part modelling, all the components of the arm (the links, base, end-effector, turn table, actuators, colour sensor, controllers and joints) were designed separately. Then, the components were then imported to assembling workspace where coupling operation was performed. The output of assembly section was a full-scale model of the arm. The model is shown in figure 4.3

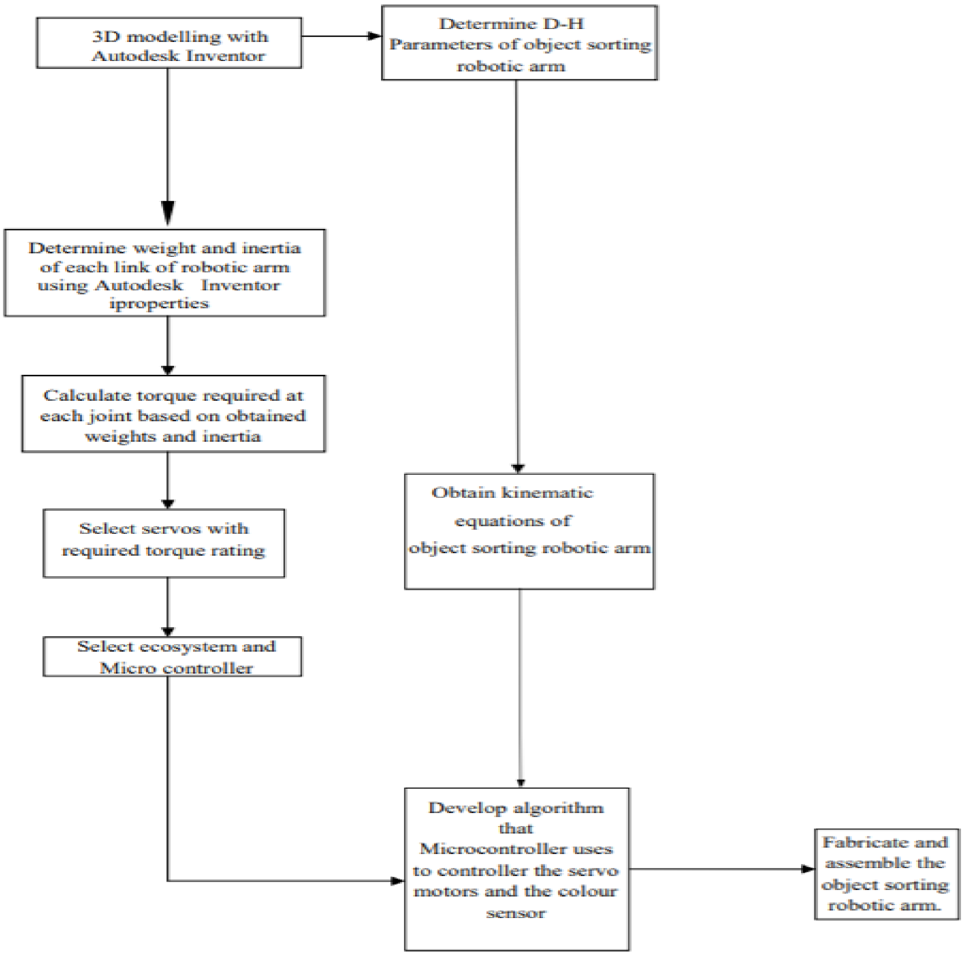

Fig 4.1. Implementation block flow diagram

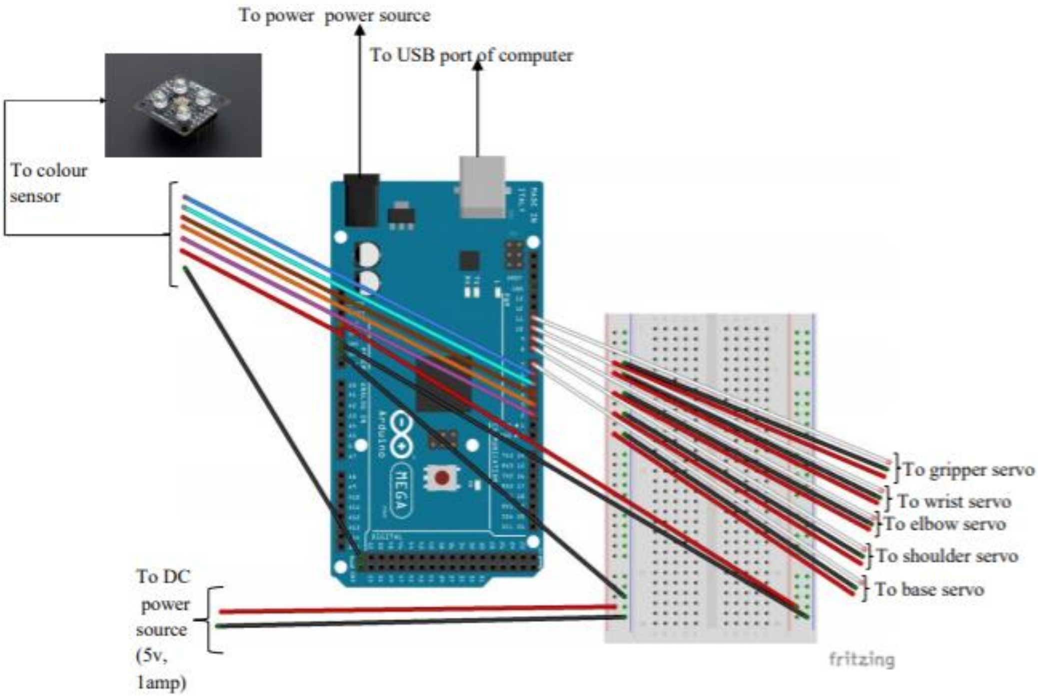

Fig 4.2. Circuit schematic diagram for the robot setup

Fig 4.3. CAD Model of object sorting robotic arm

4.5 Kinematic Analysis

It is very important at this junction to define kinematics and states its types. According to Oxford living dictionary, kinematics is the branch of mechanics concerned with the motion of objects without reference to the forces which cause the motion. The motion of a manipulator can be treated under two categories:

- Forward kinematics
- Inverse kinematics

Forward kinematics deals with the development of equations that gives the position and orientation of center of end-effector giving any set of joint angles as input parameters. The joint variables are the angles between the links in the case of revolute or rotational joints, and the link extension in the case of prismatic or sliding joints. The forward kinematics problem is to be contrasted with the inverse kinematics problem, which is concerned with determining values for the joint variables that achieve a desired position and orientation for the end-effector of the robot. According to Corke (2011), inverse kinematics is a method of determining the pose of the end-effector of a robotic arm, given that the joint coordinates has been discussed. The Denavit-Hartenberg (D-H) convection will be used to compute the forward kinematics of the object sorting robotic arm. The four D-H parameters will be determined by following the appropriate procedure.

4.5.1 Forward kinematic analysis using Denavit-Hartenberg convention

See figure 4.4. The D-H parameters of the object sorting robotic arm were determined based on the procedure for determining the Denavit-Hartenberg Parameters of a serial link.

Frames were attached to each of the links of the manipulator at the joint positions. The convention for locating frames on the links is as follows: The Z-axis of frame {i}, Z_i, is coincident with the joint axis i. The origin of frame {i} is located where a_i perpendicularly intersects with the joint i axis. X_i points along ai in the direction from joint i to joint i+1. In the case of $a_i = 0$,

X_i is normal to the plane of Z_i and Z_{i+1}. We define α_i as being measured in the right-hand sense about X_i, so we see that the freedom of choosing the sign of α in this case corresponds to two choices for the direction of X_i. Y_i is formed by the right-hand rule to complete the i^{th} frame.

If the link frames have been attached to the links according to the above convention, the following definitions of the link parameters are valid:

α_{i-1} = angle between z_{i-1} and z_i measured about x_{i-1}

a_{i-1} = distance between z_{i-1} and z_i measured along x_i

d_i = distance between x_{i-1} and x_i measured along z_i

θ_i = angle between x_{i-1} and x_i measured about z_i

where 'α' is called the link twist, 'a' is called the link length, 'd' is called the link offset and 'θ' is called the joint variable (in case of revolute joints).

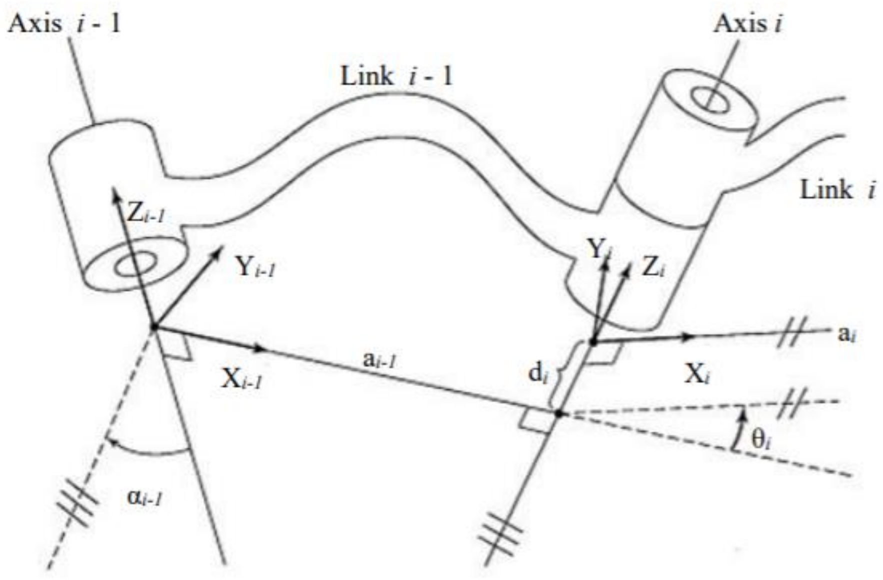

Fig 4.4. Attachment of frames to the links of a robotic arm

Figure 4.5 represents a schematic diagram of the object sorting robotic arm showing the chosen joint axes. Table 4.1 contains D-H parameters of the arm obtained from the schematic diagram as follows:

for i = 1: $\alpha_{i-1} = \alpha 0$ = angle between z_0 and z_1 measured about $x_0 = 0°$

$a_{i-1} = a_0$ = distance between z_0 and z_1 measured along $x_0 = 0_{mm}$

$d_i = d_1$ = distance between x_0 and x_1 measured along $z_1 = 0_{mm}$

$\theta_i = \theta_1$ = angle between x_0 and x_1 measured about $z_1 = \theta_1$

for i = 2: $\alpha_{i-1} = \alpha_1$ = angle between z_1 and z_2 measured about $x_1 = 90°$

$a_{i-1} = a_1$ = distance between z_1 and z_2 measured along $x_1 = 0_{mm}$

$d_i = d_2$ = distance between x_1 and x_2 measured along $z_2 = 0_{mm}$

$\theta_i = \theta_2$ = angle between x_1 and x_2 measured about $z_2 = 90° - \theta_2$

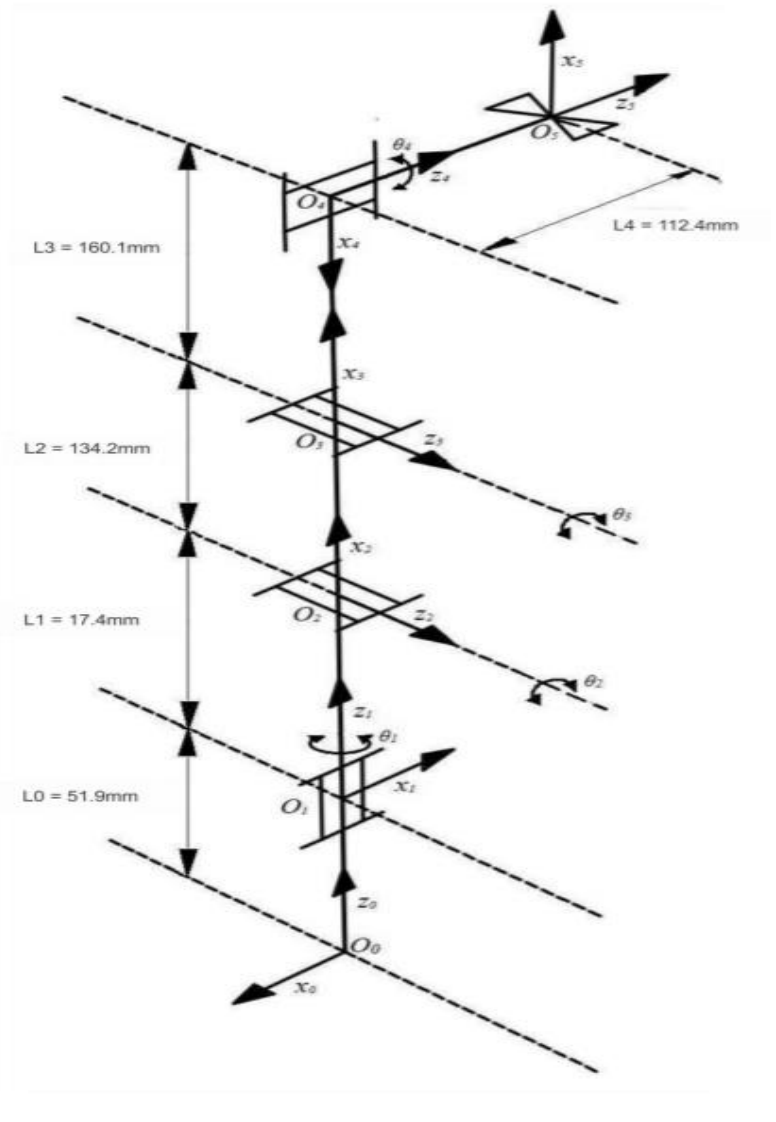

Fig 4.5. Schematic of robotic arm showing chosen joint axes

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0°	0	0	θ_1
2	90°	0	0	90° - θ_1
3	0°	L_2	0	θ_3
4	90°	L_3	0	180° - θ_4
5	0°	0	0	180°

Table 4.1. D-H parameters for the Robotic Arm

for i = 3: $\alpha_{i-1} = \alpha_2$ = angle between z_2 and z_3 measured about x_2 = 0°

$a_{i-1} = a_2$ = distance between z_2 and z_3 measured along $x_2 = L_2$

$d_i = d_3$ = distance between x_2 and x_3 measured along $z_3 = 0_{mm}$

$\theta_i = \theta_3$ = angle between x_2 and x_3 measured about $z_3 = \theta_3$

for i = 4: $\alpha_{i-1} = \alpha_3$ = angle between z_3 and z_4 measured about x_3 = 90°

$a_{i-1} = a_3$ = distance between z_3 and z_4 measured along $x_3 = L_3$

$d_i = d_4$ = distance between x_3 and x_4 measured along $z_4 = 0_{mm}$

$\theta_i = \theta_4$ = angle between x_3 and x_4 measured about z_4 = 180°-θ_4

for i = 5 : $\alpha_{i-1} = \alpha_4$ = angle between z_4 and z_5 measured about x_4 = 0°

$a_{i-1} = a_4$ = distance between z_4 and z_5 measured along $x_4 = 0_{mm}$

$d_i = d_5$ = distance between x_4 and x_5 measured along $z_5 = 0_{mm}$

$\theta_i = \theta_5$ = angle between x_4 and x_5 measured about z_5 = 180°

The D-H parameters of robot arm are exactly identical to those of the RA-01 robotic arm used by Akinwale (2011) for his M.Sc. thesis. According to Akinwale, the location of the central point of the end effector (gripper) of the robotic arm is given as (x, y, z), where:

$x = \cos\theta_1 [L_4 \cos(\theta_2 + \theta_3) - L_3 \sin(\theta_2 + \theta_3) - L_2 \sin\theta_2]$

$y = \sin\theta_1 [L_4 \cos(\theta_2 + \theta_3) - L_3 \sin(\theta_2 + \theta_3) - L_2 \sin\theta_2]$

$z = L_4 \sin(\theta_2 + \theta_3) + L_3 \cos(\theta_2 + \theta_3) + L_2 \cos\theta_2$

The three equations above were used to compute the position (x, y, z) of the center of gripper of the object sorting robotic arm.

4.6 Torque Estimation

Links are not autonomous (i.e. are not self-propelled), so, they depend on torque supplied by actuators (here, servo motors). Actuators are situated at each joint of the arm. The motion or torques to be supplied by an actuator (at a particular joint) is resisted by:

- Gravitational attraction of link to the center of the earth
- Inertial effects (i.e. resistance of link to motion).

Intensity of gravitational attraction is directly proportional to weight of link, the higher weight of link, the higher the corresponding gravitational attraction. So as to select actuators with sufficient requirement for this project, it necessary to estimate the value of gravity-induced resistive torque acting on each link of the robotic arm.

According to Corke (2011), robotic arm is subjected to highest torque when the arm is stretched horizontally. This is the worst torque scenario that can be experienced during arm operation. This worst case is chosen in other to estimate torque required at each joint.

Let Jb represent base joint, Js for shoulder joint, Je for elbow joint, Jw for wrist joint, Jg for gripper (end-effector) joint.

Let L1 represent length of link between base joint (Jb) and shoulder joint (Js), L2 for length of link between shoulder joint (Js) and elbow joint (Je), L3 represent length of link between elbow joint (Je) and wrist joint (Jw), and L4 represent the length of link between wrist joint (Jw) and gripper joint (Jg).

Let W1 stand for weight of acrylic link 1, W2 for acrylic link 2, W3 for acrylic link 3, W4 for acrylic link 4, Wg for weight of gripper, Wp for weight of payload.

Let Wj2 denote weight of joint 2, Wj3 for joint 3, Wj4 for weight of joint 4, and Wj5 for weight of joint 5.

Let G1 represent gravitational resistive torque at joint 1, G2 for that at joint 2, G3 for that at joint 3, G4 for that at joint 4, and G5 for that at joint 5.

Since gripper jaws motion, wrist motion and base motion do not act against gravity, therefore, the corresponding gravitational resistive torques have values of zeros (i.e. G1= 0, G4 = 0 and G5 = 0).

Values of G2 and G3 are results obtained from the under listed equations:

$$G3 = W3\ (L3/2) + (Wj4 + W4 + Wj5 + Wg + Wp)\ (L3)$$

$$G2 = W2\ (L2/2) + Wj3 * L2 + W3\ (L2 + L3/2) + (Wj4 + W4 + Wj5 + Wg + Wp)\ (L2 + L3)$$

When trying to change the angular motion of a body about an axis, a resisting moment is always encountered. This resisting moment is measured by calculating its moment of inertia about that particular axis. The resistance that is shown by a body to change its rotation is called **moment of inertia (I)**. The moment of inertia describes the angular acceleration produced by an applied torque. Therefore, for a given angular acceleration of any link of the object sorting robotic, the inertia of the link results in a resistive torque applied at the joint where the lower end of the link is connected. The value of this torque (Ti) is given by the product of the moment of inertia of the link and its angular acceleration, α.

$Ti = I\alpha$

The moment of inertia of a body depends on its shape and mass distribution as well as the orientation of its rotational axis, thus necessitating the use of a different formula to calculate the moment of inertia of each link of the robotic arm. “iproperties” tool of Autodesk® Inventor® Professional CAD software was used to analyses the moment of inertial of each link constituting the robotic arm structure. The decision to use this feature was made owing to the fact that the links of the robot are of complex geometrical shapes and analyzing their respective moments of inertial require complex mathematical formulae.

Figure 4. 7 illustrates the use of “iproperties” tool to determine the moments of inertia of link L_2 with respect to X, Y and Z-axes. The following values were returned by the tool:

$I_{XX} = 3.089$ kg mm^2

$I_{YY} = 8.149$ kg mm^2

$I_{ZZ} = 20.928$ kg mm^2

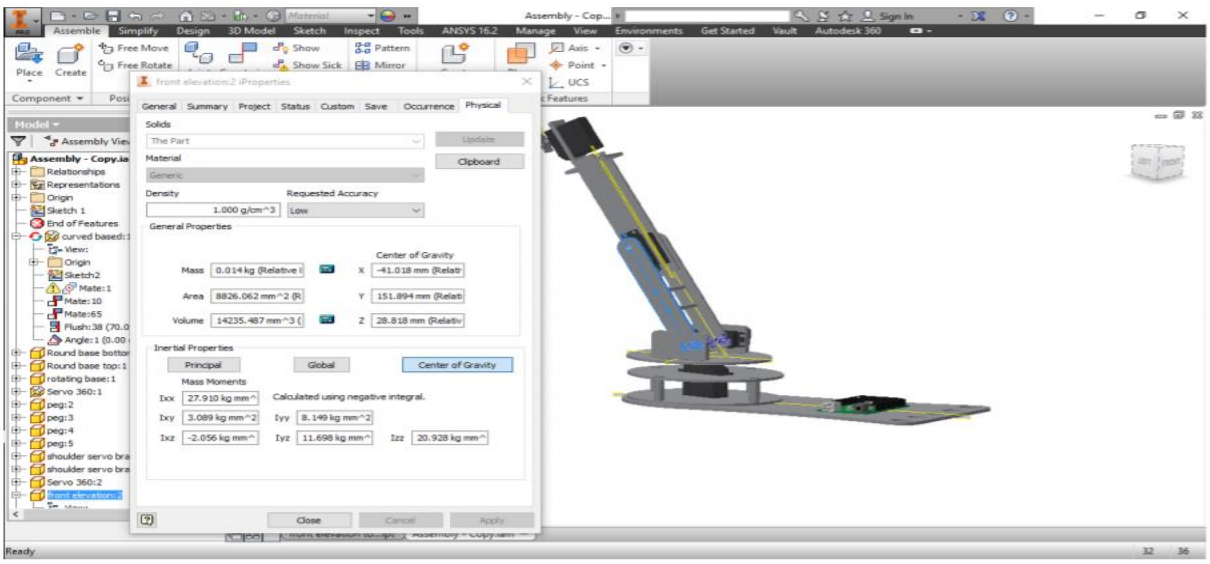

Fig 4.6.” iproperties” tool of Autodesk® Inventor® Professional displaying the moments of inertia of link L_2

I_{XX}, I_{YY} and I_{ZZ} were evaluated for other links of the object sorting robotic arm as well.

Calculation of the resistive torque exerted on each joint due to inertia effect is as follows:

Let resistive torque at joint 1 due to inertia effect = T_{1i}

Let resistive torque at joint 2 due to inertia effect = T_{2i}

Let resistive torque at joint 3 due to inertia effect = T_{3i}

Let resistive torque at joint 4 due to inertia effect = T_{4i}

Let resistive torque at joint 5 (gripper joint) due to inertia effect = T_{5i}

Recall:

J_b = base joint

J_s= shoulder joint

J_e = elbow joint

J_w = wrist joint

J_g= gripper joint

A motor (actuator) is placed at each of these joints. Thus, let:

m_{sm} = mass of shoulder motor

m_{em} = mass of elbow motor

m_{wm} = mass of wrist motor

m_{gm} = mass of gripper motor

m_{L1} = mass of link L1

m_{L2} = mass of link L2

m_{L3} = mass of link L3

m_{L4} = mass of link L4

$m_{gripper}$ = mass of gripper assembly

I_{sm} = moment of inertia of shoulder motor

I_{em} = moment of inertia of elbow motor

I_{wm} = moment of inertia of wrist motor

I_{gm} = moment of inertia of gripper motor

$I_{gripper}$ = moment of inertia of gripper assembly

I_{base} = moment of inertia of rotating base and shoulder motor bracket assembly

I_{L1} = moment of inertia of link L1

I_{L2} = moment of inertia of link L2

I_{L3} = moment of inertia of link L3

The values of the moments of inertia obtained from Autodesk® Inventor® Professional are about the axes passing through each body's centre of mass. In the case of a robotic arm, the moment of inertia must take into consideration that the part is being rotated about a pivot point (the joint in this case) located a distance away from the centre of mass. The parallel axis theorem was applied to evaluate the moments of inertia about the joint axes,

$$T_{1i} = [(I_{zz,base} + m_{base}h_{112}) + (I_{zz,sm} + m_{sm}h_{122}) + (I_{zz,L2} + m_{L2}h_{132}) + (I_{zz,em} + m_{em}h_{142}) + (I_{zz,L3} + m_{L3}h_{152}) + (I_{zz,wm} + m_{wm}h_{162}) + (I_{zz,gripper} + m_{gripper}h_{172}) + (I_{zz,gm} + m_{gm}h_{182})]\alpha$$

h_{11} = perpendicular distance between z-axes through the centroids of base motor horn and rotating base-shoulder servo bracket assembly

h_{12} = perpendicular distance between z-axes through the centroids of base motor horn and shoulder motor

h_{13} = perpendicular distance between z-axes through the centroids of base motor horn and link L_2 (stretched out)

h_{14} = perpendicular distance between z-axes through the centroids of base motor horn and elbow motor

h_{15} = perpendicular distance between z-axes through the centroids of base motor horn and link L_3 (stretched out)

h_{16} = perpendicular distance between z-axes through the centroids of base motor horn and wrist motor

h_{17} = perpendicular distance between z-axes through the centroids of base motor horn and gripper assembly (pointing downwards)

h_{18} = perpendicular distance between z-axes through the centroids of base motor horn and gripper motor

$$T_{2i} = [(I_{xx,L2} + m_{L2}h_{21}{}^2) + (I_{xx,em} + m_{em}h_{22}{}^2) + (I_{xx,L3} + m_{L3}h_{23}{}^2) + (I_{xx,wm} + m_{wm}h_{24}{}^2) + (I_{xx,gripper} + m_{gripper}h_{25}{}^2) + (I_{xx,gm} + m_{gm}h_{26}{}^2)]\alpha$$

h_{21} = perpendicular distance between x-axes through the centroids of shoulder motor horn and link L_2

h_{22} = perpendicular distance between x-axes through the centroids of shoulder motor horn and elbow motor

h_{23} = perpendicular distance between x-axes through the centroids of shoulder motor horn and link L_3

h_{24} = perpendicular distance between x-axes through the centroids of shoulder motor horn and wrist motor

h_{25} = perpendicular distance between x-axes through the centroids of shoulder motor horn and gripper assembly (pointing forward)

h_{26} = perpendicular distance between x-axes through the centroids of shoulder motor horn and gripper motor

$$T_{3i} = [(I_{xx,L3} + m_{L3}h_{31}{}^2) + (I_{xx,wm} + m_{wm}h_{32}{}^2) + (I_{xx,gripper} + m_{gripper}h_{33}{}^2) + (I_{xx,gm} + m_{gm}h_{34}{}^2)]\alpha$$

h_{31} = perpendicular distance between x-axes through the centroids of elbow motor horn and link L_3

h_{32} = perpendicular distance between x-axes through the centroids of elbow motor horn and wrist motor

h_{33} = perpendicular distance between x-axes through the centroids of elbow motor horn and gripper

h_{34} = perpendicular distance between x-axes through the centroids of elbow motor horn and gripper motor

$T_{4i} = [(I_{xx,gripper} + m_{gripper}h_{41}{}^2) + (I_{xx,gm} + m_{gm}h_{42}{}^2)]\alpha$

h_{41} = perpendicular distance between y-axes through the centroids of wrist motor horn and gripper motor

h_{42} = perpendicular distance between y-axes through the centroids of wrist motor horn and gripper motor.

4.7 Selection of Motor

The three basic types of motors currently used in contemporary robots are pneumatic, hydraulic, and electrical actuators. In this project, electrical motors, servo motors are used. The decision to use servo motors was made because of their ability to control the angular position, velocity and acceleration of the output shaft in a precise manner.

The formulae established under torque estimation section, together with inertial resistive torque equation, was used to evaluate resistive torque acting at each joint. A servo motor with appropriate torque and voltage rating were then be selected for each joint.

Since torque resistive value is unique to a joint, then servo motor rating is unique to a joint. Three to four Tower Pro servo motors of different torque ratings were selected to provide sufficient torques at respective joints.

The table 4.2 below shows total resistive torque and servo motor specifications per joint in robotic arm:

S/N	Joint name	Total resistance torque	Servo motor specifications	Servo motor name
1	Gripper joint	_____	Torque of 1.8kg/cm at 4.8v	Tower pro SG 90
2	Wrist joint	$T_{4g} + T_{4i} = 6.012 \times 10^{-4}$ kg-cm	Torque of 9.4 kg/cm at 4.8v	Tower pro MG 995
3	Elbow joint	$T_{3g} + T_{3i} =$ 2.756kg.cm	Torque of 9.4 kg/cm at 4.8v	Tower pro MG 995
4	Shoulder joint	$T_{2g} + T_{2i} =$ 6.055kg.cm	Torque of 9.4 kg/cm at 4.8v	Tower pro MG 995
5	Base joint	$T_{1g} + T_{1i} =$ 0.3040kg.cm	Torque of 9.4 kg/cm at 4.8v	Tower pro MG 995

Table 4.2. Total resistive torque and servo motor specifications per joint in robotic arm

4.8 Micro controlling section

The core element of this section is a microcontroller unit. Microcontroller unit is the central processing unit, which controls all the functions of other blocks in this system.

Robot base, shoulder, elbow and gripper angles were received as input parameters by microcontroller. The microcontroller then used this input angles to compute position of gripper and move it to pick the object. Colour sensor (attached to the gripper) scanned and identified the color of object picked. After colour identification was done, microcontroller controlled the arm to move towards specified box, and the gripper released the object into the box.

While executing this project, there were many microcontrollers available in the market (Atmega, Raspberry Pi, AVR, Picaxe, LilyPad, SparkFun and Seed Studio).

Atmega 2560 on Arduino mega 2560 development board was selected for this project because of the following reasons:

(i) Speed

(ii) Number of digital pins available

(iii) Ease of development

(iv) Availability

(v) Arduino IDE which allows software development on all major platforms (Mac, windows PC, Linux) with an easy-to-use subset of C/C++, and

(vi) Nearly instantaneous initialization. Arduino Mega 2560 development board comes in a complete package form which includes the 5V regulator, a burner, an oscillator, an Atmega2560 micro-controller, serial communication interface, LED and headers for the connections.

Fig 4.7. Arduino mega 2560 development board

The Arduino Mega is a development board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Microcontroller code:

Arduino Code block for control activities of the object sorting robotic arm

```
#include<Servo.h>
 #define S0 2
#define S1 3
#define S2 4
#define S3 5
#define sensorOut 6
int frequency = 0;
int color;


Servo gripper;
Servo elbow;
Servo base;
Servo shoulder;
void setup() { // put your setup code here, to run once:
```

```
pinMode(S0, OUTPUT);
pinMode(S1, OUTPUT);
pinMode(S2, OUTPUT);
pinMode(S3, OUTPUT);
pinMode(sensorOut, INPUT);
// Setting frequency-scaling to 20%
digitalWrite(S0, HIGH);
digitalWrite(S1, LOW);

base.attach(7);
shoulder.attach(8);
elbow.attach(9);
gripper.attach(11);

elbow.write(0);//initialize elbow
shoulder.write(0);
base.write(0);
gripper.write(0);

Serial.begin(9600); //initialize serial monitor
}
void loop() {
// put your main code here, to run repeatedly:
```

```
//move and grap object

gripper.write(0); //open the gripper

base.write(75);

delay(2000);

shoulder.write(45);

delay(2000);

elbow.write(30);

delay(2000);

gripper.write(180); //close gripper to pick object


//return

delay(2000);

elbow.write(0);

delay(2000);

shoulder.write(0);

delay(2000);


//detect color of object;

color=readColor();

//move robot to destination (and back to reference) base on color of the
object

switch(color)

{
```

```
case 1: //color is red

Serial.println("color of object = RED");

base.write(55);

delay(2000);

shoulder.write(45);

delay(2000);

elbow.write(40);

break;


case 3: //color is green

Serial.println("color of object = GREEN");

base.write(75);

delay(2000);

shoulder.write(45);

delay(2000);

elbow.write(40);

break;


case 6: //color is blue

Serial.println("color of object = BLUE");

base.write(100);

delay(2000);

shoulder.write(45);
```

```
delay(2000);

elbow.write(40);

break;

case 0:

Serial.println("Error detecting color.");

break;

default:

Serial.println("Error 400");

break;


}

delay(2000);

//drop detected object

gripper.write(0);

delay(2000);


//go back to origin

elbow.write(0);

delay(2000);

shoulder.write(0);

delay(2000);

base.write(0);

delay(2000);
```

```
}

// Custom Function - readColor()
int readColor() {
// Setting red filtered photodiodes to be read
digitalWrite(S2, LOW);
digitalWrite(S3, LOW);
// Reading the output frequency
frequency = pulseIn(sensorOut, LOW);
int R = frequency;
// Printing the value on the serial monitor
Serial.print("R= ");//printing name
Serial.print(frequency);//printing RED color frequency
Serial.print(" ");
delay(50);
// Setting Green filtered photodiodes to be read
digitalWrite(S2, HIGH);
digitalWrite(S3, HIGH);
// Reading the output frequency
frequency = pulseIn(sensorOut, LOW);
int G = frequency;
// Printing the value on the serial monitor
Serial.print("G= ");//printing name
```

```
Serial.print(frequency);//printing RED color frequency

Serial.print(" ");

delay(50);

// Setting Blue filtered photodiodes to be read

digitalWrite(S2, LOW);

digitalWrite(S3, HIGH);

// Reading the output frequency

frequency = pulseIn(sensorOut, LOW);

int B = frequency;

// Printing the value on the serial monitor

Serial.print("B= ");//printing name

Serial.print(frequency);//printing RED color frequency

Serial.println(" ");

delay(50);

if((R>17&&R<29)&&((G>52&&G<32)&&(B>47&&B<25))){

color= 1; //Red

}else if((R>16&&R<23)&&((G>28&&G<40)&&(B>26&&B<34))){

color=3; //Blue

}else{

color=0;

}

return color;

}
```

4.9 Colour sensing

Though while executing this project, there were many colour identification sensors available in the market place, sensor TCS3200 was selected because of its, price, speed and well formatted output. The output of TCS3200 is a square wave with frequency directly proportional to light intensity. This frequency was received by Atmega 2560 microcontroller for interpretation.

Color Sensor is a complete color detector, including a TCS3200 RGB sensor chip and 4 white LEDs. The TCS3200 can detect and measure a nearly limitless range of visible colors. The TCS3200 has an array of photodetectors, each with either a red, green, or blue filter, or no filter (clear). The filters of each color are distributed evenly throughout the array to eliminate location bias among the colors. Internal to the device is an oscillator which produces a square-wave output whose frequency is proportional to the intensity of the chosen color.

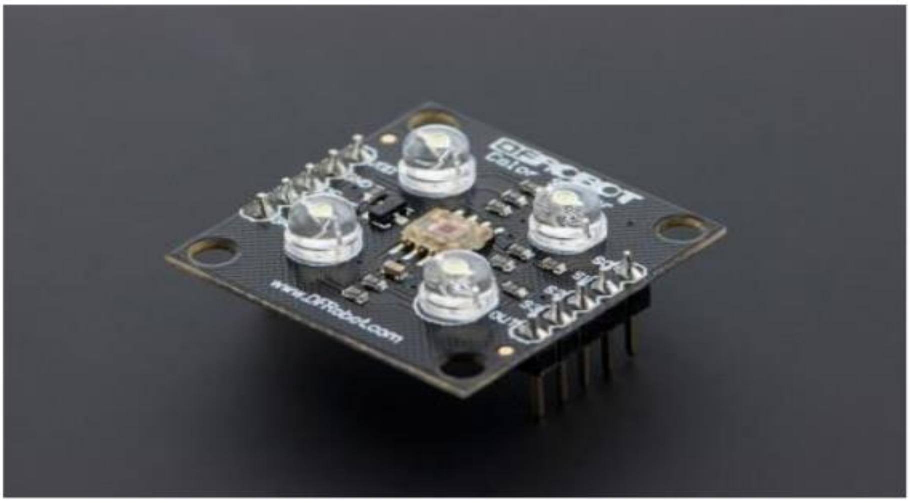

Fig 4.8. TCS3200 colour sensor for Arduino

4.10 CAD Model

Figure 4.9 shows the complete assembly model of object sorting robotic arm while annotated drawings of its constituting parts. The model was put up in Autodesk® Inventor® Professional 2015 (Student Version).

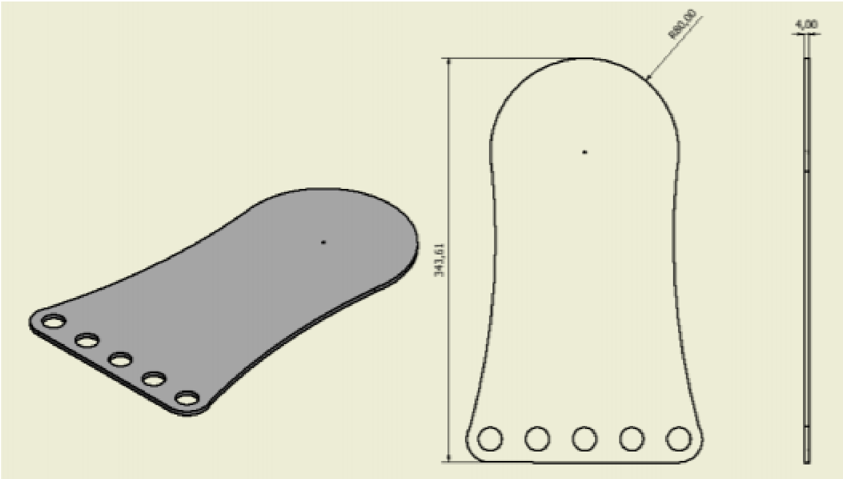

Fig 4.9 a: Curved based

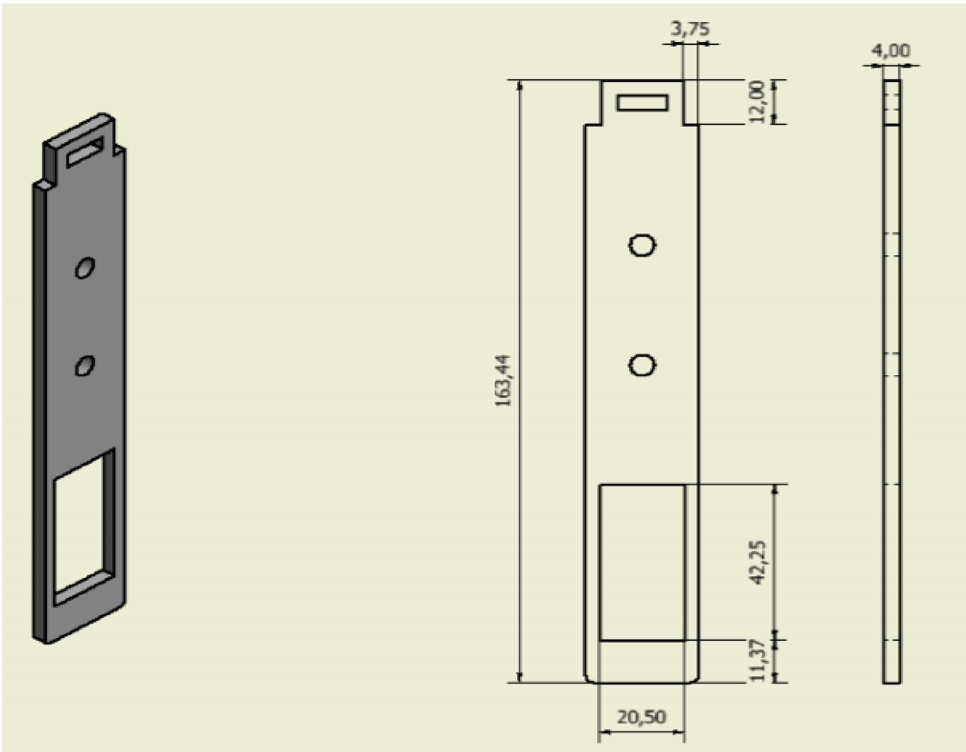

Fig 4.9 b: Front elevation top

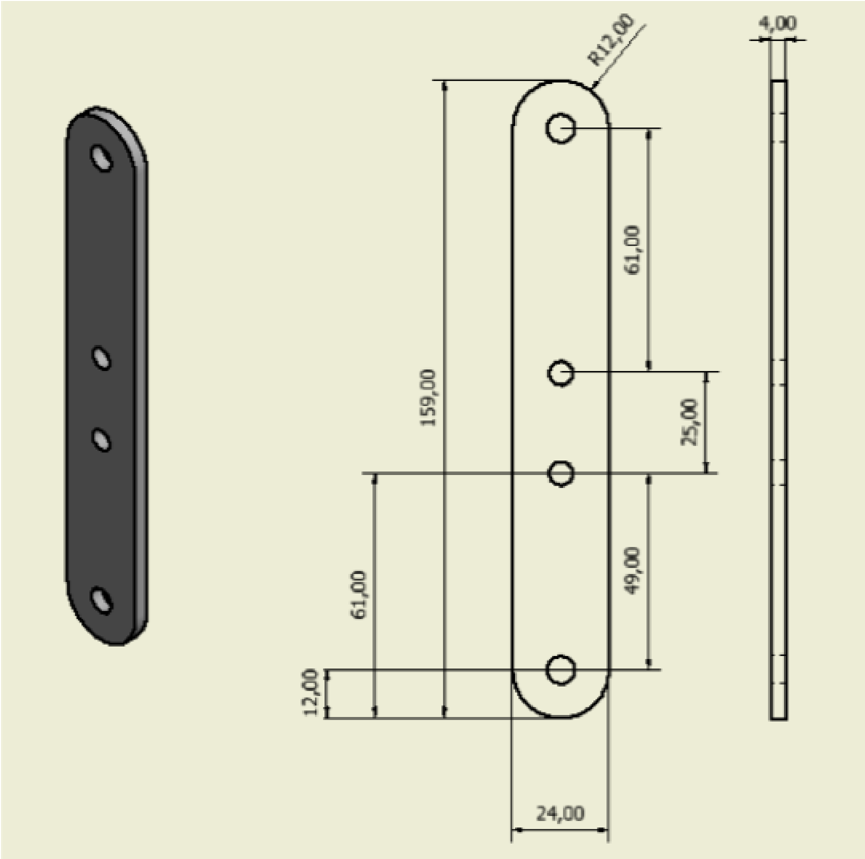

Fig 4.9 c: Front elevation

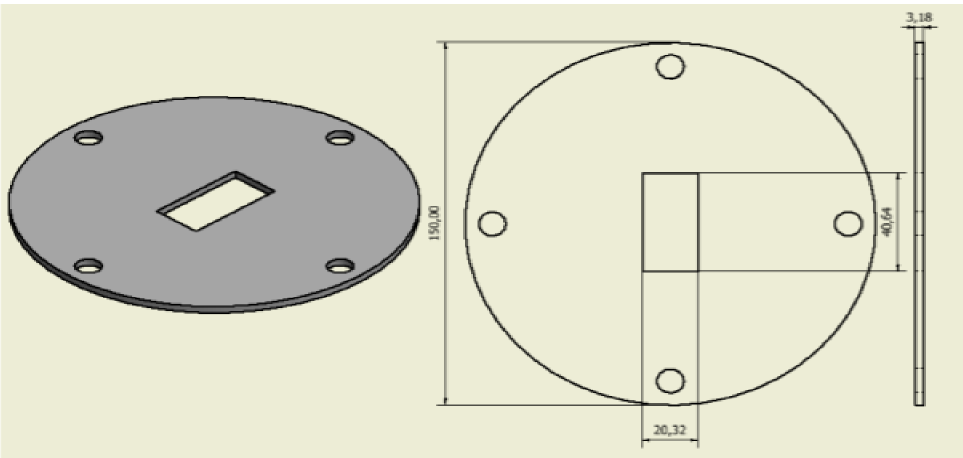

Fig 4.9 d: Top round base

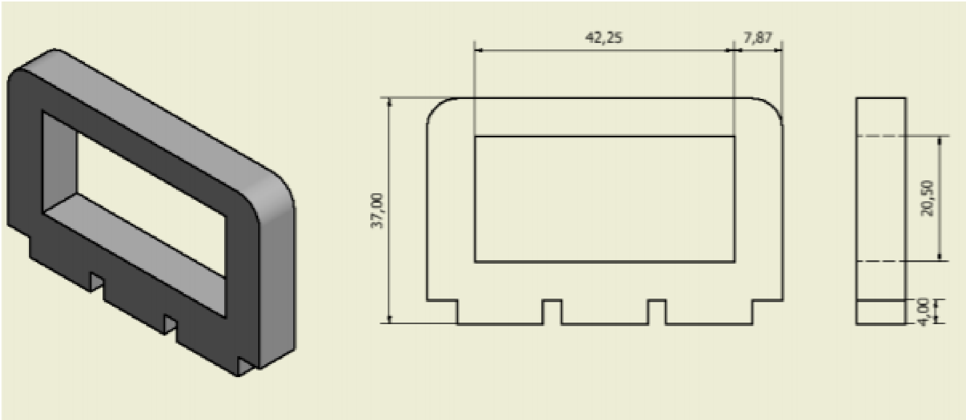

Fig 4.9 e: Right shoulder servo bracket

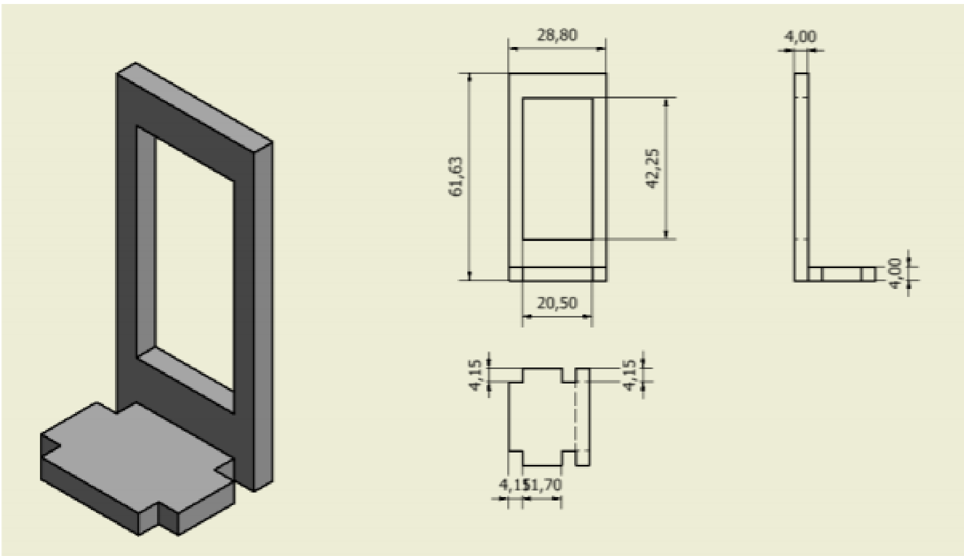

Fig 4.9 f: Wrist rotate servo holder

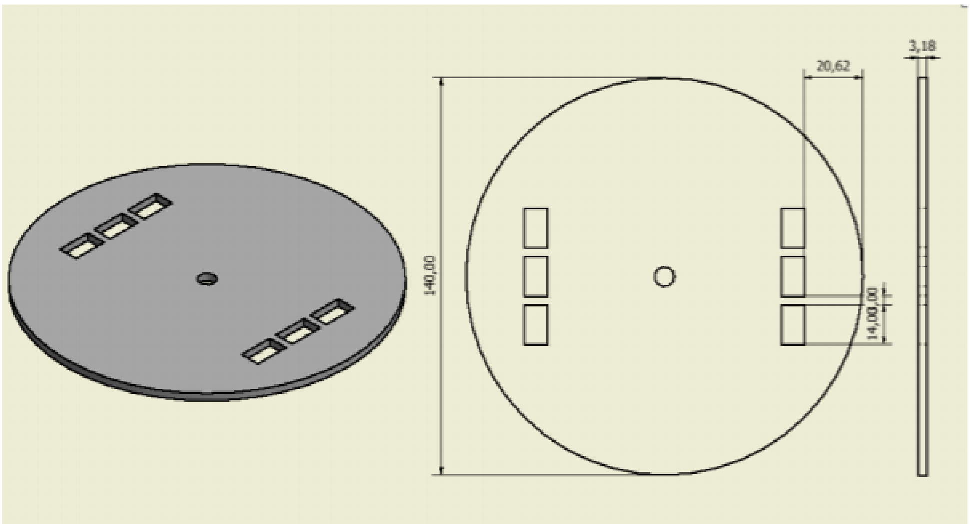

Fig 4.9 g: Rotating base

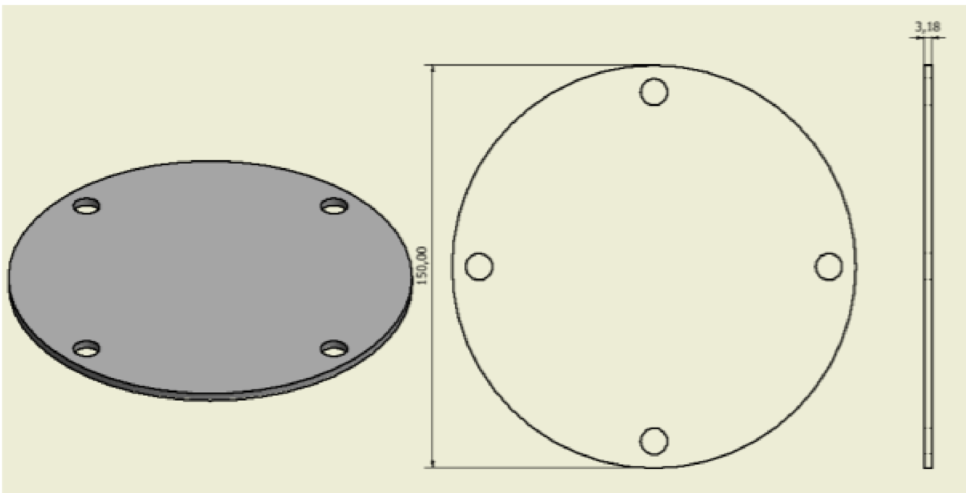

Fig 4.9 h: Bottom round base

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Advantages and Disadvantages

Following are the **advantages**:

➡It helps in sorting of objects based on three color approach. It also helps in counting of objects.

➡Automated system can be built using color sensors which help in completion of work in less time. Moreover, human intervention is not needed.

➡Powerful and large memory color sensor ICs are available at low cost. This has driven its use in many applications.

➡It is easy to change or modify manufacturing setups without even re-programing the sensor device. This is beneficial in low volume manufacturing applications having frequent color variations.

➡With the advancement of technology and memory loaded with color intensity data, color sensor controller can store and can make color matching decisions on unlimited number of colors virtually.

Following are the **disadvantages**:

➡The approach could be costly for small scale industries.

➡It does color matching or identification in applications requiring only pass/fail output.

➡Operating distance range of the color sensors are matter of concern. This needs to be chosen appropriately with rigorous testing in the setup.

5.2 Applications

- **Automotive Agro Applications**: -

The Pick and Place robot is used in agriculture for collecting ripened fruits based on the color. The ripe fruits have a different colour compared to the unripe fruits. For example, ripened tomato is bright red in color and the unripen one is green. So the pick and place robot can pick the fruits according to their necessity by identifying the color.

- **Industrial Applications**: -

As the assembly of the machine parts involving color is a tedious task for execution, the robots are conveniently used to pick and place the parts. It can be used in packing fruits and vegetables of only specific quality in industries like the good quality apples which will be bright red in color.

- **Auto industry**: -

The auto industries are the largest user of robots, which industrialize the production of various components and assemble the body of the finished vehicle based on colours. Car production is one primary example of the employment of complex and large robots. Pick and place robots based on color identification are used in that process for the picking and placing the components for assembly of the body of the automobiles.

5.3 Results and Discussions

After all electronic components, Perspex sheet and other materials required for the development of object sorting robotics arm were shipped in, the robot was set up based on the methods outlined in chapter three of this thesis.

During fabrication stage, all the links and other components constituting the robotic arm skeletal structure were map out on cardboard sheets using pencil, meter rule and protractor. The card sheets were then placed and attached firmly on Perspex sheet and with the use of fret saw and a hand-drilling machine, the links and components were cut out.

With the use of screw driver; bots and nuts; epoxy-resin gum and nails, all static and dynamic joints were formed, right and left top front elevation links were joined together to form a single rigid body, right and left bottom elevation links were also rigidly connected together, the Arduino mega 2560 development board and circuit breadboard were rigidly fixed to the circular base component. To achieve additional stability, elastic springs introduced at strategic points.

Using Figure 4.2 as guide, complete design for the robotic arm is to be developed. To prevent electrical hazard that can occur as a result of bridging, circuit rules and regulations were strictly adhered to. The affixed Arduino development board were connected to PC and code blocks, written in Arduino language, was deployed to Atmega 256 microcontroller. The code block helped the microcontroller controlled and managed activities of the robotic arm i.e. moving the servo motors, identifying colour of object and receiving data from web-based control interface remotely.

CHAPTER 6

CONCLUSIONS AND FUTURE DIRECTIONS

From the results obtained from the object sorting robotic arm in chapter four of this report, it is concluded that the aim of this project- design and development of a colour sensing based object sorting robotic arm that can be used in agro based multi-product packaging industries- was achieved. Some of the challenges faced were:

1. Variation in frequencies returned by color sensor due to sunlight intensity. This affected color detection capability of the robotic arm arrangement. It was unable to detect color at night and abled to detect color when exposed to bright daylight.

2. Variation in speed of communication between web-based control interface and the robotic system through ESP8266EX Wi-Fi module. This was as a result of week Wi-Fi network and evolving nature of Internet of Things.

This project has served as eye opener to wide range of industries where robotic technology can be applied. Robotic technology can be applied in space industry, medical line, military department etc.

Adoption of object sorting robotic technologies in agro based multi-product packaging and other industries will definitely go long way in achieving high sorting accuracy, consumption safety, high production efficiency and low cost of production.

The following features can be integrated to the object sorting robotic arm to improve it:

- Speed and efficiency of a system can be further improved by high grade microcontroller using processor for the same purpose.

- The color sensor TCS230 used for colour detection can be replaced with colour based image processing camera as this will make the system more effective at identifying colours.

- Advance design of robotic arm can be further used to pick large and heavy objects and sort them effectively.

• The colour detection capability can be increased to wide variety of colours which can sort out wide range of objects.

• Colour detection along with pattern recognition and Speech recognition can be added as this will play a vital role in many industries and also will increase accuracy.

• The number of degrees of freedom of the robotic arm can be increased in order to expand its reach, thereby making it more versatile.

This project has been effectively designed to handle the required task. It can identify the specific color of the object and grab it and place it in a required area as the user wants with the help of RGB color sensor by sensing the color of the object.

The two main tasks performed by the sensing section are:

- Detection of objects
- Recognition of colors.

This system is fully controlled by the control unit and is capable of picking objects and placing it in its respective area. This cost-effective device was designed by using a simple concept to achieve constant and reliable tasks without error by humans. This sorting device is useful in production areas and different types of household activities.

Thus, the robot with pick and place automation with color detection and distinction property is achieved successfully. The system could be used in industries for picking and placing objects efficiently and also for surveillance. The interfacing of all the components on a single board could be made compact reducing the size and making it more compact.

REFERENCES

- Adebola, S. O. (2012). 'Design of an improvised robot arm system'. BSc. thesis, Obafemi Awolowo University, Ile-Ife.
- Adekoya, A. A. (2001). Fuzzy Control Design of a Robotic Arm. BSc. Thesis, Obafemi Awolowo University, Department of Mechanical Engineering, IleIfe.
- Alsahafi, H. & Almaleky, M. (2014, April). Design an Implamentation of Metallic Waste Collection Robot. University of Bridgeport,Bridgeport, USA.
- Angelo, J. A. (2007). Robotics: A Reference Guide to the New Technology. Westport: Greenwood Press.
- Elfasakhany, A., Yanez, E., Baylon, K., & Salgado, R. (2011, November). Design and Development of a Competitive Low-Cost Robotic Arm with Four Degrees of Freedom. Modern mechanical engineering, 1, 47-55.
- Corke, P. (2011). Robotics, Vision and Control Fundamental Algorithms in MATLAB. (B. Siciliano, O. Khatib, & F. Groen, Eds.) Berlin: Springer-Verlag.
- Craig, J. J. (2005). Introduction to Robotics-Mechanics and Control (3rd Ed.). (M. J. Horton, Ed.) Upper Saddle River, USA: Pearson Prentice Hall.
- Dhanoj, M., Reshma, K. V., Sheeba, V., and Marymol P. (2015, April 4). colour sensor-based object sorting robot using embedded system. Internationa journal of advance research in computer and communication engineering, 4(4), 619-622.
- Honda Robotics. (2016). Honda Robotics: http:// asimo.honda.com/Inside-ASIMO/ Accessed December 27, 2016.
- Mabanta, M. A. B., Pabillaran, P., & Adiong M.B. (2005). Robotic

- Arm Pick and Place System. Capitol University, Philippines.
- Okedeyi, S. B. (1998). Dynamic Simulation of a Two-Link Constrained Robotic Manipulator. BSc. Thesis, Obafemi Awolowo University, Department of Mechanical Engineering, Ile-Ife.
- Oridate, A. A. (2013). Design, Simulation and Fabrication of 5-DOF robotic arm. BSc. Thesis, Obafemi Awolowo University, Department of Mechanical Engineering, Ile- Ife.
- Patil, C., Sachan, S., Singh, R. K., Ranjan, K., & Kumar, V. (2009). Self and Mutual Learning in Robotic Arm, based on Cognitive systems. West Bengal: Indian Institute of Technology Kharagpur.
- Ryan, D. (2012). History MV for Industrial Robots. In D. Ryan, E - Learning Modules: Dlr Associates Series (pp. 28-29). Bloomington: AuthorHouse. Sparkfun inc. (2016).
- https://www.sparkfun.com/products/11061. Accessed December 27, 2016.
- Thomas, B. A., Michahial, S., Shereeraksha, P., Nagvi, V. B., abd Suresh, M. (2013, May). Industry Based Automatic Robotic Arm. Internationa journal of engineering and innovative technology, 2(11), 42-48.
- Timothy, B., Teresa, M., Stephen, R., & Jaen-Claude, L. (2005). Climbing Robots in Natural Terrain. Stanford University, Stanford.
- Merriam Webster Dictionary. (2016). http:// www.webster-dictionary.org Accessed December 27, 2016.