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Design and Development of IoT-based Robot

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***Abstract*—Internet of Things (IoT) is the term used to denote the act of connecting different systems so that they may work in tandem with each other, sharing data and process variables. There is an ongoing revolution in the overall industrial environment, which is often referred to as the fourth Industrial Revolution or as 'Industry 4.0'. It has taken the world by storm, affecting not only the manufacturing industries but also the technology industries. Industry 4.0 is an umbrella for the application of Networking and connectivity to the manufacturing environment. Internet of Things has tremendous influence over human life and Industry 4.0, on the other hand is helping humans with the help of advanced robots. Integration of Robotics in Manufacturing will lead to a giant leap in output and worker satisfaction. The current work emphasizes the application of IoT in the design of a prototype Robot model, developed by additive manufacturing.**

Keywords—* *Additive Manufacturing; Computer-Aided Design; Arduino; IoT; Robot

I. INTRODUCTION

An Industrial Robot is any automated and programmable system that can be used to perform various manufacturing tasks. It uses principles from different branches of engineering, like Mechanical, Production, and Electronics. The first known Industrial Robot was developed by Griffith P. Taylor in 1937 and built using Meccano parts [1]. It was powered by just one motor but had a five-axis motion due to a mechanical gear system. It was programmed using Punched Tapes and facilitated motion using control levers.

We have come a long way from those early days of Robotics. Now some robots have as many as 7 axes and perform tasks like welding, painting, casting, etc. They have had a remarkable influence on how the various manufacturing processes are performed, with the manufacturing industry going towards automation. The Industrial Robot has been extensively applied to practical usage. In the year 2015, estimates show that there were around 1.64 million Industrial Robots worldwide in operation according to the International Federation of Robotics [2].

There are various kinds of Industrial Robots, but the kind we are most interested in is the Robot Arm. The Robot Arm is a robot that can mimic the movements of the human arm and can perform many of its functions as well. It is formed by connecting arm parts, called links, together forming a kinematic chain that moves like an arm. The Robot Arm has a manipulator or end effector installed on its last link which can be used to perform various manufacturing tasks. The various axes of motion are used to accurately place this end effector in the desired position with respect to the workpiece.

For any Robot, there has to be a system so that people may control and program it. This is where the Internet of Things comes into play. It is the name for a network of machines, robots, control devices, and sensors that can collect and exchange data in the network. It can be used to control devices remotely, away from the hazardous industrial environment [3]. In this paper, the aim is to develop an Arduino-based IoT enabled Robot Arm which can be controlled using Android smartphone.

II. LITERATURE SURVEY

The journey of Robotics started way back in 1937, when Grifith P. Taylor created the first true Industrial Robot [1]. The robot appeared in the Maccano Magazine, and was named 'Garguantua' [4]. It had a very simple field of work, it was a pick and place robot, with just a single motor running all the motions. It was built using mostly mechanical parts, with just 5 solenoids in the whole setup. The next important breakthrough came with the creation of the first automated robot using electronics by Takeo Kanade, which has been described in their paper [5]. Kanade et al created a Robotic Arm which had individual motors for each joint, thus increasing the versatility and speed of the robot. The biggest leap, and also the merging the fields of Internet of Things and Robotics, came with the installation of the a GUI app controlled robot at Linatex in 2008 [6].

Internet of Things, or IoT for short, started as a concept in 1991 [3], when a Coca-Cola machine was placed in the Carnegie Melon University which allowed a person to see whether there was a drink available through the web. This was just the beginning, the concept of IoT has now been applied to various industries such as Automobile, Transportation, etc.. But the field where it has the widest application is Manufacturing, with the Industry 4.0 concept [3], with the concept now being at the forefront of the fourth industrial revolution. Laura Belli et al in [7] talks in detail about how it has become extremely important that the companies rapidly adopt smart technologies so as to remain as connected as possible.

There has been widespread application of IoT and other smart technologies in robotics, as we see in [8] and [9]. These papers explain lot about how to integrate the principles of IoT into designing a robot, with [9] being our main paper of reference. K Gawli et al used a Wifi module to establish interconnectivity between the robot and the control system, but we will be using a Bluetooth module to keep cost low. The author [9] did not describe the mechanics of designing the robot, which has been explained very well by A Rehman et al in their paper [8].

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Additive Manufacturing, or 3D printing as is commonly known as, is a rapidly growing field of manufacturing technology. It is used to make rapid prototypes directly from CAD models. There are various kinds of 3D printing process as explained in [10]. The paper, along with the research of B Vayre et al in [11], goes into detail about the parameters that must be kept in mind while designing parts for Additive Manufacturing.

III. Problem Formulation

A. Research Gaps

After doing the literature survey, it was found that there were some drawbacks and these drawbacks were present in most of them. The following are some drawbacks that were found most frequently:

- The robots that the earlier authors had described were expensive to manufacture. They had sophisticated equipment, like DC motors, metal frames, etc.
- The programming environment for the robots were difficult to use for an average user. Most of them used some form of coding language like G-code, which is difficult to master.
- The control interface was not intuitive to use. Most of them utilized some form of Textual based User Interface, which required the user to input commands in the form of text. This interface did not feel natural to use.

B. Formulating the Solution

In order to make an Arduino-based, IoT-enabled Robot Arm which can be controlled using a smartphone, we have tried to find a solution for the problems that we found in the Robots developed by other people. We have tried to improve upon the already done work in the field by filling the gaps in the research. Following are some ways where we have tried to improve the implementation of our robot:

- To make the robot cheaper and easier to build, Additive Manufacturing is chosen. Additive Manufacturing, or 3D Printing as it is commonly known as is a process of rapidly converting Computer-Aided Design (CAD) models into actual physical prototypes. These physical prototypes can be made from various types of plastics like PLA, ABS, Acrylic, etc. 3D printing allowed us to manufacture all the parts of the Robot assembly in just two days. It also reduced the amount of finishing needed for the produced parts [12].
- To improve the programming and control environment, an Android smartphone application has been made. The App has a Graphical User Interface, in which there are toggles that move the various joints of the Robot arm. The Application has been made with MIT App Inventor, an online platform that enables you to develop a mobile application using block based GUI elements, without learning advance programming languages [13-14]. The App will be linked to the Robot Arm through the HC-05 Bluetooth module, which will let data be transferred from the phone to the Robot wirelessly. This would allow the operator to be a safe environment, away from the process.

IV. Methodology

A. Overall description of the flow of work

The project was broken down into basically five critical steps, which have been listed through a block diagram (Fig.1.), with the description of each step in detail is explained further in this paper.

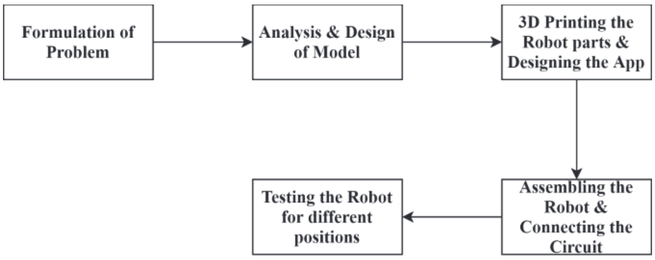

Fig. 1. Flowchart for the Progress

B. Design and Analysis of CAD Model

AutoDesk Fusion360 modelling software was used to make the CAD models required for the project. The software is available free of cost with a three-year student licence. Commands like Fillet, Extrude and Cut were used for making the model.

After completing the model, self-weight analysis of the main arm of the Robot using Ansys (Fig 2) was performed. The results of the analysis showed that the Robot will be capable of handling its own weight, and that the design is correct.

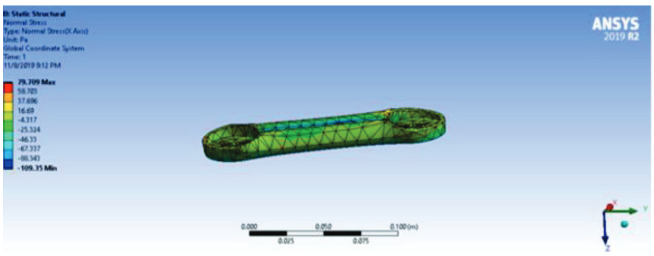

Fig. 2. Ansys Self weight Analysis on the Main Arm

C. Developing the App

In the Android application for controlling the Robot Arm was designed using MIT App Inventor platform. The MIT App Inventor is a free and open source online platform developed by Google, and maintained by Massachusetts Institute of Technology [13]. It uses a Graphical User Interface based development environment where the developer can drag and drop various virtual objects in the workplace which can perform tasks when interacted with.

The virtual elements are called blocks, and can be linked to each other using some logical statement. Like in our Control application, we have toggles for controlling the rotations of the Servos, so we can have a visual toggle element which will be connected to the block for the Bluetooth transmitter. The toggle will send the value of the rotation angle to the Bluetooth transmitter, which will then send this data to the Arduino board through the HC-05 Bluetooth module.

D. 3D Printingof the Parts

After making the CAD model of all the parts of the Robot arm, the next step that is, the printing process, was started. For printing the parts, the Olivetti S2 3D printer was used. Olivetti S2 is a type of Fused Deposition Matrix printer. The process parameters of Olivetti S2 are depicted through Table I.

TABLE I. PROCESS PARAMETERS OF 3D PRINTER OLIVETTI S2

Process Parameter	**Value**
Printing Area	40 x 40 x 40 cm (Volume = 64 litres)
Extruder Temperature	210°C
Number of Extruders	2
Draft	0.2mm
Material	Polylactic Acid (PLA)

In FDM, the extruder heats the Thermoplastic material to its melting point, which is then deposited layer by layer onto the bed to create 3D shapes [10],[14]. For the printing, we converted our CAD models into STL files and fed these files into the printer. The parts took approximately 30 hours to print. The parameters of the printers are shown in Table I.

E. Assembly and Cicuit Connections

1) Finishing the Parts

The 3D printing of all the parts was completed within a few hours. After the printing process was completed, the next step of finishing the printed parts was performed. As 3D printing also prints support material for areas that need support, the supports had to be removed. As PLA is a ductile material, processes which would put pressure on the parts couldn't be used. Usage of cutting and filing in order to finish the parts was decided. Cutting was first used to remove large volume of support material, and then the remaining was filed to get a smooth surface. To remove support material from holes and slots, a heated wire was utilized.

2) Assembling the arm

After all the parts were finished, the assembling process was started. The parts were joined at the required joints using the screws included with the Servo motors. The joints were first aligned, then the Servos were placed in their designated area, and the screws were used to fit the Servo to the two arm, with sufficient distance between them to permit rotation. One area where problem was encountered was with joining the waist joint. As the full weight of the Arm was on the Waist joint, additional support had to be givenby using an elastic band.

3) Connecting the Circuit

The circuit was joined by using Breadboard and Jumper Wires. Breadboard was used to overcome the need for soldering the wires and simplifying the circuit. The Circuit schematics are given in Fig.3. An external power supply had to be used because the Arduino board would not be able to handle the amount of current required by the 6 Servo motors. The power supply was connected in the circuit instead of through the Arduino. The Servos were connected in parallel, one was to an output node of the Arduino. The HC-05 Bluetooth module was connected to the input node, with a 1 Ohm and 2 Ohm resistors in the circuit.

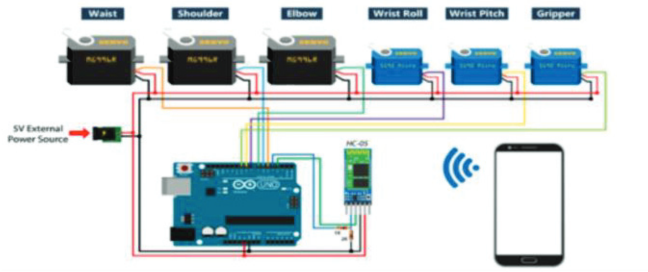

Fig. 3. Circuit Schematics used for the Robot Arm

V. MATERIAL OF THE PARTS

The material were selected by considering the maximum torque capacity of the main servo motor as well as the densities of the various materials.

Radius of the arm = 2cm

Let length of the arms be ‘l’ each

Thus, Cross Sectional Area = p * (22) = 4 p

So, Volume = Area * Length =4 p *l

Mass (M) = Volume * Density = 4 p *l * r

where r is the material density

Max. Torque for Main MG996R Servo (T) is 11000 g-cm Weight of Servo (Ws) is 55g

Weight of End Effector (We) is 16g

Therefore, the Torque equation is

$$T = \frac{Mgl}{2} + \frac{3Mgl}{2} + (Ws)l + 2(We)l \quad (1)$$

Densities of different materials were put in equation 1 and arm lengths were found from equation 1. The data obtained from the above equation is in Table II. The relationship has been shown in Fig.4.

TABLE II. MATERIAL PROPERTIES AND PARAMETERS

Material Name	**Material Density,**	**Arm Length, l (cm)**
PLA	1.25	5.86
Acrylic	1.18	6.03
Mild Steel	7.85	2.36
Aluminium	2.7	4.01
ABS	1.07	6.32
PVC	1.4	5.54

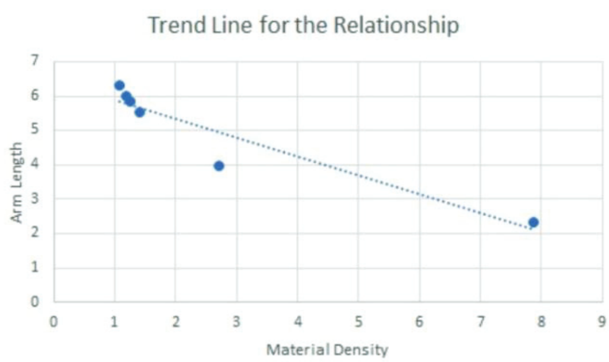

Fig. 4. Relationship between Material Density and Arm length

VI. RESULTS AND DISCUSSIONS

After completing the assembly and connecting process, the Robot arm was complete. It was then subjected through various kinds of tests. The first test was to measure the delay in the response of the Robot, which was found. The delay was due to the limit of the speed of data transmission that is inherent in Bluetooth communication. The response time could be improved by using a higher version of Bluetooth like Bluetooth 5. Another test was to find the resolution of the motion of the Arms. Resolution is the minimum distance that one Servo can rotate in one pass.

After testing the hardware, software was tested. The Mobile control App was installed on various smartphones and then the Robot was paired. This was done to test whether the App would work on different hardware, and how the Robot would respond to different Bluetooth versions.

In this paper, an Arduino-based, IoT-enabled Robot Arm has been designed and developed. The Robot arm could have many applications in both household and industry. The use of Arduino has made the robot to easily adapt to the required tasks. For example, if one requires the robot to perform Welding, then they could easily add welding parameters and sensors in the Arduino code through the IDE. This really helps in enhancing the versatility and flexibility of the Robot arm in dealing with the changing needs of the industry.

Some of the most important advantages of our Robot Arm are:

- It can be rapidly deployed to perform a wide variety of tasks, even if it was not originally programmed to perform them.
- It can be controlled through an Android mobile application which has Graphical User Interface, making it easier to handle the Robot.
- It is built on the Arduino platform, which is open-source and for which there many readymade add-ons available.

Some areas where problems were faced are:

- The parts printed through the 3D printer, Olivetti S2, had a of support material which needed finishing processes like cutting and filing to remove
- Printing the parts to the highest quality could not be done due to limited time.

VII. CONCLUSION

Internet of Things is the latest trend in technology and as such has tremendous application in the field of manufacturing and operations. It has led to a new Industrial Revolution, Industry 4.0, with connectivity being the main focus. This paper is an effort to implement the concepts of IoT into robotics. The future scope of this paper would be to utilise the much more capable Raspberry platform, which would enable higher logical and calculation ability.

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