Panamerican Mathematical Journal
ISSN: 1064-9735
Vol 35 No. 1s (2025)

Design and Implementation of a Bluetooth-Controlled Robotic Arm for Efficient Pick-and-Place Operations

Dr. Dilip S. Choudhari[1,*], Prof.G.D.Gosavi[2], Dr. Mangesh D.Shende[3], Dr.S.P.Joshi[4]
[1,] Dr.D.Y.Patil Institute of Technology, Pune, India
[2,3,4]JSPM Imperial College of Engineering and Research, Pune, India
[1,2,3,4]Faculty of Department of Mechanical Engineering
*Corresponding author E-mail: dilipchoudhari2009@gmail.com

Article History:

Received: *03-09-2024*

Revised: *23-10-2024*

Accepted: *03-11-2024*

Abstract:

The advancement in Robotics and Automation, particularly in IoT, has led to the development of Bluetooth-operated robotic arms. These arms perform tasks like pick and place, reducing human fatigue and error. Two control strategies, force, and motion control, enable precise operations. By using smartphones with Bluetooth connectivity, users can control the arm remotely. The Bluetooth module, like HC05, facilitates this connection. Such arms can handle hazardous materials or tasks in inaccessible areas. These arms offer flexibility and can be reprogrammed for various tasks. Designed using Arduino Uno and four servo motors, they are controlled via a mobile app, ensuring user-friendly operation. The system, modeled using CAD software and 3D printing, enhances safety and efficiency in industrial setups. It enables remote control and precise movements for tasks like handling munitions.

Keywords: Bluetooth, Robotics Arm, human fatigue reduced, Arduino, CAD software, 3D printing.

1. Introduction

Robotic arms have become increasingly common in many industries, such as manufacturing, healthcare, and agriculture. Robotic arms are made to carry out a variety of duties, such as accurately and precisely lifting, moving, and manipulating things. With the advancement of technology, robotic arms are becoming more accessible and easier to control. One such advancement is the use of Bluetooth technology to control robotic arms wirelessly. In recent years, Bluetooth-operated robotic arms have gained popularity in research fields such as robotics, mechatronics, and automation. They are used as a tool for experimentation and development of new technologies, as well as for testing and evaluation of existing technologies. The use of Bluetooth technology makes it possible to control the robotic arm remotely, allowing for greater flexibility and mobility.

In this research paper, we aim to explore the capabilities and limitations of Bluetooth-operated robotic arms in various research applications [1-3]. A robot is programmable, virtually intelligent, and can perform tasks with minimum human supervision and intervention [4]. A robot is an electro-mechanical system or machine that is controlled by computers and some electronic programming [5-6]. Robots are classified as autonomous, semi-autonomous, and remotely controlled. A robotic arm is used for many applications or tasks that are too dangerous for humans to perform [7-8]. Robotic manipulator is another name for a Robotic arm because it can perform similar functions to a human arm. The robotic arm can be reprogrammed and can be manipulated to do different tasks with minimum modifications [9]. The robotic arm can perform all the tasks that have been performed by human hands for a very long time such as welding, lifting, spraying, drilling, etc. Robots can be self-sufficient here Self-sufficient robots are built using microcontrollers and motors [10]. This increases the speed of operation and reduces error and work time. Hazardous objects are handled efficiently and safely. Shifting hazardous objects from one place to another becomes easy and low risk for humans. The automation of the robotic arm involves designing of whole circuit [11]. The main part of the design is the Arduino Uno microcontroller which coordinates and controls all the actions of the robotic arm. Several servo motors are used for precise control of the robotic arm movement. Bluetooth module (HC05) is used for remotely controlling the robot arm from Bluetooth devices. The app is developed for an easy-to-use interface according to user requirements for controlling the robotic arm [12]. A Bluetooth-operated robotic arm is a type of robotic arm that is controlled by a Bluetooth connection. The robotic arm is designed to be controlled remotely via a smartphone, tablet, or computer with a Bluetooth connection. Robotic arms have been around for many years and have been used in various industries, such as manufacturing, assembly, and packaging [13]. They are highly versatile and can perform a wide range of tasks, including lifting, moving, and manipulating objects. With the advancement of technology, robotic arms are now becoming more accessible to hobbyists and enthusiasts [14]. Bluetooth technology, in particular, has made it possible to control robotic arms wirelessly, making them more convenient and portable [15]. For lightweight components of the robotic arm, gripper body, and 3-D printer, hence short carbon fiber reinforced to polyamide materials must be used [16-18]. A flexible hand that reverted to its initial position was made possible by the unions' modification of materials [19]. A 3 DOF robotic arm with a stepper motor that is operated over Wi-Fi and the IoT App with easily accessible and reasonably priced widgets like a joystick and sliders is suggested [20-21]. Five subjects were gathered for this experiment to train and evaluate the suggested control system's dependability and performance. The robot's time and distance traveled are recorded by the system [22].

A Bluetooth-operated robotic arm typically consists of several motors or servos that control its movement. The arm is often attached to a base or a platform that provides stability and support. The Bluetooth module is integrated into the robotic arm, allowing it to communicate with a smartphone, tablet, or computer. Users can control the movement of the robotic arm through a dedicated app or software installed on their device. The app sends signals to the Bluetooth module, which then translates these signals into movements of the robotic arm. Some Bluetooth-operated robotic arms also come with pre-programmed movements that can be activated through the app. Overall, Bluetooth-operated robotic arms offer a fun and engaging way to learn about robotics and automation. They are also useful for performing tasks that require precision and accuracy, such as assembling small parts or picking and placing objects.

2. Literature Review

Several studies have explored the use of Bluetooth-operated robotic arms in various research applications. In the field of agriculture, Bluetooth-operated robotic arms have been used for tasks such as picking fruits and vegetables and pruning plants. For example, Chen et al. (2017) developed a Bluetooth-operated robotic arm for strawberry harvesting, which was able to achieve high accuracy and efficiency compared to manual harvesting. In the healthcare field, Bluetooth-operated robotic arms have been used for rehabilitation and assistive purposes. For instance, Ghasemzadeh et al. (2016) developed a Bluetooth-operated robotic arm for upper limb rehabilitation, which allowed patients to perform repetitive exercises with adjustable resistance levels. In the manufacturing industry, Bluetooth-operated robotic arms have been used for assembly and inspection tasks. For example, Kim et al. (2018) developed a Bluetooth-operated robotic arm for assembling electronic components, which was able to achieve high accuracy and speed compared to manual assembly. Several studies have also investigated the design and control of Bluetooth-operated robotic arms. For example, Jiang et al. (2019) developed a novel control system for a Bluetooth-operated robotic arm, which used a fuzzy neural network algorithm to optimize the control parameters and improve the accuracy of the arm's movements. Overall, the literature suggests that Bluetooth-operated robotic arms have the potential to be useful in a variety of research applications. They offer several advantages, including wireless control, flexibility, and mobility. However, the performance of Bluetooth-operated robotic arms can be limited by factors such as communication latency, signal interference, and power consumption. Therefore, further research is needed to optimize the design and control of Bluetooth-operated robotic arms and to explore their full potential in various research fields.

3. Methodology

3.1 Design Work

The functions of the various work units and development methodologies are described in the design work.

3.1.1 Mode of Operation: All necessary operations are performed by transmitting signals to the microcontroller via a Bluetooth module when the robotic arm receives a command from the remote control. After receiving commands or signals from the microcontroller, the motor influences the robotic arm's movement.

3.1.2 System Description: The robot has 5 DOF and it is made up of different links forming an open chain. The arm has a rotating base of one DOF and a gripper of two DOF at another end. The remaining two degrees of freedom are the shoulder and elbow links of the robot arm.

3.1.3 End Effector: This is the gripper and one servo motor connected for its grip and out-grip action.

3.1.4 Elbow: The joint that links between gripper and shoulder has a servo motor and has 1 degree of freedom.

3.1.5 Base: This is the joint on which the entire load of all other components including payload will have its effect and one servo motor has to be placed so that it will counter-effect that load. The base determines the maximum load the robotic arm can lift.

3.1.6 Servo motors: Required to move the gripper and robotic arm to the desired position

3.2 Design Analysis of Robotic Manipulator: Calculations are necessary to ensure that the torque of the elbow and shoulder motors will be enough to rotate the joints with a load of 200 grams. The torque calculations without considering the weight of the link as shown in Figure 1.

Panamerican Mathematical Journal
ISSN: 1064-9735
Vol 35 No. 1s (2025)

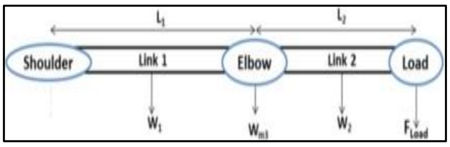

Figure 1. Diagram showing torque calculations without considering the weight of the link.

The maximum torque corresponding to the worst-case scenario with full arm stretched out is shown above. Torque can be found out using moment equilibrium equations.

Wm = Weight of motor at elbow = 0.05 Kg

F = Load of link = 0.2 kg

L_1 and L_2 are the lengths of link 1 and link 2 are 0.14 m and 0.15 m respectively.

In the torque calculations, the material weight is not considered because it is negligible compared to the weight of servo motors.

Moment sustained at Shoulder:

M1= (0.2*29) + (0.05*14) = 6.5 Kg-cm

The servo's actual torque = 13 Kg-cm

Excessive torque = 6.4 Kg-cm

Moment sustained at elbow: M2 = 0.2*15 = 3 Kg-cm

The servo's actual torque = 7 Kg-cm

Excessive torque = 4 Kg-cm

Moment at base = 6.5 Kg-cm

The base servo establishes the maximum load that the robotic manipulator can successfully lift based on the design analysis. The aforesaid study indicates that the excess torque of the base is 6.5 kg.cm. Thus, 6.5 kg is the maximum load that can be estimated. Because the arm's construction material had a low weight and was not considered, the actual load will be lower than the estimated amount. Figure 2 shows the loads and moments on joints on the link's force diagram while taking weight into account.

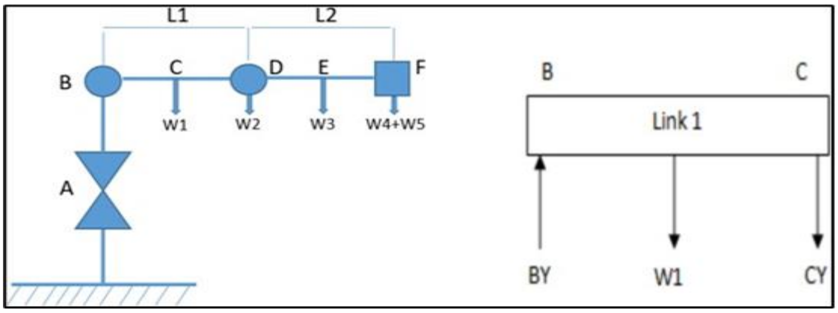

Figure 2. Loads and moments on joints on the link's force diagram

If the weight of links is considered then torque calculations are given below.

Weight of link1, W_1 = 0.019 kg

Weight of motor2, $W_2 = 0.050$ kg

Weight of link2, $W_3 = 0.020$ kg

Weight of gripper, $W_4 = 0.027$ kg

Weight of load, $W_5 = 200$ g

Length of the link, $L_1 = 0.15$ m

Length of the link, $L_2 = 0.14$ m

Calculating the Y-axis force sum,

$\Sigma Fy = 0$ & $\Sigma By = 0$

$\Sigma Fy = (W_2+W_3+W_4+W_5)\ g - CY=0$

$CY = (0.200+0.027+0.020+0.050) * 9.8 = 2.91$ N

$\Sigma Fy = (W_1+W_2+W_3+W_4+W_5+W_6)\ g-BY=0$

$BY = (0.200+0.027+0.020+0.050+0.019) * 9.8 = 3.096$ N

$\Sigma Mc = 0$ and $\Sigma Mb = 0$

$Mc = (W_3*L_2/2)+(W_5+W_4)*L_2$

$Mc = (0.020*0.14/2)+(0.200+0.027)*9.8 = 0.03318$ Nm

$Mb=(W_5+W_4)\ (L_1+L_2) + W_3\ (L_1+L_2/2) + (W_2\ L_1) + W_1\ (L_1/2)$

$Mb = (0.200+0.027)\ (0.15+0.14) + 0.02*\ (0.15+0.14/2)+$

$(0.05*0.15) + 0.019*(0.15/2) = 0.0864$ N

$Mc = 0.0331$ Nm

$Mb = 0.0864$ Nm

3.3 Design of Centre of Mass for Robotic Arm

According to the estimate above, the robotic arm's base will be able to support the maximum load with a high-torque servo motor. A typical 7.2 kg-cm torque servo motor will be used for the robotic arm's base. It takes 15 milliseconds to turn 60 degrees. Since not much torque is required at points B and C, we will utilize a tiny servo with a 1.6 kg-cm power output servo with a speed and 0.12 sec/60 degrees.

Every component of the robotic arm had a motor with a distinct function.

Motor 1 was used for rotating motion.
Motor 2 is used to move the elbow.
Motor 3 is used to move the wrist.
Motor 4 is used for gripping motion.

Size of the robotic arm: Regarding the robot's base, it is necessary to measure the location of the center of mass when the robot is holding the object and confirm that it lies between the two red lines in the picture. Figure 3 shows the robotic arm's center of mass.

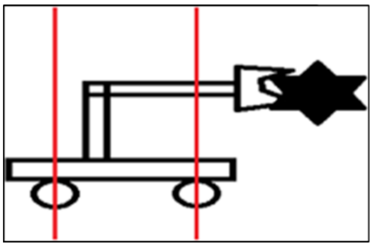

Figure 3. Centre of mass for robotic arm

A robot will flip over if its center of mass crosses these lines. The torque of each motor is expressed in kg-cm units. The motor can raise 1 kg of weight at a distance of 1 cm from the axis of rotation, 0.5 kg at a distance of 2 cm, and so on. This is known as 1 kg-cm. The arm's length increases with motor strength.

3.4 Design of Electrical Circuit

The circuits comprise parts for giving the system electricity, managing the system's electric power, managing the electric motors, and connecting the robotic arm to distant or mobile devices. Based on the Arduino Uno's output, the electrical circuit was made to be both tidy and effective. The Arduino Uno's total outputs are listed below, and they are connected by wrapping wires around the doughnut board. The ground pin is located on the board's left and right sides. 3.33V power supply for module 3. The Bluetooth module's digital output 0 is used to receive signals.

To send a signal to the Bluetooth module, use digital output 1.
Four digital outputs for the Gripper servo.
Elbow servo digital output number five.
Digital output 6 for the servo on the shoulder.
Rotation base servo digital output 7.
Servo and Arduino Uno power supply.

The circuit connection design is shown in Figure 4.

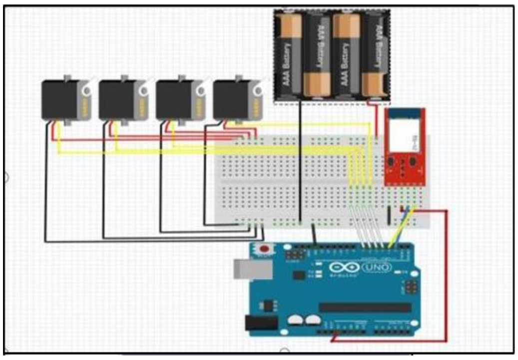

Figure 4. Circuit Connections Design Diagram

4.0 Power Requirement for Motor

Power requirements of the above servo motors, Arduino, and HC05 Bluetooth module are calculated using:

Arduino: Current consumes: 0.08 A, Voltage required: 5v, Power required: 0.08*5= 0.4 W

HC05: Current Required: 0.05 A, Voltage required: 5v, Power required: 0.05 * 5 = 0.25 W

MG996R: Current required under load: 0.5 A, Voltage required:5V, Power required: 0.5 * 5 = 2.5 W

MG996R: Current required in idle condition: 0.006 A, Voltage required: 0.006 * 5 = 0.030 W

SG90: Current required under load: 0.5 A, Voltage required: 5 V, power required: 0.5 *5 = 2.5 W

SG90: Current required in idle condition: 0.006A, Voltage required = 5V, Power required: 0.006*5 = 0.030 W

Total Power required = Arduino + HCO5 + 1 Working servo + 5 idle servos = 0.4 + 0.25 + 2.5 + 0.030 = 3.18 Watts in hour

Power provided by external power source like 9v battery and 1 ampere current: 9 * 1 = 9 Watts

which is too high for this specific application so we have to decrease the voltage to 5 volts as it is the ideal voltage to Run the Arduino, Servo motors, and HC05 Bluetooth module. IC 7805 is used to decrease voltage from 9V to 5V with the same current as input Power = 5 * 1 = 5 watts The power required by all components is 3.18 Watts (minimum power) and a 5V battery provides extra power used in load conditions and different loading conditions. Figure 5 shows the block diagram of a robotic arm control system.

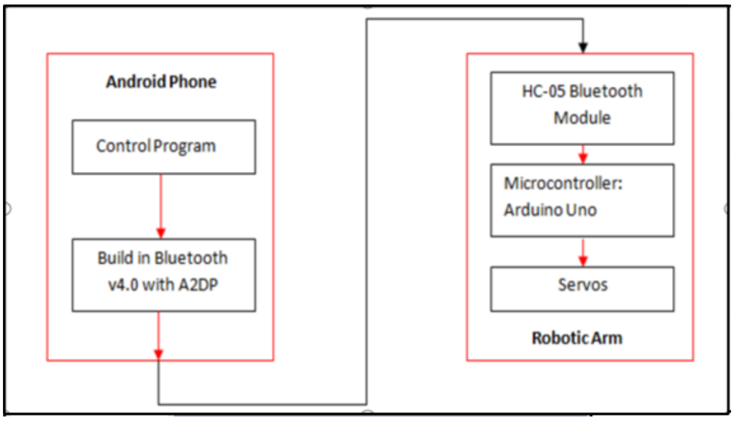

Figure 5. Robotic Arm Control System block diagram

Using Bluetooth devices like smartphones data or instructions like how much to move is sent to the Bluetooth modulefrom Bluetooth API inside the smart device. This Bluetooth module is in connection with a microcontroller like Arduino Uno and it receives data or instruction from the Bluetooth module and is responsible for the control of the servo motor. This instruction from Arduino is then sent to the respective motor for movement. Arduino Uno is programmed initiallyto communicate with Bluetooth module and to control six servo motors. The App design for the Robotic arm Using the MIT App inventor is shown in Figure 6.

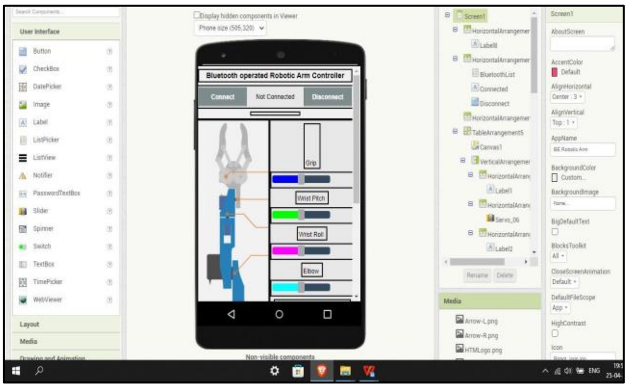

Figure 6. App design for Robotic arm Using MIT App inventor

5. Results & Discussion

5.1 Software Development

To control the Robotic Arm remotely we need to use a Bluetooth module for Bluetooth wireless communication. But to communicate the HC05 module with smart devices like smartphones we need Bluetooth API. Using the MIT app Inverter can develop a personal app which is Bluetooth API and can implement an easy-to-use interface and build user-friendly apps.

5.2 Simulation (CFD):

The goal of the robotic gripper and arm is to statics analysis to observe the maximum stress caused by applied forces at the various parts of the robotic gripper and arm to determine the maximum load-carrying capability. Dynamic analysis is required to determine the dynamic forces created by the robotic gripper and arm and joints rotating. The Solid Works design software is used to design the robotic arm with a gripper. The Robotic arm and assembly of the model are simulated as shown in Figure 7.

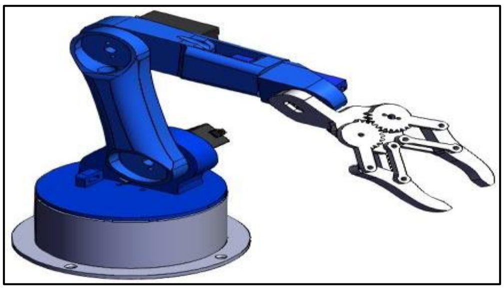

Figure 7. Robotic arm Final Model Simulated

5.3 Robotic Arm Simulation

The various parts of the robotic arm are the Base, Waist, Arm 1, Arm 2, Arm 3, Gripper, and 5 servo motors. The joint between the base and the shaft is concentric and is controlled by a servo motor. Arm 1, Arm 2, and Arm 3 revolute have concentric joints with servo motors. The gripper has one micro servo motor connected to Arm 3. Simulation of the robotic arm is carried out at solid works. The Robotic arm Simulation and Analysis as shown in Figure 8.

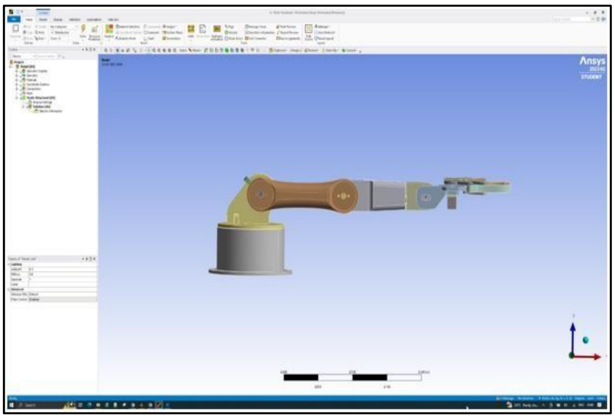

Figure 8. Robotic arm Simulation and Analysis in Solid-works.

5.4 Robotic arm Analysis and simulation

A few presumptions exist about the robotic arm and gripper's analysis and design. The presumptions are listed below.

1. The substance is isotropic and homogeneous.
2. The robotic arm's components are rigid during kinematics and dynamics analysis.
3. The gripper and robotic arm have frictionless joints throughout.

The simulation of the robotic arm was performed in Solid Works and Free CAD. Designing part of individual components was performed in solid works and total assembly was built and simulated in solid works itself. Analysis of the robotic arm was performed on free CAD for maximum load-carrying capacity. The below figure shows the maximum load-carrying capacity of a robotic arm when it is stretched. The Robotic arm Analysis and simulation for maximum payload as shown in Figure 9.

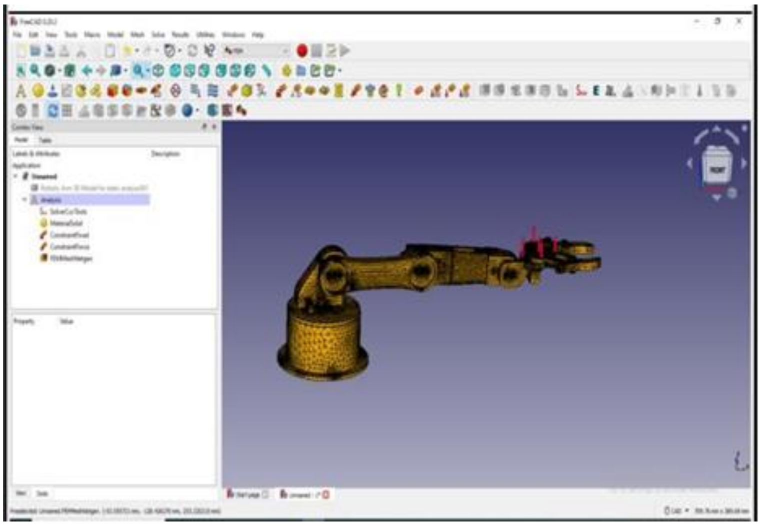

Figure 9. Robotic arm Analysis and simulation for maximum payload

Analysis for robotic arm standing in initial reference position as shown in Figure 10.

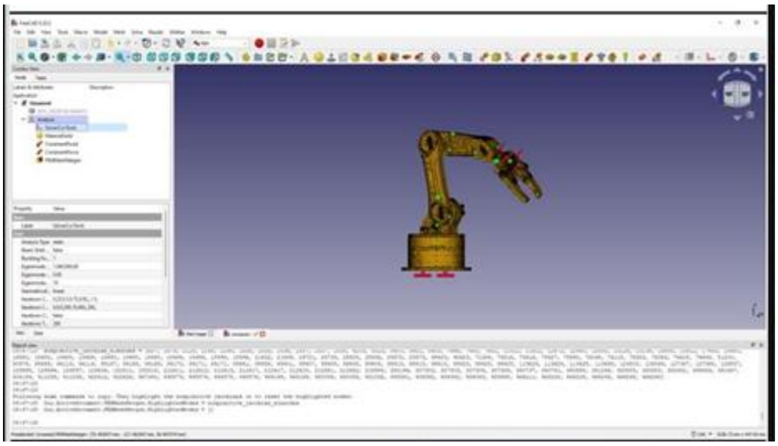

Figure 10. Analysis of the robotic arm standing in the initial reference position is carried out

It is determined that there is a one-way connection between the Android application and the robotic arm. The robotic arm is extremely easy and effective for even inexperienced users to operate. The purpose of this paper is to use a microcontroller and Bluetooth module with an Android application to pick and place dangerous objects and control a 5 DOF robotic arm. It is anticipated that this robotic arm control mechanism address issues like choosing or placing objects distant from the user. The Bluetooth-operated robotic arm is implemented to increase efficiency while reducing human efforts.

6. Conclusion

The main objective is to design and build the hardware and software for a Bluetooth-controlled robotic arm so that the physical connection between the controller and the robotic arm is eliminated. Another purpose was to integrate a Bluetooth module in the system with an easy-to-use interface that can be built according to user demands.

Another objective was to Implement power consumption technology like Bluetooth making the system more energy efficient and to understand the working of the robot and its application to pick and place hazardous objects and chemicals. In this paper power consumption and power required calculations are carried out to ensure efficient use of power and energy. Torque calculations are carried out to select the appropriate servos required and to reduce the overall weight of the robot. Simulations were carried out to watch for force and stress distributions in the whole robotic arm when it is in a fully stretched position and when it is in reference conditions. Center of mass calculations were carried out to balance the overall robot.

References

[1] Anandh B. A, Shankar Ganesh. A, "Implementation of Robotic ARM for Object Pick and Place via Bluetooth", Volume - 9, (2021).

[2] Manjunatha.S.C, Raghu. S, "Bluetooth Control Pick and Place Robot using Arduino", Volume - 10, (2022).

[3] Sai Krishna Aitha, Y. Deepthi Reddy, P. Mani Kumar, "Robotic arm to pick and place", International Journal of Advance Research, Ideas, and Innovations in Technology, Volume - 7, (2012).

[4] Dr. K.V. Manjunath, Kushal Pandith M L, "Optimization of Robotic arm Movement Vehicle for Pick-And Place", Volume - 9, (2021).

[5] Zol Bahri Razali, Mohd Hisham Daud, "Design and Analysis on Robotic Arm for Serving Hazard Container", 3rd Electronic and Green Materials International Conference, AIP Conference proceeding, Vol-3, (2017).

[6] Rakesh B. Thakare, Pagare Yuvraj Ramdas, Dutta Sparsh Mirnmoy, Sonawane Rushabh Bharat, Chitte Rohit Pandit, “Design of Automated Robotic Arm Mechanism using Arduino”, IJARIIE, Vol.7, (2021).

[7] Adeline Neo Wei QI, Meera Ismail, “Design and Development of a Mechanism of Robotic Arm for Lifting Part 1”, Faculty of Mechanical Engineering, (2015).

[8] Muhammad Farhan Mustaffa, Ruhizan Liza Ahmad Shauri, “Development of a 4 - DOF Robotic Arm: Prototype design”, International Journal of Engineering and Technology, Vol.7, (2018).

[9] Jignesh Patoliya, Haard Mehta, Hitesh Patel, “Arduino Controlled War Field Spy Robot using Night Vision Wireless Camera and Android Application”, Nirma University International Conference on Engineering, (2015).

[10] Paolo Creas Carando1, Suzette Antoniette Dela Cruz, “Wireless Controlled Robotic Arm for Handling Hazardous Chemicals”

[11] Durgesh Nandini Pandey, Priyanka Tiwari, Jvala Rai, Isma Imtiyaz, Mr. Permendra Verma, “Bluetooth Control Pick and Place Robotic Vehicle”, International Research Journal of Modernization in Engineering Technology and Science, Vol 3, (2021).

[12] K. Meenendranath Reddy, S Maddilety, S Reshma, “Design and Implementation of Robotic Arm for Pick and Place by using Bluetooth Technology”, Journal of Energy Engineering and Thermodynamics, Vol. 3, (2023).

[13] Umar M. Pirjade, Sahil R. Tonde, Zia-Ur-Rehman Junnedi, Shekhar S. Wankhede, Prashant A. Kamble, Amita N. Dubey, “Pick and Place Robotic Arm utilizing Microcontroller and Wireless Communication”, International Research Journal of Engineering and Technology, vo. 10, (2023).

[14] Cheepurupalli Krishna Chaitanya, Pillla Likhitha Sri, Ellapu Bhanu Prakash, “Pick and Place Robotic Arms Movement Controlled by Android Wirelessly”, IJRASET, Vo. 4, (2023).

[15] Swati Vaid Dogra, “Design and development of Bluetooth Controlled pick and place robotic vehicle”, IPEC Journal of Science & Technology, Vol. 02, (2023).

[16] Dilip S. Choudhari, Vyasraj J. Kakhandki, Prateek D. Malwe, Hitesh Panchal, Dinesh Mevada, Mustafa Musa Jaber & Ankit D. Oza, “Investigation and performance analysis of short carbon fiber reinforced polyamide 66 of spur gears”, International Journal on Interactive Design and Manufacturing (IJIDeM), Springer, (2023).

[17] Dilip S. Choudhari, Vyasraj J. Kakhandki, “Comprehensive study and analysis of mechanical properties of chopped carbon fiber reinforced nylon 66 composite materials” Journal of Material Today, Proceeding. 44(Part 6), 4596–4601(2021).

[18] Dilip S. Choudhari, Vyasraj J. Kakhandki, “Characterization and Analysis of Mechanical Properties of Short Carbon Fiber Reinforced Polyamide66 Composites”, EVERGREEN- Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol.8, issue 4, (768-776), (2021).

[19] Jose Villena Torresa , Fredys Simanca Herreraa, Fabian Blanco Garridoa, Pablo Carreno Hernandez, Miguel Hernandez Bejaranob , Harold Neira Molinac, Jorge Luis Diaz Martínez, “Construction of a robotic arm to improve the communication of people with auditive or non-verbal disabilities”, Procedia Computer Science, Elsevier, Vol. 177, 292-299 (2020).

[20] H. Kareemullah, D. Najumnissa, M.S. Murshitha Shajahan, M. Abhineshjayram, Varshan Mohan, S. Ayisha Sheerin, “ Robotic Arm controlled using IoT application”, Computers and Electrical Engineering Journal Elsevier, Vol. 105, 108539 (2023).
https://doi.org/10.1016/j.compeleceng.2022.108539

[21] Juan Botero-Valencia, David Marquez-Viloria, Luis Castano-Londono, Luis Morantes-Guzman, “A low-cost platform based on a robotic arm for parameters estimation of Inertial Measurement Units”, Measurement journal, Elsevier, Vol. 110, 257-262, (2017).

[22] Yang An, Johnny Wong, Sai Ho Ling, “Development of real-time brain-computer interface control system for robot”, Applied Soft Computing Journal, Elsevier, Vol. 159, 111648 (2024).