BIPEDAL ROBOT

Submitted in partial fulfillment of the requirements of the degree of

BACHELOR OF MECHATRONICS ENGINEERING by

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(2022-2023)

NEW HORIZON INSTITUTE OF TECHNOLOGY AND MANAGEMENT, THANE

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This is to certify that the project entitled “Bipedal Robot” is a bonafied work of **Mihir Udeshi (11915028), Harshal Rai (11925022), Ashish Wadkar (11915025), Gavardhan Lagishetty (11915004)** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **Bachelor of Engineering in Mechatronics Engineering.**

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Project Report Approval for B.E.

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Declaration

We declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

A biped is a multi-jointed machine that can move like a person. Because of the intricacy of the mathematical description, it appears more challenging to analyze the behavioral characteristics of a walking robot. The goal of this project is to create a method for calculating a biped robot's inverse kinematic joint solution. This project attempted to construct a biped robot's lower half, the movement section. It combines design considerations with design simplicity to produce an inverse kinematics study of a biped robot with 11 degrees of freedom (DOF). Five links make up the model, which is joined together by revolute joints. The hip, knee, and ankle joints are present in both legs identically. To solve a univariate polynomial, a symbolic formulation for problem reduction is discussed in this study.

To solve an analytical inverse kinematics problem for a specific end-effector position, a successful methodology is created. This approach offers a quick and easy process for determining the joint solution for bipeds.

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CHAPTER 1: INTRODUCTION

Nowadays, there are a growing number of ways that machines and robots may help people execute their jobs. Robotics systems are now used in industrial settings to a degree that their speed and precision are superior to those of humans. The progress, on the other hand, is still far from flawless in the area of household or service robots. The primary distinction between industrial and service robots is the working environment. A service robot must be able to adapt to and deal with the typical human living environment in order to effectively do its tasks. Bipedal robots are the most feasible robot structure from a practical standpoint because they resemble humans physically, especially in terms of mobility. However, due to the unstable nature of bipedal walking, the realization of a bipedal robot is more difficult than that of other types of mobile robots. As a result, numerous studies have been conducted, particularly with regards to the stability sensing and control techniques used by bipedal robots.

Although numerous traditional model-based control strategies, including trajectory tracking control, robust control, and model predictive control, have been suggested for the control of bipedal robots, these control laws are often pre-computed and rigid. In terms of stability, adaptability, and robustness, the resulting bipedal robots are typically unsatisfactory. Bipedal robots have five special qualities that make creating control systems difficult and constrained:

CHAPTER 2: LITERATURE SURVEY

The kinematics of manipulators under computer control

Remote manipulation involves having a machine perform tasks requiring human dexterity. Originally, the purpose of a manipulator was to protect man from the hazards of performing the work himself. With the advance of technology, the variety of tasks performed in hostile environments has increased. In addition the scope of the tasks performed by machines has broadened, so that it is desirable for machines to extend the capabilities of men and to replace men at tedious as well as dangerous Jobs. Although, today, many processes and machines are automatically controlled, the problems of remote manipulation have yet to be fully solved. One approach to this problem is to use a digital computer to control a manipulator. Then with information obtained from visual as well as other sensory feedback, the computer would hopefully be able to direct the manipulator to perform tasks requiring some intelligence as well as dexterity.

Machine Learning Algorithms in Bipedal Robot Control

Over the past decades, machine learning techniques, such as supervised learning, reinforcement learning, and unsupervised learning, have been increasingly used in the control engineering community. Various learning algorithms have been developed to achieve autonomous operation and intelligent decision making for many complex and challenging control problems. One of such problems is bipedal walking robot control. Although still in their early stages, learning techniques have demonstrated promising potential to build adaptive control systems for bipedal robots. This paper gives a review of recent advances on the state-of-the-art learning algorithms and their applications to bipedal robot control. The effects and limitations of different learning techniques are discussed through a representative selection of examples from the literature. Guidelines for future research on learning control of bipedal robots are provided in the end.

Simulation and Control of Biped Walking Robots

During the past three decades research and development in robotics has expanded from traditional industrial robot manipulators to include autonomous and animal-like or humanoid robots. Over the past two decades, the field of humanoid robotics has witnessed significant advances. This development has been driven by improvements in actuator, computer and other enabling technologies and guided by the vision of building machines with (some) human-like capabilities.

CHAPTER 3:PROBLEM STATEMENT

3.1 Problem Statements :

This thesis concerns the modeling, simulation and real-time control of a specific kind of biped walking robot. Biped walking is a process of alternatingly supporting the body's weight with one leg while moving the other leg to a new foothold. During this activity, forces generated by gravity and accelerated limbs must be balanced by contact forces acting on the supporting foot or feet. Feasible contact forces are limited due to the unilateral foot-ground contact. This strongly limits the range of physically feasible motions and complicates the process of maintaining balance. In walking pattern generation and stabilizing control, feasibility conditions take the form of inequality constraints. Violating these constraints is physically impossible. However, if the boundary of the feasible region is reached, the contact state will change, i.e., the robot will start tipping over. While controlling individual joints is straightforward, this is not equivalent to maintaining balance, since the compliant foot-ground contact makes the robot underactuated, i.e., the system has more degrees of freedom (DoFs) than inputs.

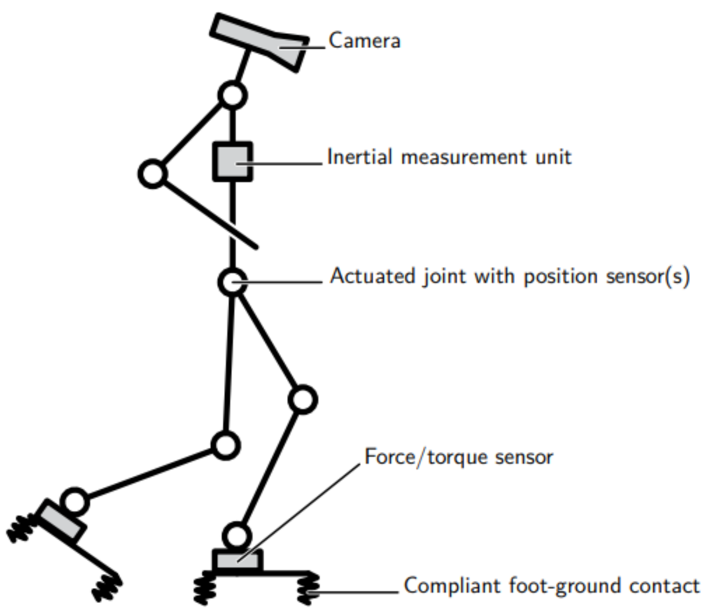


Fig. 3.1 Basic structure of biped robots

Real-time control is especially challenging, since the complex dynamics of the robot must be approximated to reduce the computational cost and enable real-time execution of planning and control algorithms. At the same time, relevant physical effects must be taken into account in order to achieve fast and robust walking.

To enable autonomous locomotion, the robot must identify viable footstep locations. In cluttered environments this means identifying a collision-free path from the current to the target position. This can be achieved by combining the robot's walking control with a computer vision system capable of recognizing obstacles and choosing a viable path. This thesis does not concern aspects of computer vision and path planning. However, to enable autonomous locomotion, the real-time control system must supply information about the robot's state to the vision system and must be able to execute continuously changing commands coming from the path planning module. Systematic design of walking control algorithms is greatly simplified by dynamics simulations, since they allow a detailed analysis of dynamics, stability issues, the influence of sensor noise, etc. Dynamics simulations also are the basis for calculating loads that are required for hardware design. Especially during the early stages of hardware design a large number of different kinematic configurations, motors, gears and other parameters must be evaluated. Therefore, a library of robot models of varying complexity is an essential tool for analysis, hardware design and model-based real-time control.

OBJECTIVES

3.2 <u>OBJECTIVE</u> :

There are several good reasons for developing bipedal walking robots, despite the fact that it is technically more difficult to implement algorithms for reliable locomotion in such robots than in e.g. Wheeled robots. First, bipedal robots are able to move in areas that are normally inaccessible to wheeled robots, such as stairs and areas littered with obstacles that make wheeled locomotion impossible. Second, Walking robots causeless damage on the ground than wheeled robots. Third, it may be easier for people to interact with walking robots with a humanoid shape rather than robots with a nonhuman shape. It is also easier for a (full scale) humanoid robot to function in areas designed for people (e.g. houses, factories), since its humanlike shape would allow it to reach shelves etc.

SCOPE

3.3 <u>SCOPE</u> :

The scope of a humanoid robot can vary depending on the specific goals and objectives of the project. However, in general, the scope of a humanoid robot includes the following aspects:

- Design and Construction: The humanoid robot will be designed and constructed to have a human-like appearance with a flexible and dexterous body, and the ability to move and manipulate objects in a manner similar to humans.

- Locomotion and Navigation: The humanoid robot will have the capability to move autonomously or under human control, with various modes of locomotion such as walking, running, crawling, or climbing stairs. It will be equipped with sensors and algorithms for perception and navigation to avoid obstacles and navigate in complex environments.
- Human Interaction: The humanoid robot will be designed to interact with humans in a natural and intuitive way. This may include speech recognition, facial recognition, and emotion detection to understand and respond to human commands, gestures, and expressions.
- Manipulation and Object Recognition: The humanoid robot will have the capability to manipulate objects with its hands and fingers, and perform tasks that require dexterity and precision, such as grasping, picking, placing, and manipulating tools. It will also be equipped with sensors and algorithms for object recognition and hand-eye coordination.
- Autonomy and Learning: The humanoid robot will be designed to operate autonomously with decision-making capabilities, and the ability to adapt to changing environments. It may also incorporate machine learning algorithms to improve its performance over time and learn from its interactions with the environment.
- Applications: The humanoid robot may have a wide range of applications, including but not limited to household chores, healthcare settings, personal assistance, industrial tasks, and research and development in robotics, AI, and human-robot interaction.
- Safety and Ethics: The scope of a humanoid robot project should also include considerations for safety, including risk assessment, safety features, and ethical considerations such as privacy, security, and human safety during interactions with the robot.
- Project Timeline and Deliverables: The development of a humanoid robot project will typically be carried out in multiple phases, with specific milestones and deliverables defined in a project timeline. This may include prototype development, testing, and refinement stages.
- Resources and Constraints: The scope of a humanoid robot project

should take into account the available resources, including budget, expertise, and technology constraints, to ensure a realistic and achievable scope.

In conclusion, the scope of a humanoid robot project encompasses various aspects such as design, construction, locomotion, human interaction, manipulation, autonomy, safety, applications, timeline, and resources. The specific scope will depend on the goals and objectives of the project, and should be clearly defined and communicated to ensure successful project execution.

CHAPTER 4: MATERIAL & METHODOLOGY

Materials and methodology are critical aspects of designing and building a bipedal robot. Here is a general outline of the material and methodology for creating a bipedal robot:

- Material Selection: Choosing the suitable materials for the robot's body, limbs, and other components is crucial for its stability, durability, and functionality. Materials such as lightweight metals (e.g., aluminum, titanium), composites (e.g., carbon fiber, fiberglass), and plastics (e.g., ABS, polycarbonate) are commonly used for building robot structures. The selection of materials may depend on factors such as weight requirements, strength, and cost.
- Mechanical Design: The mechanical design of the bipedal robot involves creating the structural framework, joints, and linkages that allow the robot to walk and perform other desired movements. CAD (Computer-Aided Design) software is typically used to create 3D models of the robot's components, which can then be manufactured using CNC machining, 3D printing, or other fabrication methods.
- Actuators and Sensors: Bipedal robots require actuators (motors) to provide motion to the limbs and joints, and sensors to gather feedback on the robot's position, orientation, and other environmental variables. The selection and integration of appropriate actuators and sensors depending on the desired functionalities and performance requirements of the robot.
- Control System: Developing a control system is a crucial part of creating a bipedal robot. It involves designing algorithms, software, and hardware to process sensor data, generate control signals for the actuators, and manage the robot's movements. This may include implementing control strategies such as PID (Proportional-Integral-Derivative) control, inverse kinematics, and gait generation algorithms.
- Assembly and Integration: Once all the individual components are fabricated, the robot must be assembled and integrated into a

functional system. This involves connecting the actuators, sensors, and control system, and calibrating them to work together seamlessly.

- Testing and Iteration: After the robot is assembled, it needs to be thoroughly tested in various conditions and environments to evaluate its performance, identify any issues, and make necessary adjustments. Iterative testing and refinement may be required to optimize the robot's performance and stability.
- Safety Considerations: Bipedal robots can be complex and potentially hazardous machines. Ensuring the safety of the robot during its operation and interactions with humans is paramount. Incorporating safety features such as emergency stop buttons, collision detection, and compliance mechanisms can be crucial to mitigating risks.

MG995 Servo Motors

MG995 is a type of servo motor commonly used in hobbyist and robotics applications. It is a high-torque servo motor, which means it can exert a large amount of force relative to its size. The MG995 servo motor is rated for a maximum torque of 10 kg-cm, which makes it suitable for applications that require precise control of motion, such as robotic arms, vehicles, and drones. The servo motor is also known for its reliability, accuracy, and affordability, which makes it a popular choice among hobbyists and professionals alike

Ardunio Uno

Arduino Uno is a popular microcontroller board designed for hobbyists, artists, and professionals to create interactive and electronic projects. It is based on the Atmel AVR microcontroller and comes with various digital and analog input/output pins that can be used to connect to sensors, actuators, displays, and other electronic components.

Arduino Uno board features a USB interface, a power jack, a reset button, and a 16 MHz quartz crystal oscillator, which provide the board with the ability to communicate with the computer, run programs, and control external devices. It can be programmed using the Arduino Integrated Development Environment (IDE), which is an easy-to-use software platform that allows users to write, upload, and debug their code.

The Uno board is open-source, which means that the hardware and software designs are freely available, and users can modify and improve them to suit their needs. It is widely used in various fields, including robotics, home automation, wearable technology, and Internet of Things (IoT) applications.

Ardunio uno motor shield

The Arduino Uno Motor Shield is an expansion board designed for use with the Arduino Uno board. It allows you to easily control up to two DC motors, or a single stepper motor, with the Arduino Uno.

The shield has two H-bridge circuits, which allow you to control the speed and direction of two DC motors independently. The H-bridge circuits also allow you to brake the motors and provide current sensing feedback.

In addition to the DC motor control, the shield also has a connection for a stepper motor, which can be controlled with the Arduino's built-in stepper library. The shield also has a range of other features, including a 5V regulator to power the Arduino Uno board, and several additional inputs and outputs.

Overall, the Arduino Uno Motor Shield is a great way to add motor control to your Arduino projects, and is a popular choice for robotics and automation applications.

In conclusion, creating a bipedal robot requires careful consideration of materials, mechanical design, actuators and sensors, control systems, assembly, testing, and safety measures. An interdisciplinary approach involving expertise in mechanical engineering, robotics, control systems, and materials science is often necessary to successfully build a functional and safe bipedal robot.

CHAPTER 5:EXPERIMENTATION

Experimentation is a crucial part of developing a bipedal robot, as it helps to evaluate its performance, optimize its functionality, and refine its design. Here are some key areas of experimentation that may be conducted in the development of a bipedal robot:

Gait and Locomotion: Bipedal robots require a coordinated and stable gait to walk and move efficiently. Experimentation may involve testing different gait patterns, step lengths, step heights, and walking speeds to optimize the robot's locomotion performance. This may include studying the robot's stability, energy efficiency, and walking speed under various conditions such as different terrains, slopes, and obstacles.

Balance and Stability: Maintaining balance and stability is critical for a bipedal robot to prevent falls and ensure safe operation. Experimentation may involve testing the robot's ability to maintain balance during dynamic movements, recover from disturbances, and perform tasks that require shifting its center of mass. This may include studying the robot's stability margins, joint torques, and feedback control algorithms for balance.

Sensing and Perception: Bipedal robots often rely on sensors to gather information about their environment, position, and orientation. Experimentation may involve testing the accuracy, reliability, and response time of the sensors, such as accelerometers, gyroscopes, force sensors, and vision systems. This may also include exploring sensor fusion techniques to combine data from multiple sensors for more robust perception.

Actuation and Control: The actuators and control system of a bipedal robot play a critical role in its performance. Experimentation may involve testing the performance of the actuators, such as motors or servos, in terms of their torque, speed, and power consumption. It may also involve experimenting with different control strategies, such as PID control, feedback control, or reinforcement learning algorithms, to optimize the robot's movements and responses.

Human-Robot Interaction: If the bipedal robot is intended to interact with humans, experimentation may involve studying how humans perceive and interact with the robot. This may include conducting user studies to assess the robot's usability, acceptability, and safety in human-robot interactions, and incorporating feedback to improve the robot's design and behavior.

Environmental Adaptation: Bipedal robots may need to operate in various environments, such as indoor and outdoor settings, different terrains, and weather conditions. Experimentation may involve testing the robot's performance and adaptability in different environmental conditions to assess its robustness, reliability, and safety.

Durability and Reliability: Experimentation may also involve long-term testing to evaluate the durability and reliability of the robot's components, including its mechanical structure, actuators, sensors, and control system. This may include conducting stress tests, fatigue tests, and reliability analyses to identify potential weaknesses and improve the robot's overall performance and lifespan.

Safety and Risk Assessment: Experimentation may involve conducting risk assessments and safety tests to identify and mitigate potential hazards associated with the operation of a bipedal robot. This may include testing emergency stop mechanisms, evaluating collision detection and avoidance strategies, and assessing the robot's compliance with safety standards and regulations.

In summary, experimentation in the development of a bipedal robot encompasses various areas, including gait and locomotion, balance and stability, sensing and perception, actuation and control, human-robot interaction, environmental adaptation, durability and reliability, and safety and risk assessment. Experimentation is crucial for optimizing the robot's performance, ensuring its safety, and refining its design for real-world applications.

CHAPTER 6:EXPERIMENTAL SETUP

The experimental setup for a bipedal robot will depend on the specific research or development goals of the project. However, here are some common components that may be included in an experimental setup for a bipedal robot:

Bipedal Robot Platform: The bipedal robot itself will be the primary component of the experimental setup. It may consist of a mechanical structure, actuators (such as motors or servos), sensors (such as accelerometers, gyroscopes, force sensors, or vision systems), and a control system. The robot platform should be designed and built to meet the specific requirements of the experimentation, such as the desired gait patterns, stability requirements, sensing capabilities, and control strategies.

Motion Capture System: A motion capture system may be used to accurately track the movements of the bipedal robot during experimentation. This system typically involves placing markers on the robot's body and using cameras to capture the positions and orientations of these markers in real-time. The motion capture data can be used for analyzing the robot's kinematics, dynamics, and gait patterns.

Force Plates or Force Sensors: Force plates or force sensors may be used to measure the ground reaction forces and moments experienced by the bipedal robot during walking or other tasks. These measurements can provide important information about the robot's balance, stability, and interaction with the environment.

Environmental Setup: Depending on the experimental goals, the bipedal robot may need to operate in a specific environment or terrain. This may require setting up a controlled environment, such as an indoor laboratory with a flat surface or an outdoor environment with different terrains, slopes, or obstacles. The environmental setup should be carefully designed to replicate the real-world conditions relevant to the experiment.

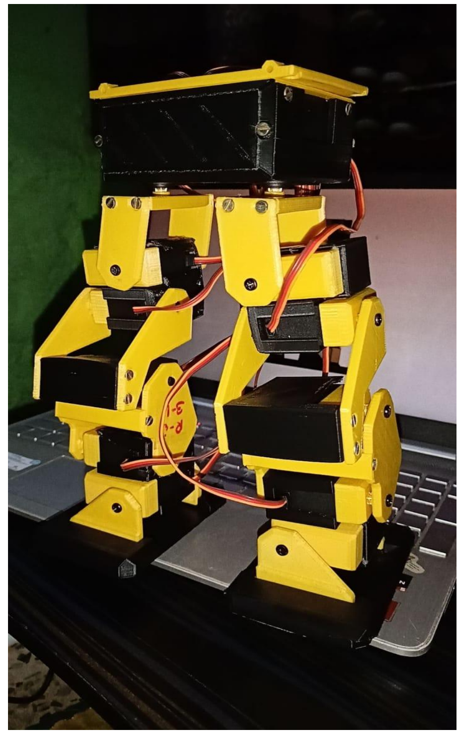
Data Acquisition System: A data acquisition system may be used to collect and record data from the robot's sensors, actuators, and other relevant parameters during experimentation. This may include data such as joint angles, joint torques, sensor readings, and control commands. The data acquisition system should be synchronized with the experimental setup to ensure accurate data collection and analysis.

Computational Resources: Computational resources, such as computers, software, and algorithms, may be required for processing and analyzing the data collected during experimentation. This may involve tasks such as data processing, motion analysis, control algorithm implementation, and simulation.

Safety Measures: Safety measures should be implemented in the experimental setup to ensure the well-being of researchers, operators, and the robot itself. This may include emergency stop buttons, protective barriers, safety guidelines, and appropriate training for personnel involved in the experimentation.

Experimental Protocol: An experimental protocol should be designed and followed to ensure consistency and reproducibility of the experiments. This may include defining the experimental conditions, specifying the tasks or tests to be performed by the bipedal robot, and detailing the data collection procedures. A well-designed experimental protocol is crucial for obtaining reliable and meaningful results.

In summary, the experimental setup for a bipedal robot may include the robot platform, motion capture system, force plates or force sensors, environmental setup, data acquisition system, computational resources, safety measures, and an experimental protocol. The specific components and setup will depend on the research or development goals of the project and should be carefully planned and implemented to conduct accurate and reliable experiments.



INVERSE KINEMATICS 3DOF ROBOTIC ARM

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*Abstract:-***This paper explores the application of inverse kinematics to control a 3-degree-of-freedom (DOF) robotic hand using an open-source robotic hand model. This study's analytical approach entails calculating the joint angles necessary to get the desired end-effector position. The workspace of the robot hand and its control settings are described. It should be emphasized that only three parameters, namely the positions of the end-effectors, may be controlled due to the robot hand's limited DOF (x, y, z). The benefit of rotatory actuators over linear actuators for robotic hands is also addressed in the piece. Lastly, the method's limitations are examined, including the fact that it only applies to this specific robot system. The concept presented in this paper, which may be used to control a 3DOF robotic hand using inverse kinematics, has potential applications in a number of areas, including industrial automation, prosthetics, and robotics research.**

INTRODUCTION

Robotic systems that behave dynamically like human hands are known as robotic arms. This feature of robotic arms has made them helpful in a variety of applications, such as industrial manufacturing, assembly, surgery, or anything that a human hand can accomplish, but with more precision and a wider range of force and strength.

The popularity of robotic dogs, humanoids, and other "such bio-robots" (robots inspired by biology) is also rising.

These robots will become increasingly significant as the robotics sector develops in various fields and applications. It's important to note that rotary actuators, rather than linear actuators, are typically used in the mechanics of robotic systems.

In comparison to rotary actuators, linear actuators move slowly and provide less power. A robotic system that uses linear actuators for movement may be limited in terms of speed and overall effectiveness as a result. Due to their increased size and weight as well as the additional components needed to transform their linear motion into rotating movement, linear actuators can prove particularly challenging to integrate into a robotic system. As a result, they might be less useful in some situations where weight and space restrictions are an issue.

Rotatory actuators, on the other hand, allow movement and functionality in robotic systems to be more adaptable by having the ability to rotate and pivot in multiple directions. Moreover, rotatory actuators are more compact and lighter than linear actuators, making them simpler to integrate into robotic systems and lowering the system's overall weight.

Therefore, it becomes challenging to analyze the kinematics of a robotic system containing rotatory actuators. An extremely counterintuitive shift in the system's position and speed can result from changing the angles between any two links.

We also go through the 3DOF robotic hand's management of this intricacy.

Figure 1 Robotic Arm

ROBOTIC ARM CONSTRUCTION

A 6DOF open-source robotic hand was utilized, but the gripper was taken out, leaving the remaining system with only 3DOF. Three revolving joints make up the robotic hand. A position-controlled MG995 servo motor is used to actuate the three revolute joints (180 degrees). The robot's foundation and all of its linkages are 3D printed. An Arduino Uno is used to control the robotic hand.

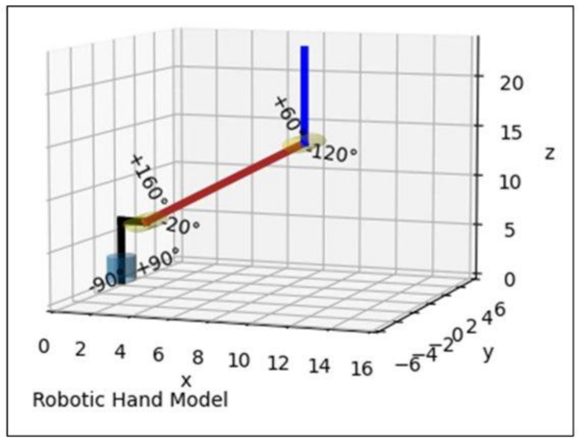

Figure 2 shows graphical model or the Robotic Arm

An end effector is frequently moved in robotics to accomplish a particular position (x, y, z) and orientation (a, b, g) in 3D space. But nonetheless, a robotic hand normally needs at least 6 degrees of freedom to provide this level of control. In the case of a 3DOF robotic hand, control is restricted to just three end effector parameters, namely the locations of (x, y, z).

DH PARAMETER

Link_1_length = 113.2, Joint 2 offset = 13.6, Link_2_length = 120, Link_3_length = 89.5

Joint	a(mm)	α(degree)	d(mm)	θ(degree)	Range(degree) ϕ
1	13.6	90	0	0	-90 to 90
2	120	0	0	0	-20 to 160
3	89.5	-90	0	0	-120 to 60

Table 1 DH parameter of the Robotic Arm

ISSN NO:1934-7197

a -- Distance between z axis of joint$_i$ and joint$_{i+1}$.
α -- Angle between z_i and z_{i+1} about x_i.
d -- Distance between x axis of joint$_i$ and joint$_{i+1}$.
θ -- Angle between x_i and x_{i+1} about z_i.
Range – Min-Max angle to its previous joint.

WORKSPACE OF ROBOTIC ARM

The workspace of a robotic hand cannot be determined in a general way. The workspace will vary depending on the range/type of joints and the length of each link.

For the given robotic arm keeping the joint 1 at 0 degree and iterating joint 2 and joint 3 for different angles of theta, we can obtain a 2D work space of that plane. Figure 3 represents that plane.

We may acquire a 3D workspace of the robotic arm if we rotate this section along the joint 1's range angle, which is between -90 and 90 degrees. Figures 4 and 5 represent the 3D workspace. The robotic arm's workplace is located between the red curved wall and the green wire frame.

The technique discussed in this study is exclusive to the selected robot system, it should be emphasized. A specific posture can be achieved by the robot hand in a maximum of two states thanks to its three joints, each of which can rotate up to 180 degrees. The 2D vertical segment of the robot's workspace in Figure 3 shows that the dot density is greater on the area close to the outer edge. This is due to the fact that the robotic hand can reach those positions in two different states. This indicates that there are two distinct sets of joint angles that can be used to achieve those positions in dense area. The regions where two states are obtained are determined by the range of the revolute joint. At bigger ranges, the region where two states can be obtained expands, whereas for smaller ranges, it contracts. Since there is only one revolute joint along the z-axis, this behavior will remain same for every section for any angle of z axis.

The robotic hand's workplace is located between the red surface and the green wireframe in the 3D plot.

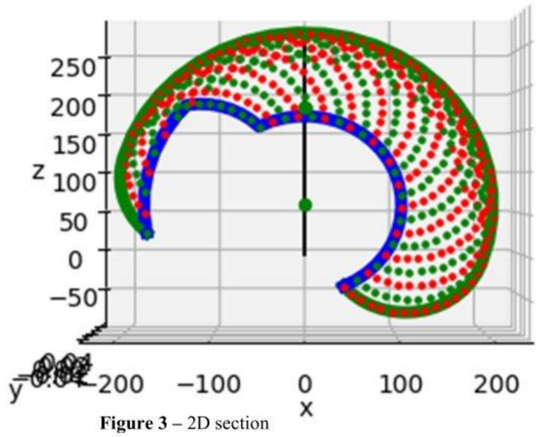

Figure 3 – 2D section

2D section of workspace

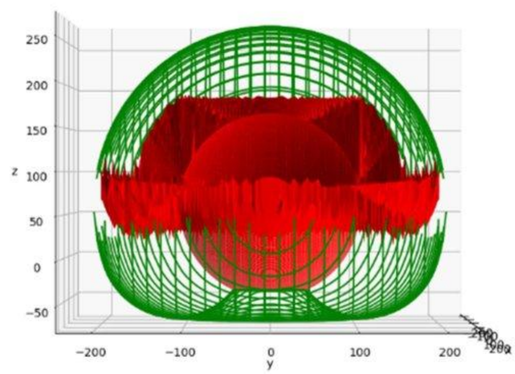

Figure 4 – 3D front view

3D section of workspace(Front_view)

The graph just serves to provide an understanding of the 3D workspace; it does not accurately depict the workspace. Also, the surface's gap can be reached and is necessary for correct interpolation when graphing the surface. Figure 5 with a different view and Figure 6 with a different plot style are provided below for a better understanding of the workspace.

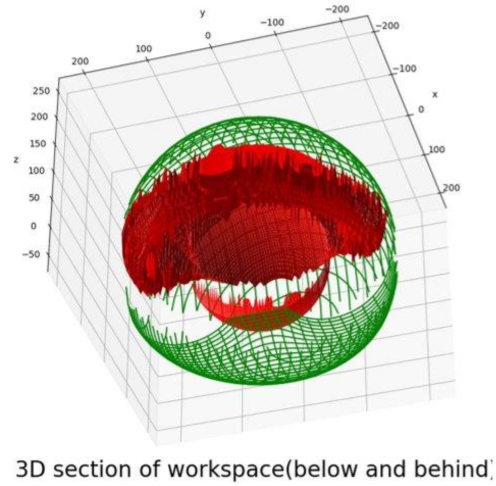

Figure 5 – Orientation changed

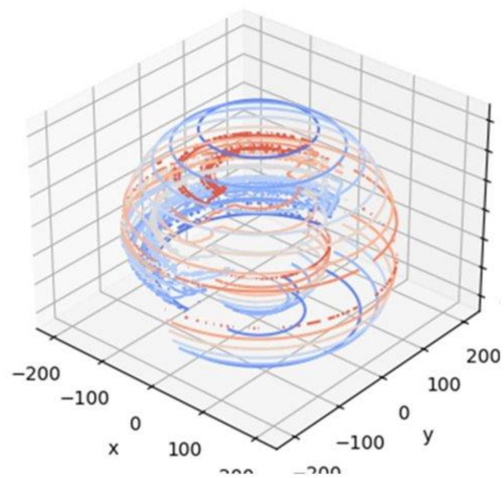

Figure 6 – Plot Method Changed

INVERSE KINEMATICS

The most crucial component of any robotic system is this. Here, the system is provided the specific position where the end effector must be put, and the robotic hand uses inverse kinematics to calculate the revolute joint angles of the robot.

With the analytical approach to inverse kinematics, the joint angles necessary to reach a specified end-effector position are explicitly calculated using mathematical formulas. This approach is relatively quick and easy to use, and it doesn't involve any mathematical optimization methods.

The Newton approach for inverse kinematics, on the other hand, requires iteratively resolving an equation system using numerical optimization techniques. Although this approach is more difficult and computationally demanding, it can be used to systems with complex or non-linear kinematics.

Generally, the Newton technique is more appropriate for complicated systems with non-linear or complex kinematics whereas the analytical method is simpler and simpler to execute for simple robotic systems.

It should be mentioned that based on the particular application and system requirements, each solution has benefits and drawbacks.

We employ an analytical method to do inverse kinematics for the robotic hand because the model being used is straightforward. Geometry is used to calculate the robot equation. The formulas read as follows.

$$\emptyset 1 = \tan^{-1}\frac{y}{x} \text{ ------(i)}$$

$$\emptyset 3 = \cos^{-1}\left[\frac{\left[\left(\frac{x-(a1\times\cos\emptyset 1)}{\cos\emptyset 1}\right)^2 + (z-L1)^2 - (a2^2 + a3^2)\right]}{2\times a2\times a3}\right] \text{ ------(ii)}$$

$$\emptyset 2 = \tan^{-1}\left[\frac{(z-L1)\times\cos\emptyset 1}{x-(a1\times\cos\emptyset 1)}\right] - \tan^{-1}\left[\frac{a3\times\sin\emptyset 3}{a2+(a3\times\cos\emptyset 3)}\right] \text{ -----(iii)}$$

Because each equation depends on the results of the one before it, the aforementioned equations must be solved in the sequence specified.

The robotic model cannot be commanded using the generated angles directly. It is important to consider the servo motor's range limitations. An issue for the robot can arise if a specific coordinate point generates a series of angles, any one of which is beyond the permitted range for that specific joint.

Determine the angle (theta) the point makes with the XY plane as well as its separation from the origin. To determine whether a point is below the workspace's outer boundary, add the height components of link 1 and the offset of link 2 together, subtract them from the point's distance, and then compare the result to the sum of lengths of links 2 and 3.

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Journal of Engineering, Computing and Architecture

An UGC-CARE Approved Group-II Journal
ISSN NO: 1934-7197
Website: http://www.journaleca.com/ E-Mail ID: submitjournaleca@gmail.com

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Journal of Engineering, Computing and Architecture

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VOLUME 13, ISSUE 4 APRIL- 2023

Michal A. Olszewski
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Journal of Engineering, Computing and Architecture

An UGC-CARE Approved Group-II Journal

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VOLUME 13, ISSUE 4 APRIL- 2023

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Journal of Engineering, Computing and Architecture
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ISSN NO: 1934-7197
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Has been published in

VOLUME 13, ISSUE 4 APRIL- 2023

Michal A. Olszewski
Editor-in-Cheif