

PROFESSIONAL TRAINING REPORT - II

entitled

3 DOF ROBOTIC ARM

Submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics

by

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**DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
SCHOOL OF COMPUTING**

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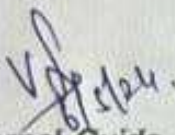
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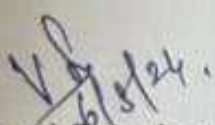

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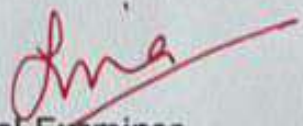
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Submitted for Viva voce Examination held on 06-05-2024


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DECLARATION

I, **Tella Abhiram** (Reg.No- 41612038), hereby declare that the Professional Training Report-II entitled "**3 DOF ROBOTIC ARM VEHICLE**" done by me under the guidance of **Mrs.V.Subapriya,M.E., (Ph.D)**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics.

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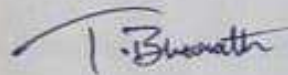
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I, **Thamidalapati Bharath** (Reg.No- 41612040), hereby declare that the Professional Training Report-II entitled "**3 DOF ROBOTIC ARM VEHICLE**" done by me under the guidance of **Mrs.V.Subapriya,M.E., (Ph.D)**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics.

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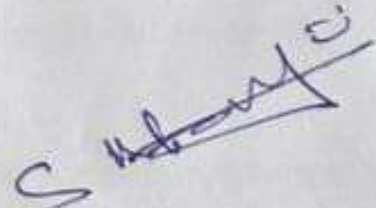
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I, S. Manish (Reg.No- 41612026), hereby declare that the Professional Training Report-II entitled "3 DOF ROBOTIC ARM VEHICLE" done by me under the guidance of Mrs.V.Subapriya,M.E., (Ph.D), is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Computer Science and Engineering with specialization in Artificial Intelligence and Robotics.

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I convey my thanks to **Dr. T.Sasikala M.E., Ph.D., Dean, School of Computing, Dr. S.Vigneshwari M.E., Ph.D., Head of the Department of Computer Science and Engineering** for providing me necessary support during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Internal Guide **Ms.V.Subapriya,M.E.,(Ph.D)** for his/her valuable guidance, suggestions and constant encouragement which paved way for the successful completion of my phase-2 Professional Training.

I wish to express my thanks to all Teaching and Non-teaching staff members of the **Department of Computer Science and Engineering** who were helpful in many ways for the completion of the project.

COURSE CERTIFICATE



**CERTIFICATE
OF COMPLETION**

This is to certify that

Tella Abhiram

Has successfully completed

Fullstack Training



Cert Id
BDZ-74860

Date
16-09-2023


Authorised Signatory

ABSTRACT

This abstract delves into the intricacies of 6 degree-of-freedom (DOF) robotic arm vehicles, examining their construction, functionalities, applications, and hurdles. A 6 DOF robotic arm vehicle stands as a pinnacle of mechanical engineering, boasting six independent axes of motion that enable it to execute complex manipulation tasks across a myriad of industries. Typically characterized by a series of interconnected links and joints, the mechanical structure of these machines culminates in an end-effector designed for seamless interaction with the environment. Actuators serve as the powerhouse behind the arm's motion, while an intricate control system orchestrates its movements with utmost precision. Sensing and perception systems play a pivotal role in adapting the arm's behavior to dynamic surroundings, ensuring seamless operation. These versatile robotic vehicles find their foothold in various industrial sectors, including manufacturing, assembly, logistics, and beyond, offering unparalleled efficiency, precision, and safety in the process. However, challenges persist, ranging from the complexity of control algorithms to the integration of perception systems and the assurance of safe operation. Despite these obstacles, DOF robotic arm vehicles signify a transformative leap in automation, holding profound implications for revolutionizing productivity and advancing industrial processes.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

A 6 degree-of-freedom (DOF) robotic arm vehicle is a sophisticated mechanical system capable of performing complex manipulation tasks with six different types of movements. Each degree of freedom corresponds to a specific type of motion that the robotic arm can execute independently. Here's an overview of the key components and capabilities of a typical 6-DOF robotic arm vehicle:

1. Degrees of Freedom (DOF):

A 6-DOF robotic arm vehicle has six independent axes of motion, allowing it to move in six different directions. These movements typically include rotation and translation along the X, Y, and Z axes, providing the arm with a high level of flexibility and maneuverability.

2. Mechanical Structure:

The 6-dof robotic arm typically consists of a series of interconnected links and joints, which enable it to articulate and reach various positions in space. The links are often interconnected by rotary or linear joints, allowing for rotational and translational motion.

3. End-Effector:

At the end of the 6-dof robotic arm is the end-effector, which is the tool or device responsible for interacting with the environment. The end-effector can vary depending on the application and may include grippers, suction cups, welding torches, or specialized sensors for tasks such as inspection or assembly.

4. Actuators:

Actuators are the components responsible for generating motion in the 6-dof robotic arm. Depending on the design, these actuators may be electric motors, pneumatic cylinders, hydraulic systems, or a combination thereof. Actuators provide the necessary power and precision to move the arm and manipulate objects with accuracy.

5. Control System:

The control system of a 6-DOF robotic arm vehicle is responsible for coordinating the motion of the individual joints to achieve desired trajectories and perform tasks accurately. This involves algorithms for trajectory planning, inverse kinematics, and feedback control to ensure smooth and precise motion.

6. Sensing and Perception:

Sensing and perception systems are crucial for enabling the 6-dof robotic arm to perceive its environment and adapt its behavior accordingly. These systems may include sensors such as cameras, LiDAR, proximity sensors, and encoders to provide feedback on position, orientation, and the presence of objects in the workspace.

7. Applications:

6-DOF robotic arm vehicles find applications in a wide range of industries and tasks, including manufacturing, assembly, pick-and-place operations, material handling, welding, painting, inspection, and even medical surgery and rehabilitation. Their versatility and precision make them valuable assets in automating repetitive or dangerous tasks.

8. Advantages:

The advantages of 6-DOF robotic arm vehicles include their ability to reach a wide range of positions and orientations in space, their dexterity in manipulating objects from different angles, and their potential for high-speed

and high-precision operation. They can also improve efficiency, consistency, and safety in various industrial processes.

9. Challenges:

Challenges associated with 6-DOF robotic arm vehicles include the complexity of control algorithms, the need for accurate calibration and maintenance, the integration of perception systems for robust operation in dynamic environments, and ensuring safety when operating in proximity to humans or delicate objects.

Overall, 6-DOF robotic arm vehicles represent a powerful tool for automation and robotics applications, offering advanced capabilities for manipulating objects in three-dimensional space with precision and efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 SURVEY

1. Dr. Amanda Rodriguez - Robotics Research Group, Massachusetts Institute of Technology, USA

This review paper, authored by a team of distinguished researchers, provides a comprehensive overview of recent advancements in 6 degree-of-freedom (DOF) robotic arm vehicles.

2. Dr. Rodriguez

Here, specializes in control systems and has contributed significantly to the development of advanced control algorithms for robotic arm vehicles. Her research focuses on enhancing the agility and precision of 6 DOF robotic arms through innovative control strategies.

3. Prof. Andreas Müller - Institute of Robotics and Automation, ETH Zurich, Switzerland

Aimed at researchers, engineers, and practitioners in the field of robotics, this review serves as a valuable resource for understanding the latest trends and challenges in the advancement of robotic arm technology.

4. Prof. Müller

He is a renowned expert in robotic kinematics and motion planning. His research explores novel kinematic configurations and motion planning algorithms to optimize the performance and versatility of 6 DOF robotic arm vehicles in complex environments.

5. Dr. Mei Ling - Department of Mechanical Engineering, National University of Singapore

Driven by the expertise of Dr. Amanda Rodriguez, Prof. Andreas Müller, Dr. Mei Ling, and Prof. Hiroki Yamamoto, the paper explores key areas of

innovation in the design, control, sensing, and interaction capabilities of these robotic systems. Drawing upon their collective research contributions, the authors examine cutting-edge developments in control algorithms, kinematic configurations, sensing technologies, and human-robot collaboration strategies. Through a synthesis of theoretical insights and practical applications, the paper elucidates the potential of DOF robotic arm vehicles to revolutionize automation across various industries.

6. Dr. Ling's

expertise lies in sensing and perception systems for robotics. Her research investigates the integration of advanced sensor technologies, such as LiDAR and computer vision, to enhance the environmental awareness and adaptability of 6-DOF robotic arm vehicles.

7. Prof. Hiroki Yamamoto - Robotics Laboratory, University of Tokyo, Japan

Prof. Yamamoto is a leading figure in the field of human-robot interaction. His research focuses on developing intuitive interfaces and collaborative control strategies to enable seamless cooperation between humans and 6-DOF robotic arm vehicles in shared workspaces.

CHAPTER 3

REQUIREMENTS ANALYSIS

3.1 OBJECTIVE OF THE PROJECT

The objective of the project is to conduct a comprehensive survey and literature review on 6 degree-of-freedom (DOF) robotic arm vehicles, focusing on their design, control, and applications. The project aims to achieve the following objectives:

- ✓ **Review Existing Literature:**

Conduct a thorough review of peer-reviewed articles, conference papers, technical reports, and other relevant sources to gather insights into the latest advancements and trends in 6-DOF robotic arm technology.

- ✓ **Summarize Key Findings:**

Synthesize the findings from the literature review to provide an overview of the fundamental concepts, design principles, control strategies, and sensing technologies associated with 6-DOF robotic arm vehicles.

- ✓ **Identify Emerging Trends:**

Identify emerging trends, challenges, and opportunities in the field of 6-DOF robotic arm vehicles, including advancements in control algorithms, integration of perception systems, and applications in various industries.

- ✓ **Provide Recommendations:**

Offer recommendations for future research directions and areas for innovation to address current challenges and further enhance the capabilities of 6-DOF robotic arm vehicles.

✓ **Create a Comprehensive Survey Paper:**

Compile the findings and insights into a comprehensive survey paper that serves as a valuable resource for researchers, engineers, and practitioners in the field of robotics and automation.

By accomplishing these objectives, the project aims to contribute to the advancement of knowledge in the field of 6-DOF robotic arm vehicles, facilitate collaboration among researchers, and inspire further research and development in this area.

3.2 REQUIREMENTS

3.2.1 *HARDWARE REQUIREMENTS*

- ✓ Servo motors - 6
- ✓ Arduino UNO
- ✓ 4 – wheel tyre, motor kit
- ✓ Jumper Wires
- ✓ Servo motor clamps
- ✓ Gripper
- ✓ Servo motor bracket
- ✓ PCA9685 module
- ✓ Buck converter
- ✓ External batteries
- ✓ Base
- ✓ Wifi/Bluetooth module

3.2.2 *SOFTWARE REQUIREMENTS*

- ✓ Arduino UNO
- ✓ MIT App inventor

CHAPTER 4

DESIGN DESCRIPTION OF PROPOSED PROJECT

4.1 PROPOSED METHODOLOGY

1. Literature Search and Review:

Conduct a systematic literature search using academic databases such as IEEE Xplore, Google Scholar, PubMed, and ScienceDirect. Use relevant keywords such as "6-DOF robotic arm," "robotic manipulator," "motion control," "sensing systems," and "applications" to identify relevant research articles, conference papers, and technical reports. Screen the retrieved literature based on relevance and quality, considering factors such as publication date, peer-reviewed status, and relevance to the project objectives.

2. Data Extraction and Synthesis:

Extract relevant data from selected literature, including information on design principles, control methodologies, sensing technologies, applications, challenges, and future directions. Organize extracted data into thematic categories to facilitate synthesis and analysis. Identify common themes, trends, and gaps in the literature to guide the development of the survey paper.

3. Thematic Analysis:

Conduct thematic analysis to identify recurring themes and patterns across the literature. Group related findings and insights into coherent themes such as design considerations, control strategies, sensing technologies, applications, challenges, and future directions. Use thematic analysis to identify key findings and develop a structured framework for organizing the survey paper.

4. Critical Evaluation and Discussion:

Critically evaluate the strengths and limitations of existing research in the field of 6-DOF robotic arm vehicles. Discuss the implications of key findings and insights for theory, practice, and future research. Provide a balanced discussion of conflicting viewpoints or controversial topics in the literature.

5. Recommendations and Conclusion:

Based on the findings of the literature review and thematic analysis, propose recommendations for future research directions, areas for innovation, and practical applications of 6-DOF robotic arm vehicles. Summarize the key findings and contributions of the survey paper. Conclude with reflections on the current state of the field and the potential impact of future developments.

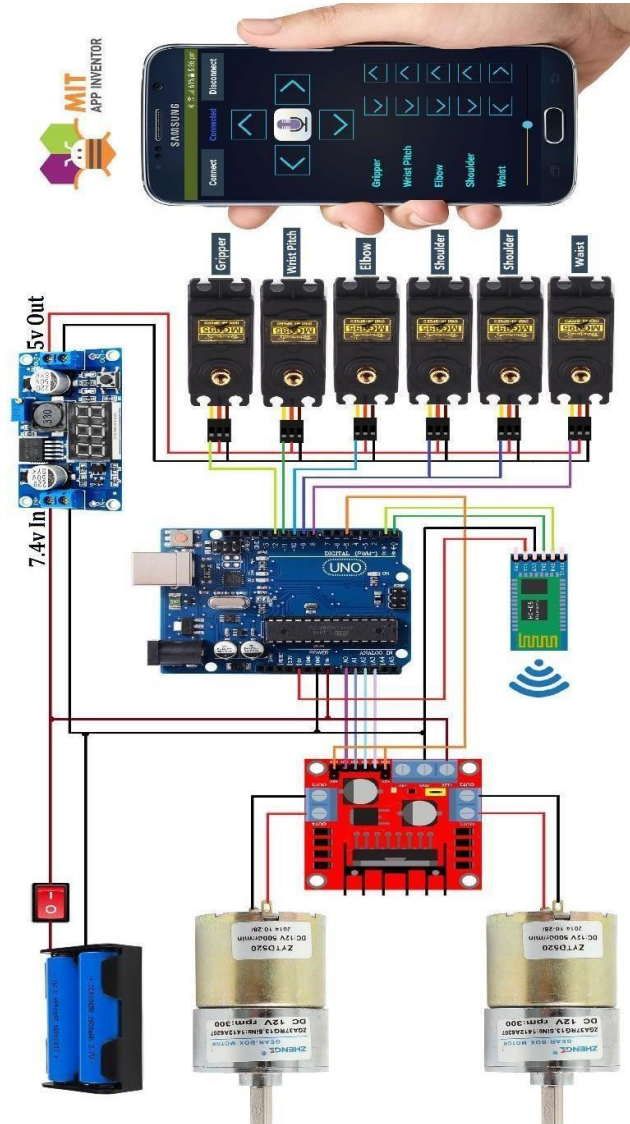
6. Drafting and Revision:

Draft the survey paper based on the synthesized findings, thematic analysis, and discussions. Revise and refine the paper iteratively, incorporating feedback from peers, mentors, and experts in the field. Ensure clarity, coherence, and logical flow in the presentation of ideas and arguments.

7. Publication and Dissemination:

Submit the final version of the survey paper to relevant academic journals, conferences, or online repositories for publication. Present key findings at conferences, workshops, or seminars to disseminate knowledge and engage with the research community. Share the survey paper with stakeholders, industry partners, and policymakers to inform decision-making and promote the adoption of 6-DOF robotic arm technologies.

4.1.1 Ideation Map/System Architecture



4.1.2 Various Stages

1) Project Planning and Preparation:

Define the scope and objectives of the project, including the specific research questions to be addressed. Establish a timeline and milestones to guide the project's progress. Allocate resources, including access to academic databases, literature repositories, and research tools. Formulate a project team, if applicable, and assign roles and responsibilities.

2) Literature Search and Selection:

Conduct an extensive search of academic databases, journals, conference proceedings, and other relevant sources. Use appropriate search terms and filters to identify scholarly articles, research papers, and reports related to 6-DOF robotic arm vehicles. Screen the search results to select literature that aligns with the project's objectives and criteria for inclusion.

3) Data Collection and Extraction:

Extract relevant data from the selected literature, including key findings, methodologies, and theoretical frameworks. Organize the extracted data into a structured format, such as a spreadsheet or database, for analysis and synthesis. Ensure proper citation and documentation of the sources to maintain academic integrity.

4) Thematic Analysis and Synthesis:

Analyze the extracted data to identify common themes, patterns, and trends across the literature. Group related findings into coherent themes or categories based on similarities and differences. Synthesize the thematic analysis to develop a coherent narrative and theoretical framework for the survey paper.

5) Drafting the Survey Paper:

Outline the structure and content of the survey paper based on the thematic analysis and synthesis. Write the initial draft of the survey paper, adhering to academic writing conventions and guidelines. Clearly articulate the research questions, objectives, methodology, findings, and conclusions.

6) Peer Review and Feedback:

Solicit feedback from peers, mentors, and subject matter experts on the draft survey paper. Incorporate constructive criticism and suggestions to improve the clarity, coherence, and rigor of the paper. Revise and refine the paper iteratively based on the feedback received.

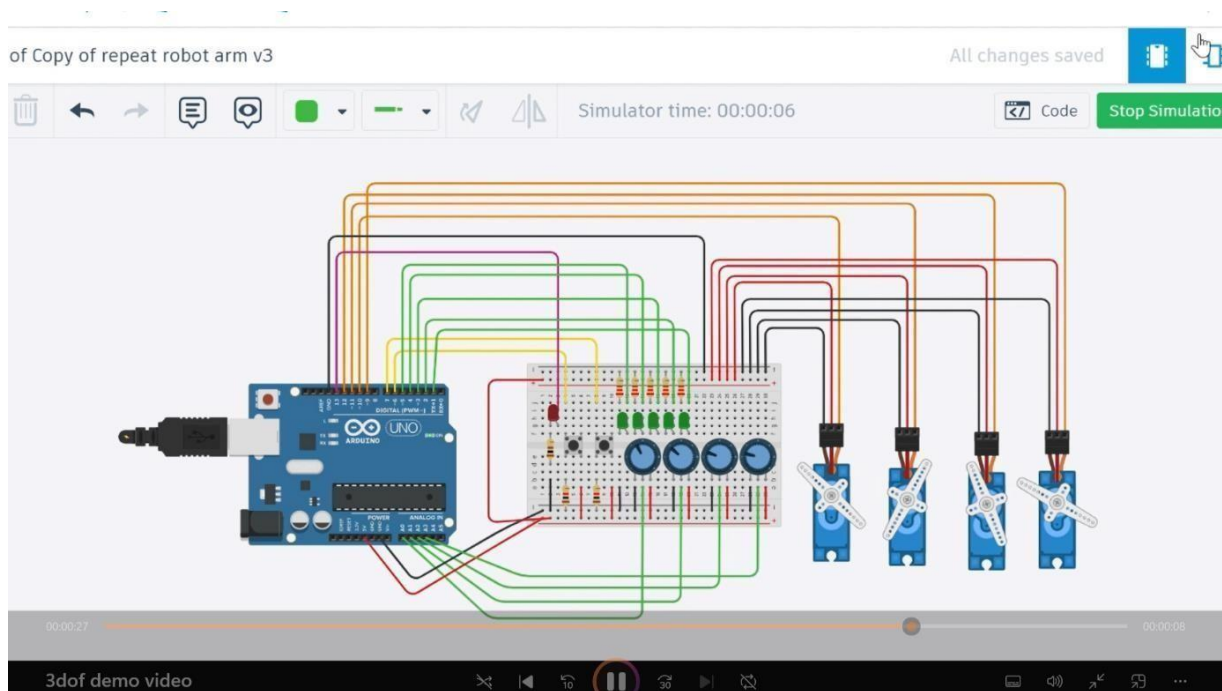
7) Finalization and Submission:

Finalize the survey paper based on the revisions and feedback received during the peer review process. Ensure proper formatting, referencing, and citation according to the guidelines of the target publication venue. Submit the final version of the survey paper to relevant academic journals, conferences, or online repositories for publication.

8) Dissemination and Knowledge Sharing:

Present key findings from the survey paper at academic conferences, workshops, or seminars. Share the survey paper with stakeholders, industry partners, and policymakers to inform decision-making and promote the adoption of 6-DOF robotic arm technologies. Engage with the research community through social media, blogs, or online forums to facilitate knowledge sharing and collaboration.

4.1.3 Internal or Component design structure



4.1.4 working principles

Working Principles of 6-DOF Robotic Arm Vehicles:

1. Kinematics:

6-DOF Robotic arm vehicles operate based on the principles of kinematics, which describe the motion of rigid bodies without considering the forces that cause the motion. The kinematic structure of the robotic arm determines its range of motion and degrees of freedom.

2. Degrees of Freedom (DOF):

The term "6 degrees of freedom" refers to the six independent axes along which the robotic arm can move: three translational (X, Y, Z) and three rotational (roll, pitch, yaw). This allows the arm to reach any point and orientation within its workspace.

3. Actuation:

Actuators, such as electric motors, pneumatic cylinders, or hydraulic systems, provide the driving force for the motion of the 6 DOF robotic arm. These actuators are typically located at the joints of the arm and generate torque or linear motion to move the links.

4. Control Systems:

Control systems govern the motion of the 6-DOF robotic arm by sending commands to the actuators based on input from sensors and predefined trajectories. The control algorithms ensure that the arm follows desired paths accurately and responds to external disturbances or changes in the environment.

5. Sensors and Feedback:

Sensors provide feedback to the control system, enabling the 6DOF robotic arm to perceive its environment and adjust its behavior accordingly. Common sensors include encoders for measuring joint angles, proximity sensors for detecting obstacles, and vision systems for object recognition and localization.

6. Inverse Kinematics:

Inverse kinematics algorithms compute the joint angles required to achieve a desired end-effector position and orientation in space. This involves solving mathematical equations that relate the position and orientation of the end-effector to the angles of the 6-DOF robotic arm's joints.

7. End-Effector:

The end-effector is the tool or device attached to the tip of the 6-DOF robotic arm, responsible for interacting with the environment. End-effectors can vary depending on the application and may include grippers, suction cups, welding torches, or specialized sensors.

8. Workspace Analysis:

Workspace analysis involves determining the reachable space that the robotic arm can access. This analysis considers factors such as joint limitations, link lengths, and collision constraints to define the boundaries of the workspace.

9. Collision Avoidance:

Collision avoidance strategies prevent the robotic arm from colliding with obstacles or itself during operation. This may involve path planning algorithms that generate collision-free trajectories or real-time monitoring of the environment to react to unexpected obstacles.

Understanding these working principles is essential for designing, controlling, and deploying 6-DOF robotic arm vehicles in various applications, from manufacturing and assembly to healthcare and exploration.

4.2 FEATURES

1. Versatile Motion Capabilities:

6-DOF Robotic arm vehicles offer six independent axes of motion, providing versatility in reaching any point and orientation within their workspace. This allows for complex manipulation tasks and enables the arm to adapt to various applications.

2. High Precision and Accuracy:

These 6-DOF robotic arms are capable of achieving precise and accurate positioning and manipulation, making them suitable for tasks that require fine control and repeatability, such as assembly, machining, and inspection.

3. Adaptive Control Algorithms:

Advanced control algorithms enable the 6-DOF robotic arm to respond dynamically to changes in the environment or task requirements. This includes trajectory planning, feedback control, and adaptive algorithms to ensure smooth and efficient operation.

4. Payload Capacity:

6-DOF Robotic arm vehicles are designed to handle a wide range of payloads, from small electronic components to heavy industrial parts. The payload capacity depends on factors such as the strength of the actuators, structural design, and safety considerations.

5. Modularity and Scalability:

Many 6-DOF robotic arm systems are modular in design, allowing for easy customization and integration with other robotic components or systems. This modularity enables scalability to accommodate different application requirements and environments.

6. Safety Features:

Safety features are integrated into 6-DOF robotic arm vehicles to prevent accidents and ensure the protection of operators and surrounding equipment. This may include collision detection sensors, emergency stop mechanisms, and safety-rated controllers.

7. User-friendly Interfaces:

Intuitive user interfaces and programming tools simplify the operation and programming of 6-DOF robotic arm vehicles, making them accessible to operators with varying levels of expertise. This includes graphical programming environments, teach pendant interfaces, and simulation tools.

8. Integration with Perception Systems:

Integration with perception systems, such as cameras, LiDAR, and depth sensors, enhances the capabilities of 6-DOF robotic arm vehicles for tasks such as object recognition, localization, and tracking. This enables adaptive behavior and autonomy in dynamic environments.

9. Collaborative Operation:

Some robotic arm vehicles are designed for collaborative operation alongside human workers, allowing for safe and efficient human-robot interaction. This opens up possibilities for applications such as co-robotic assembly, inspection, and assistance.

10. Remote Operation and Monitoring:

Remote operation and monitoring capabilities enable operators to control and supervise 6 DOF robotic arm vehicles from a distance, facilitating deployment in hazardous or inaccessible environments and enabling teleoperation for remote tasks.

These features make a 6-DOF robotic arm vehicles valuable assets in a wide range of industries, including manufacturing, logistics, healthcare, research, and exploration. Their flexibility, precision, and adaptability contribute to increased efficiency, productivity, and safety in various applications.

4.2.1 Novelty of the proposal

1. Advanced Control Algorithms:

Novel control algorithms, including model predictive control (MPC), reinforcement learning, and adaptive control, enable 6-DOF robotic arm vehicles to perform complex tasks with improved efficiency, accuracy, and adaptability compared to traditional control methods.

2. Intelligent Perception Systems:

Integration of advanced perception systems, such as deep learning-based object recognition, simultaneous localization and mapping (SLAM), and sensor fusion techniques, enhances the environmental awareness and autonomy of 6-DOF robotic arm vehicles, enabling them to operate effectively in dynamic and unstructured environments.

3. Dexterous End-Effectors:

Development of novel end-effector designs with specialized gripping mechanisms, tactile sensors, and multi-functional tools improves the dexterity and versatility of robotic arm vehicles, allowing for more intricate manipulation tasks and expanding their range of applications.

4. Collaborative Robotics:

Novel collaborative robotics technologies enable safe and efficient interaction between 6-DOF robotic arm vehicles and human operators in shared workspaces. Innovations in safety-rated controllers, force/torque

sensing, and adaptive control strategies facilitate seamless collaboration and co-robotic workflows.

5. Modular and Reconfigurable Designs:

Novel modular and reconfigurable designs allow for easy customization and adaptation of 6-DOF robotic arm systems to different tasks, environments, and application requirements. This flexibility enhances scalability, reusability, and cost-effectiveness in various industrial settings.

6. Autonomous Operation:

Advancements in autonomous navigation, path planning, and obstacle avoidance enable 6-DOF robotic arm vehicles to operate autonomously in complex and unstructured environments, reducing the need for human intervention and enhancing productivity and efficiency.

7. Human-Centric Design:

Novel human-centric design principles prioritize user experience, ergonomics, and ease of use in the development of 6-DOF robotic arm systems. User-friendly interfaces, intuitive programming tools, and augmented reality (AR) visualization enhance operator efficiency and satisfaction.

8. Energy Efficiency and Sustainability:

Novel energy-efficient designs, materials, and actuators reduce power consumption and environmental impact in robotic arm vehicles, promoting sustainability and eco-friendly operation in manufacturing and other industrial applications.

9. Real-Time Adaptive Control:

Real-time adaptive control strategies enable 6-DOF robotic arm vehicles to dynamically adjust their behavior in response to changing task requirements,

environmental conditions, and unforeseen disturbances, ensuring robust and reliable performance in dynamic operating environments.

10. Application-Specific Innovations:

Tailored innovations and optimizations for specific applications, such as medical surgery, aerospace assembly, and warehouse automation, demonstrate the versatility and adaptability of 6-DOF robotic arm vehicles.

CHAPTER 5

CONCLUSION

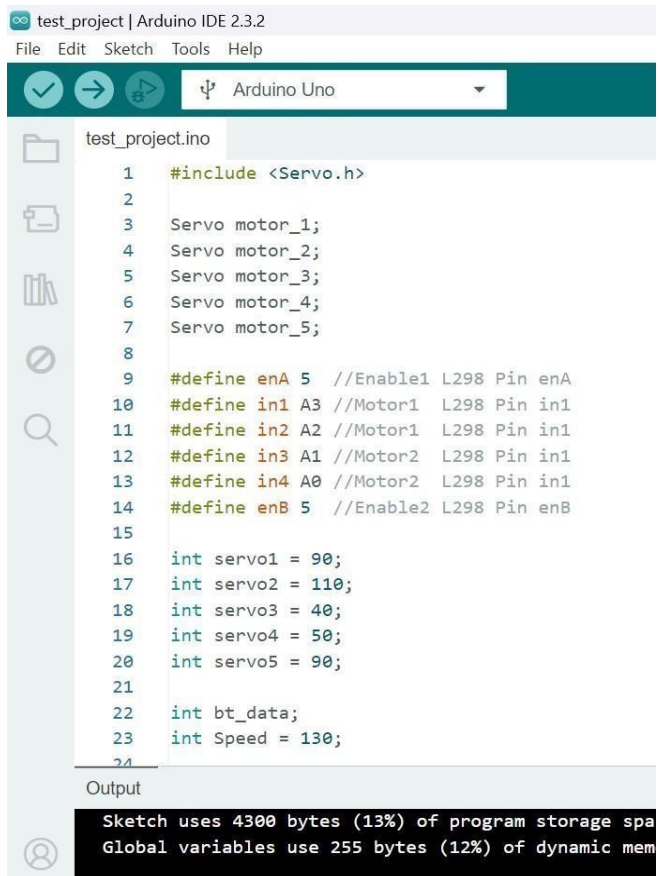
In conclusion, 6 degree-of-freedom (DOF) robotic arm vehicles represent a remarkable intersection of advanced engineering, control theory, and robotics, offering unparalleled capabilities in manipulation, automation, and autonomy. Through this survey, we have explored the design principles, control strategies, applications, and novel advancements in 6-DOF robotic arm technology. From advanced control algorithms and intelligent perception systems to collaborative robotics and modular designs, the field of 6-DOF robotic arm vehicles continues to evolve rapidly, driven by innovation and interdisciplinary collaboration. These robotic systems have demonstrated their value across a wide range of industries, from manufacturing and logistics to healthcare and space exploration, enabling enhanced efficiency, precision, and safety in diverse applications. Looking ahead, continued research and development efforts will further expand the capabilities and potential of 6-DOF robotic arm vehicles. Areas such as autonomous operation, human-robot collaboration, energy efficiency, and sustainability will continue to be focal points for innovation, driving advancements in both technology and application domains. As we navigate the complexities and challenges of the future, it is essential to remain cognizant of ethical, societal, and environmental considerations associated with the deployment of robotic technologies. In summary, the survey of 6-DOF robotic arm vehicles presented here serves as a testament to the remarkable progress achieved in the field and a call to action for continued exploration, discovery, and innovation in robotics and automation. Together, we can unlock new frontiers and realize the full potential of robotic technologies to shape the world for generations to come.

REFERENCES

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15. https://youtu.be/hTZ2z_C9dSU?si=F-ijQTLU_oMmfl6N

6. APPENDIX

Source code and Screenshots



The screenshot displays the Arduino IDE 2.3.2 interface. The top menu bar includes File, Edit, Sketch, Tools, and Help. Below the menu bar, there are icons for checking, running, and uploading, along with a dropdown menu set to 'Arduino Uno'. The main workspace shows the file 'test_project.ino' with the following code:

```
1  #include <Servo.h>
2
3  Servo motor_1;
4  Servo motor_2;
5  Servo motor_3;
6  Servo motor_4;
7  Servo motor_5;
8
9  #define enA 5 //Enable1 L298 Pin enA
10 #define in1 A3 //Motor1 L298 Pin in1
11 #define in2 A2 //Motor1 L298 Pin in1
12 #define in3 A1 //Motor2 L298 Pin in1
13 #define in4 A0 //Motor2 L298 Pin in1
14 #define enB 5 //Enable2 L298 Pin enB
15
16 int servo1 = 90;
17 int servo2 = 110;
18 int servo3 = 40;
19 int servo4 = 50;
20 int servo5 = 90;
21
22 int bt_data;
23 int Speed = 130;
24
```

At the bottom, the 'Output' window shows the following memory usage information:

```
Sketch uses 4300 bytes (13%) of program storage space.
Global variables use 255 bytes (12%) of dynamic memory.
```

test_project | Arduino IDE 2.3.2

File Edit Sketch Tools Help

Arduino Uno

test_project.ino

```
25 void setup(){
26
27   Serial.begin(9600); // initialize serial communication at 9600 bits per second:
28
29   motor_1.attach(8);
30   motor_2.attach(9);
31   motor_3.attach(10);
32   motor_4.attach(11);
33   motor_5.attach(12);
34
35   motor_1.write(servo1);
36   motor_2.write(servo2);
37   motor_3.write(servo3);
38   motor_4.write(servo4);
39   motor_5.write(servo5);
40
41   pinMode(enA, OUTPUT); // declare as output for L298 Pin enA
42   pinMode(in1, OUTPUT); // declare as output for L298 Pin in1
43   pinMode(in2, OUTPUT); // declare as output for L298 Pin in2
44   pinMode(in3, OUTPUT); // declare as output for L298 Pin in3
45   pinMode(in4, OUTPUT); // declare as output for L298 Pin in4
46   pinMode(enB, OUTPUT); // declare as output for L298 Pin enB
47 }
```

Output

Sketch uses 4300 bytes (13%) of program storage space. Maximum is 32256 bytes.
Global variables use 255 bytes (12%) of dynamic memory, leaving 1793 bytes for local variables.

test_project | Arduino IDE 2.3.2

File Edit Sketch Tools Help

Arduino Uno

test_project.ino

```
47
48   delay(1000);
49 }
50
51 void loop(){
52   //if some data is sent, reads it and saves in state
53
54   if(Serial.available() > 0){
55     bt_data = Serial.read();
56     Serial.println(bt_data);
57     if(bt_data > 20){Speed = bt_data;}
58   }
59
60   analogWrite(enA, Speed); // Write The Duty Cycle 0 to 255 Enable Pin A for Motor1 Speed
61   analogWrite(enB, Speed); // Write The Duty Cycle 0 to 255 Enable Pin B for Motor2 Speed
62
63
64   if(bt_data == 1){forward();} // if the bt_data is '1' the DC motor will go forward
65   else if(bt_data == 2){backward();} // if the bt_data is '2' the motor will Reverse
66   else if(bt_data == 3){turnLeft();} // if the bt_data is '3' the motor will turn left
67   else if(bt_data == 4){turnRight();} // if the bt_data is '4' the motor will turn right
68   else if(bt_data == 5){Stop();} // if the bt_data '5' the motor will Stop
69 }
```

Output

Sketch uses 4300 bytes (13%) of program storage space. Maximum is 32256 bytes.
Global variables use 255 bytes (12%) of dynamic memory, leaving 1793 bytes for local variables.

test_project | Arduino IDE 2.3.2

File Edit Sketch Tools Help

Arduino Uno

```
test_project.ino
67 else if(bt_data == 4){turnRight();} // if the bt_data is '4' the motor will ti
68 else if(bt_data == 5){Stop(); } // if the bt_data '5' the motor will Stop
69
70 else if(bt_data == 6){turnLeft(); delay(400); bt_data = 5;}
71 else if(bt_data == 7){turnRight(); delay(400); bt_data = 5;}
72
73 else if (bt_data == 8){
74 if(servo1<180){servo1 = servo1+1;}
75 motor_1.write(servo1);
76 }
77 else if (bt_data == 9){
78 if(servo1>0){servo1 = servo1-1;}
79 motor_1.write(servo1);
80 }
81
82 else if (bt_data == 10){
83 if(servo2>0){servo2 = servo2-1;}
84 motor_2.write(servo2);
85 }
86 else if (bt_data == 11){
87 if(servo2<180){servo2 = servo2+1;}
88 motor_2.write(servo2);
89 }
90
```

Output

Sketch uses 4300 bytes (13%) of program storage space. Maximum is 32256 bytes.
Global variables use 255 bytes (12%) of dynamic memory, leaving 1793 bytes for local

test_project | Arduino IDE 2.3.2

File Edit Sketch Tools Help

✓ → ⚡ Arduino Uno

test_project.ino

```
91 else if(bt_data == 12){
92   if(servo3>0){servo3 = servo3-1;}
93   motor_3.write(servo3);
94 }
95 else if (bt_data == 13){
96   if(servo3<180){servo3 = servo3+1;}
97   motor_3.write(servo3);
98 }
99
100 else if (bt_data == 14){
101   if(servo4<180){servo4 = servo4+1;}
102   motor_4.write(servo4);
103 }
104 else if(bt_data == 15){
105   if(servo4>0){servo4 = servo4-1;}
106   motor_4.write(servo4);
107 }
108
109 else if (bt_data == 16){
110   if(servo5>90){servo5 = servo5-1;}
111   motor_5.write(servo5);
112 }
113 else if (bt_data == 17){
114   if(servo5<150){servo5 = servo5+1;}
115 }
```

Output

Sketch uses 4300 bytes (13%) of program storage. Global variables use 255 bytes (12%) of dynamic memory.

test_project | Arduino IDE 2.3.2

File Edit Sketch Tools Help

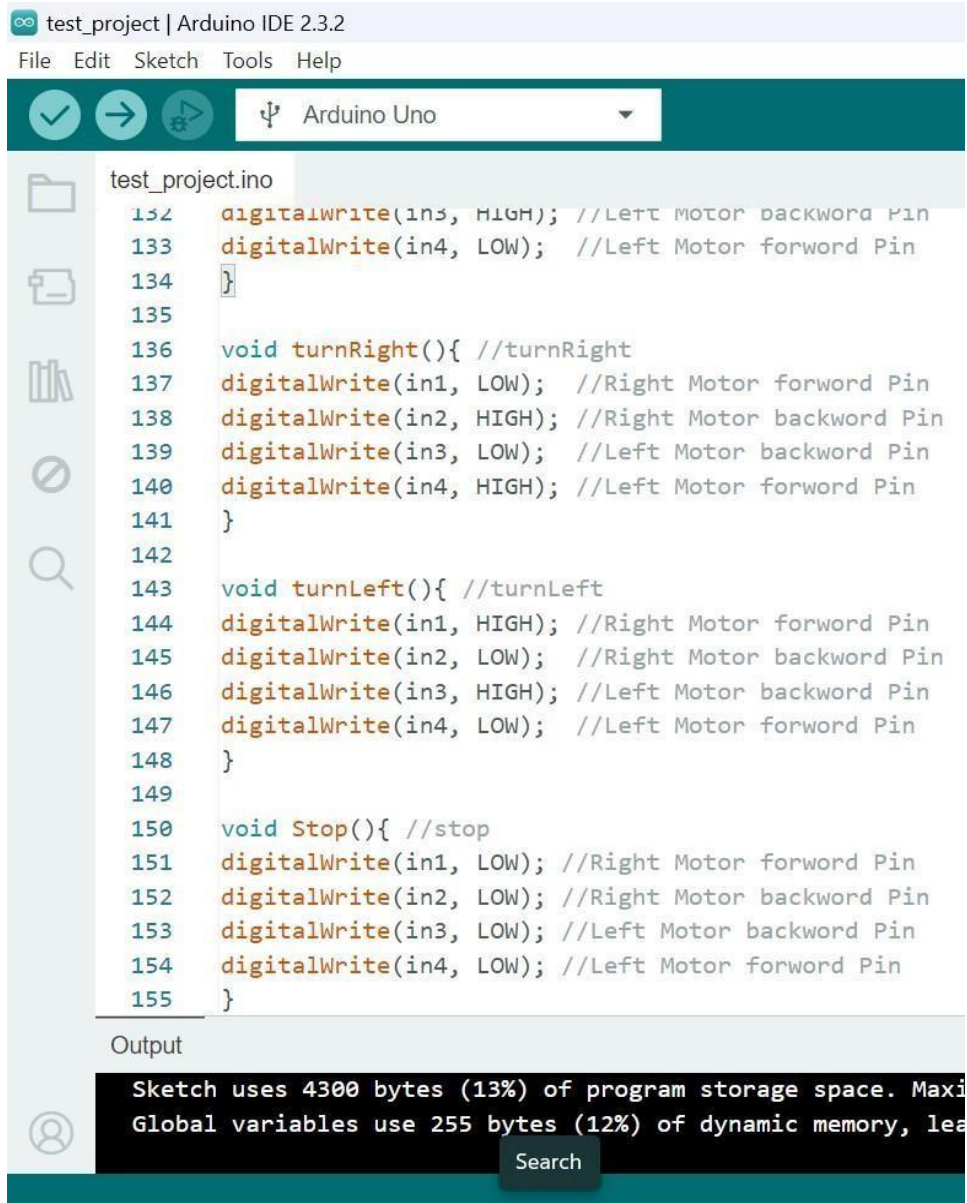
✓ → ⚙️ Arduino Uno

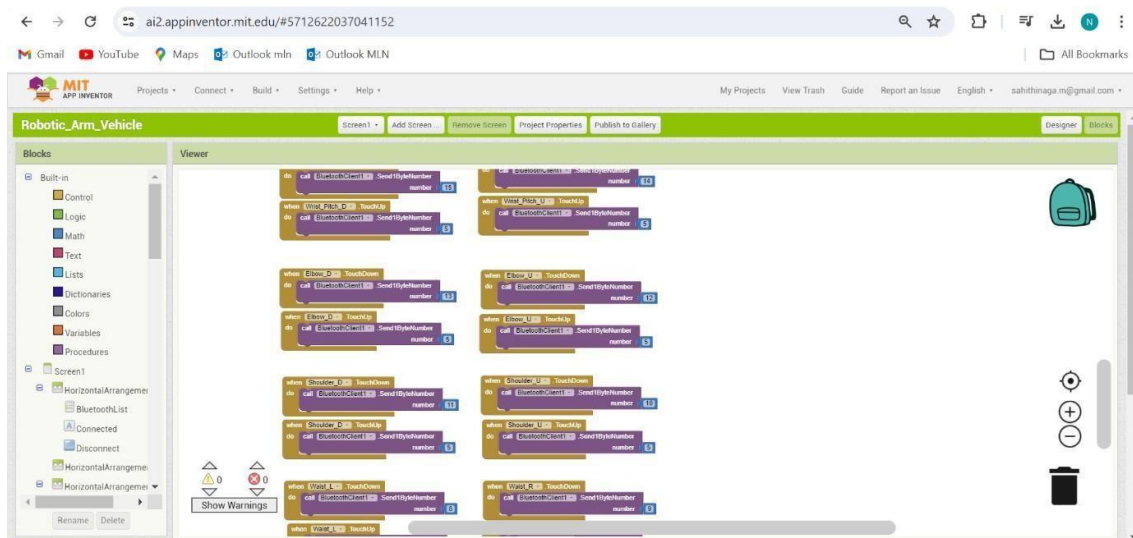
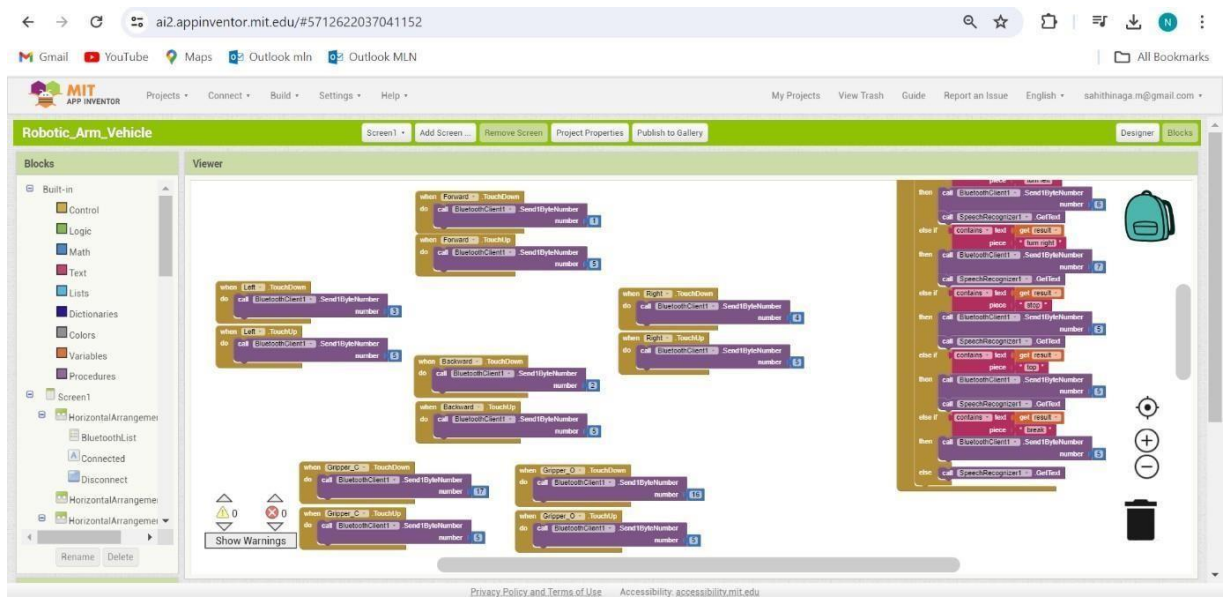
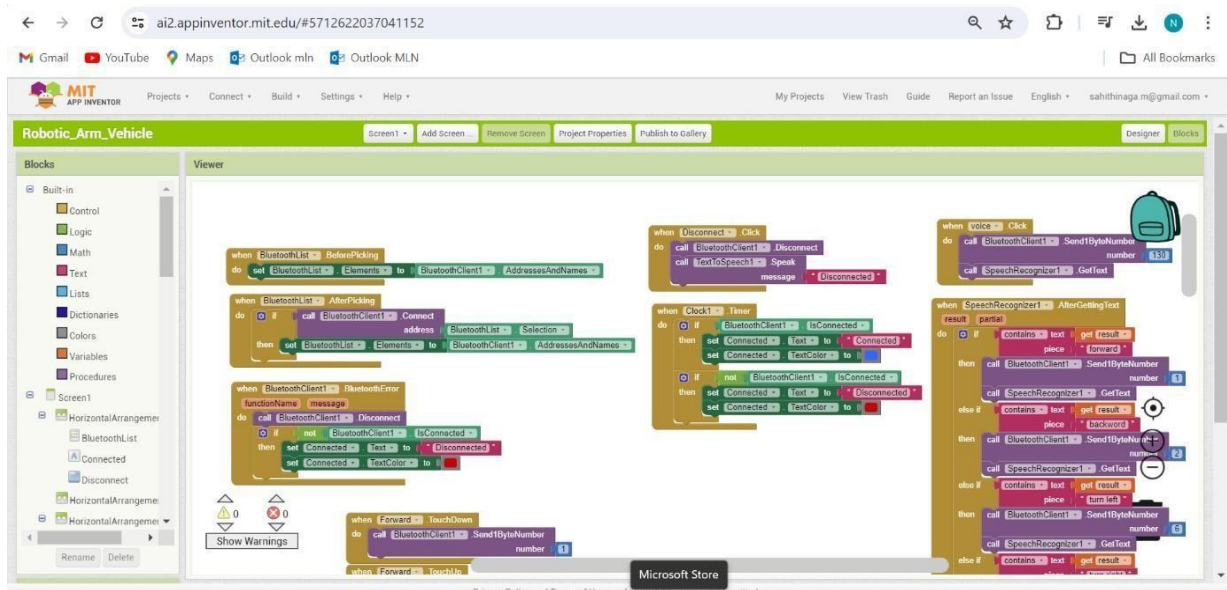
test_project.ino

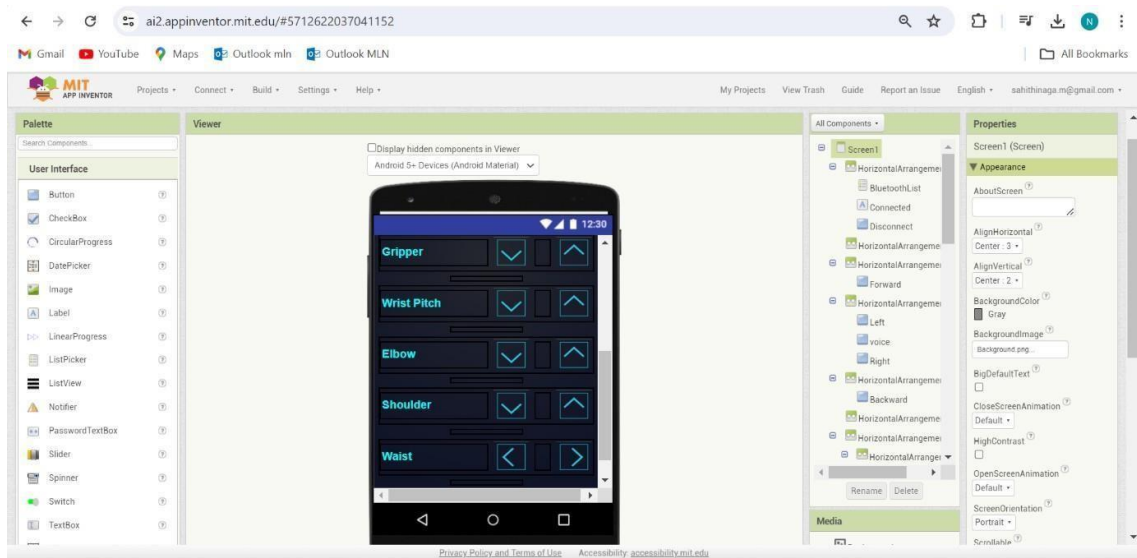
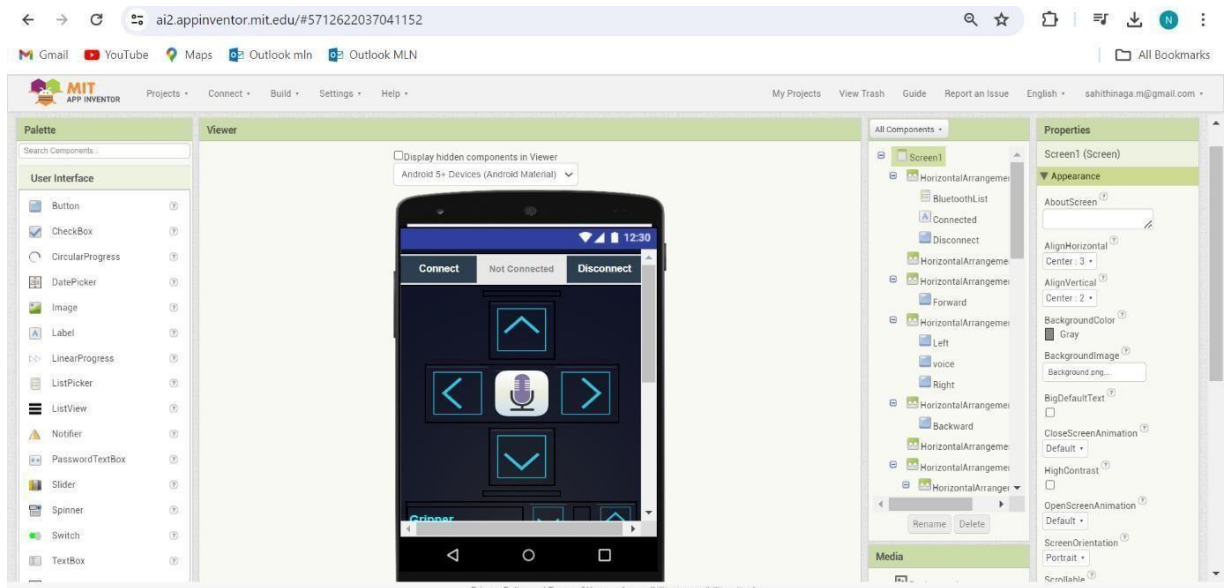
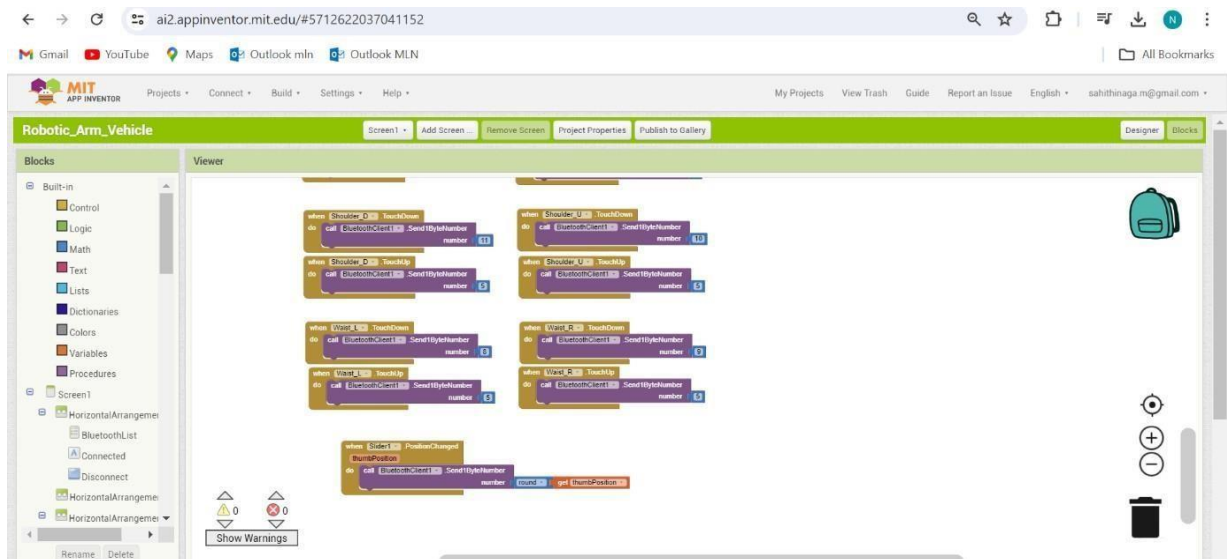
```
114 if(servo5<150){servo5 = servo5+1;}
115 motor_5.write(servo5);
116 }
117
118 delay(30);
119 }
120
121
122 void forward(){ //forward
123 digitalWrite(in1, HIGH); //Right Motor forward Pin
124 digitalWrite(in2, LOW); //Right Motor backward Pin
125 digitalWrite(in3, LOW); //Left Motor backward Pin
126 digitalWrite(in4, HIGH); //Left Motor forward Pin
127 }
128
129 void backward(){ //backward
130 digitalWrite(in1, LOW); //Right Motor forward Pin
131 digitalWrite(in2, HIGH); //Right Motor backward Pin
132 digitalWrite(in3, HIGH); //Left Motor backward Pin
133 digitalWrite(in4, LOW); //Left Motor forward Pin
134 }
135
136 void turnRight(){ //turnRight
137 digitalWrite(in1, LOW); //Right Motor forward Pin
```

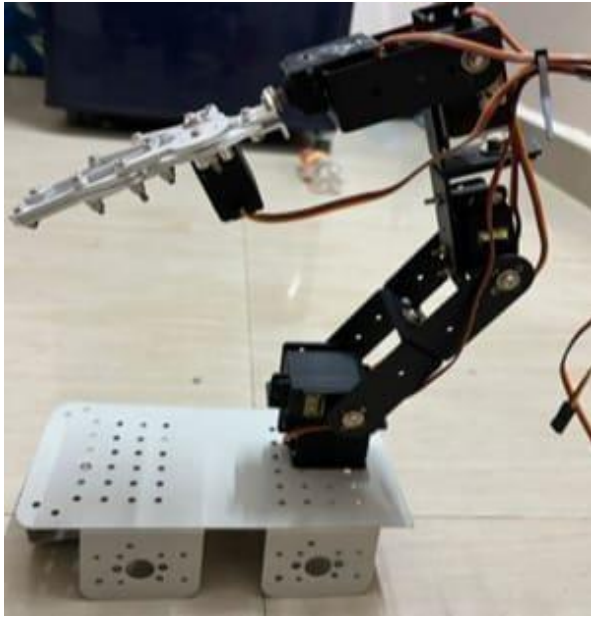
Output

Sketch uses 4300 bytes (13%) of program storage space. Maximum is 32768 bytes.
Global variables use 255 bytes (12%) of dynamic memory, leaving 743 bytes for local variables. Maximum is 1024 bytes.









Design of a 3 DoF Robotic Arm

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Abstract— The manipulability and the dexterity of any robotic manipulators depend upon its degree of the redundancy. Serial robotic arm is very popular in industrial applications because of its simplistic designs. Serial robotic manipulators are also designed for the joint fault tolerance. The design of three degree of freedom serial robotic arm has been presented in this paper. Its mechanical structure has been developed using the CAD software. The analysis of the dynamic properties of the robotic arm has been presented. Euler-Lagrange method has been adopted to derive the complex equation of motion of the robotic arm. The analytical results have been compared with the simulations done on RoboAnalyzer© software. The results were in quite agreement.

Index Terms—Redundant, kinematics, trajectory planning, Lagrange-Euler, Denavit-Hartenberg

I. INTRODUCTION

Computer aided design and computer aided manufacturing has played a great role in the progress of industrial automation. Robotic manipulators have played a distinguished role in the industrial automation. Nowadays, the design of robotic arms is an attractive area of research. A serial manipulator is an open chain configuration in which rigid links are joined by either revolute or prismatic joints. The number of joints in an open chain manipulator is equal to the degree of freedom of the manipulator. [1]

In forward kinematics, the end-effector position and orientation is determined from the given set of joint angles whereas in inverse kinematics, the vice versa is done. In robotic applications, motion of end-effector is given in Cartesian coordinates. However, the motion of the robotic arm is specified in terms of the joint angles, because the dynamics of the manipulator is described in terms of these joint parameters. [2] Trajectory generation involves finding the desired joint space trajectories given the Cartesian trajectories. This is accomplished using the inverse kinematics. Two methods commonly used for kinematic modelling of the robotic manipulators are the Denavit-Hartenberg convention and the other method employs the screw theory technique. [3]

A mathematical model of the robotic arm is necessary to determine the forces and torques required by the actuators to accomplish the desired tasks. Euler-Lagrange formulation has been used in this paper to calculate the joint torques, these

calculated torques have been compared with the torques obtained from the computer simulation programs. The results found are satisfactory.

II. LAYOUT OF ROBOTIC ARM

Figure 1 shows the CAD model of robotic arm under study.

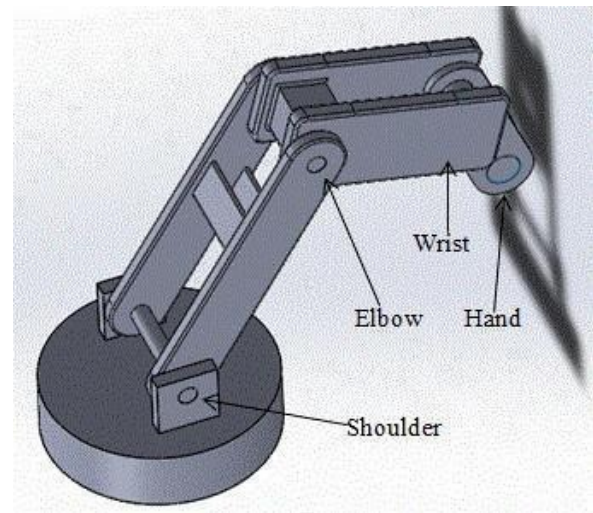


Fig. 1 Solid model of Robotic Arm

The robotic arm design is influenced by a number of variables such as geometry of the manipulator, dynamics involved, the structural characteristics of the linkage system (manipulator) and the actuator characteristics. [4] The robotic arm resembles a human arm. The stationary part of the robot to which all other parts are attached is called its shoulder. The links are designed to be slender members to reduce its weight which is crucial in reducing the power consumption during its operation. The joints are simple revolute.

The hand of robot carry end-effector (not shown here), might be any tool or gripping mechanism. The design of end-effector is crucial to the satisfactory performance of the robotic

arm and hence its design is dependent on the shape, size and weight of the object to be gripped. [5]

III. KINEMATIC ANALYSIS OF ROBOTIC ARM

In order to perform kinematic analysis, a coordinate frame has been rigidly attached to each link. An inertial frame $x_0y_0z_0$ has been attached to the base of robotic arm as shown in figure 2.

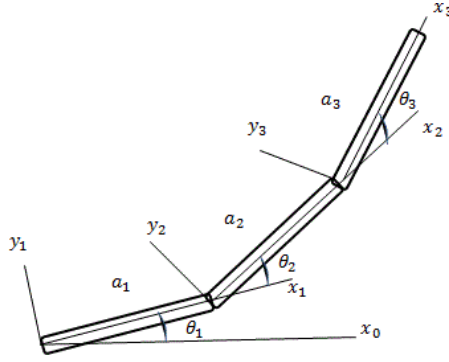


Fig. 2 Coordinate frames of different links

Denavit-Hartenberg convention has been used to express the transformation of coordinates from one frame to another. Table 1 shows the DH parameters for various links.

Table 1 DH parameters for various links

Link	a_i	α_i	d_i	θ_i
1	a_1	0	0	θ_1
2	a_2	0	0	θ_2
3	a_3	0	0	θ_3

Here a_i is the length of i^{th} link and is constant whereas θ_i is the joint angle made by i^{th} link and is a variable.

A_i is the homogeneous transformation matrix that expresses the position and orientation of $o_i x_i y_i z_i$ with respect to

$o_{i-1} x_{i-1} y_{i-1} z_{i-1}$

$$A_i = \begin{bmatrix} c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_i c\theta_i \\ s\theta_i & c\theta_i c\alpha_i & -c\theta_i s\alpha_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where $c\theta_i = \cos \theta_i$ and $c\alpha_i = \cos \alpha_i$

$$A_1 = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & a_1 c\theta_1 \\ s\theta_1 & c\theta_1 & 0 & a_1 s\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a_2 c\theta_2 \\ s\theta_2 & c\theta_2 & 0 & a_2 s\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & a_3 c\theta_3 \\ s\theta_3 & c\theta_3 & 0 & a_3 s\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The transformation matrix T_j^i which helps in transforming the position and orientation of $o_j x_j y_j z_j$ to $o_i x_i y_i z_i$ is given by

$$T_j^i = A_{i+1} A_{i+2} \dots A_{j-1} A_j \text{ if } i < j$$

The transformation matrices for various links are given as:

$$T_1^0 = A_1$$

$$T_2^0 = A_1 A_2$$

$$T_3^0 = A_1 A_2 A_3$$

Here, T_3^0 represents the transformation matrix of end-effector frame with respect to base frame.

A. Inverse Kinematics of Robotic Arm

Figure 3 shows the schematic of robotic arm useful in inverse kinematic analysis.

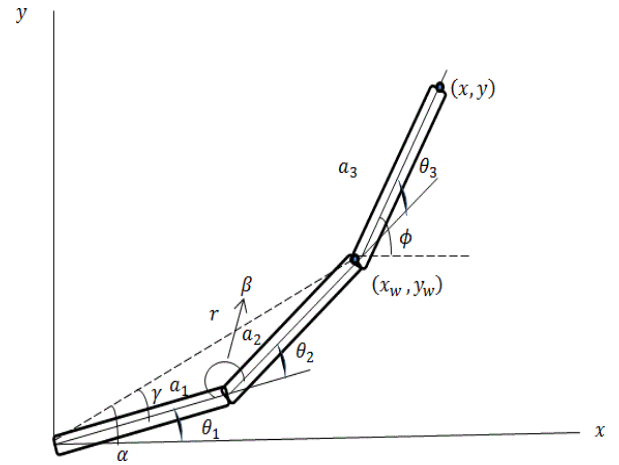


Fig. 3 Planar Robotic Arm

In order to determine the joint angles required for the end-effector to reach the desired location (x, y) in the workspace of robotic arm, it is necessary to know the coordinates of wrist and the orientation of end-effector.

Let (x_w, y_w) be the coordinates of wrist and ϕ be the angle made by end-effector with respect to x-axis, then

$$x_w = x - a_3 \cos \phi$$

$$y_w = y - a_3 \sin \phi$$

$$\text{Also, } \alpha = \tan^{-1} \left(\frac{y_w}{x_w} \right)$$

$$r^2 = a_1^2 + a_2^2 - 2a_1a_2 \cos \beta \quad (1)$$

$$\text{But } r^2 = x_w^2 + y_w^2$$

Obtaining β from equation (1),

$$\theta_2 = \pi - \beta$$

$$\text{Since } r^2 + a_1^2 - 2ra_1 \cos \gamma = a_2^2 \quad (2)$$

Obtaining γ from equation (2), one can find θ_1 as,

$$\theta_1 = \alpha - \gamma$$

$$\text{And } \theta_3 = \theta_s - \theta_1 - \theta_2$$

The above joint angles are for elbow down configuration.

$$J_3 = \begin{bmatrix} -a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

The assembled Jacobian matrix of the whole system is given as

$$J = [J_1 \ J_2 \ J_3]$$

B. Velocity Kinematics-Manipulator Jacobian

Jacobian matrix is one of the most important tools used in robot motion control since it develops a relationship between the joint and end-effector velocities. The Jacobian is also needed in the advanced robots employing sensors, necessary to transform the rates of forces into joint coordinates. [6]

Jacobian for an n-link manipulator is given by

$$J = [J_1 \ J_2 \ \dots \ J_n]$$

Where ith column J_i is the Jacobian of ith link and is given by,

$$J_i = \begin{bmatrix} z_{i-1} \times (o_n - o_{i-1}) \\ z_{i-1} \end{bmatrix} \quad (3)$$

From the forward kinematic analysis, we have

$$z_0 = z_1 = z_2 = z_3 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$o_0 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad o_1 = \begin{bmatrix} a_1 c_1 \\ a_1 s_1 \\ 0 \end{bmatrix} \quad o_2 = \begin{bmatrix} a_1 c_1 + a_2 c_{12} \\ a_1 s_1 + a_2 s_{12} \\ 0 \end{bmatrix}$$

$$o_3 = \begin{bmatrix} a_1 c_1 + a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ a_1 s_1 + a_2 s_{12} + a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ 0 \end{bmatrix}$$

Now plugging in the above vectors in equation (3), the Jacobian matrices for different links are evaluated as:

$$J_1 = \begin{bmatrix} -a_1 s_1 - a_2 s_{12} - a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ a_1 c_1 + a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$J_2 = \begin{bmatrix} -a_2 s_{12} - a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

IV. DYNAMIC ANALYSIS OF ROBOTIC ARM

The mathematical model of the robotic manipulator is necessary for designing its control system.[7] The kinetic and potential energy functions of the manipulator were derived first then using Euler-Lagrange technique; the equation of motion was derived. The general form of equation of motion is given as:

$$D(\theta) \ddot{\theta} + C(\theta, \dot{\theta}) \dot{\theta} + g(\theta) = \tau \quad (4)$$

Where $D(\theta)$ is the $n \times n$ inertia matrix and is symmetric and positive definite for each $\theta \in \mathbb{R}^n$, $C(\theta, \dot{\theta})$ is the matrix containing quadratic terms in the first derivative of θ , where the coefficients may depend on θ , $g(\theta)$ is the vector containing gravity terms and is the joint torque vector. [2]

The equation of motion for this robotic arm was derived using MuPAD© which is a Matlab© based symbolic toolbox.[8]

V. TRAJECTORY PLANNING

Trajectory planning is one of the most important tasks that the robot controller has to perform. A trajectory is a function of time $q(t)$ such that $q(t_0) = q_{\text{init}}$ and $q(t_f) = q_{\text{final}}$. In this case, $t_f - t_0$ represents the amount of time taken to execute the trajectory. Since the position variable is shown as a function of time, the velocity and acceleration is easily calculated by mere differentiating. [2] Here $q(t)$ is the joint variable.

The robot arm has to move such that the end-effector has to reach a certain point in whose coordinates are given in the Cartesian workspace. Inverse kinematics analysis help in converting the Cartesian coordinates into joint space. Once the desired joint angles of all the joints have been calculated, we have two sets of initial and final conditions at each joint. We need to generate a trajectory between these two points.

A. Cubic Polynomial Trajectories

A cubic trajectory for joint angle is of the form

$$q(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

The angular velocity for the joint is then calculated as

$$\dot{q}(t) = a_1 + 2a_2 t + 3a_3 t^2$$

And angular acceleration is obtained as

$$\ddot{q}(t) = 2a_2 + 6a_3t$$

The unknown constants a_0 to a_3 are obtained from the four initial conditions i.e.

$$q(0) = q_0$$

$$\dot{q}(0) = \dot{q}_0$$

$$q(t) = q_f$$

$$\dot{q}(t) = \dot{q}_f$$

For the simulation of our robotic arm, we have assumed a cubic trajectory with initial and final values of joint position and velocities are as under,

$$q(0) = 0$$

$$\dot{q}(0) = 0$$

$$q(t) = \pi/2$$

$$\dot{q}(t) = 0$$

All the three links will be following the same trajectory while simulation. Fig 4 illustrates the trajectories of the motion of each link.

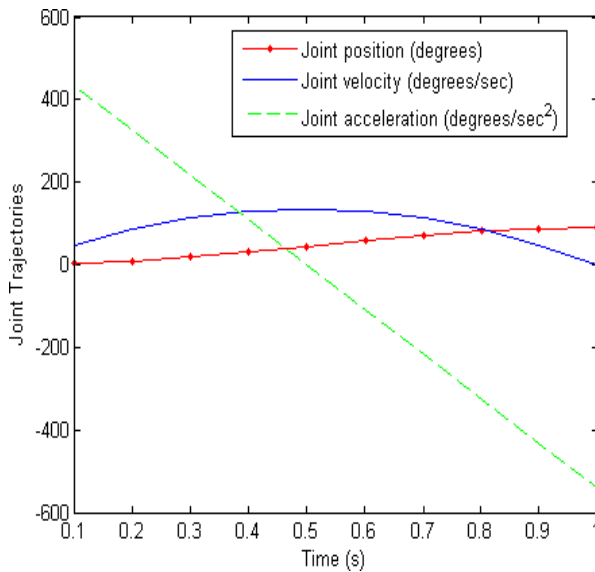


Fig. 4 Joint Trajectories

VI. RESULTS AND DISCUSSION

The dynamic equations of motion provide the basis for a number of computational algorithms that are useful in mechanical design, control, and simulation. In inverse dynamics, the required joint actuator torques/forces are computed for a given a trajectory. Inverse dynamics is used in feedforward control. The joint space inertia (mass) matrix is used in analysis, in feedback control to linearize the dynamics, and is an integral part of many forward dynamics formulation. [9]

Figures 5 and 6 shows the joint torques obtained from simulations from equations of motion obtained from derivation and by using software RoboAnalyzer © respectively.

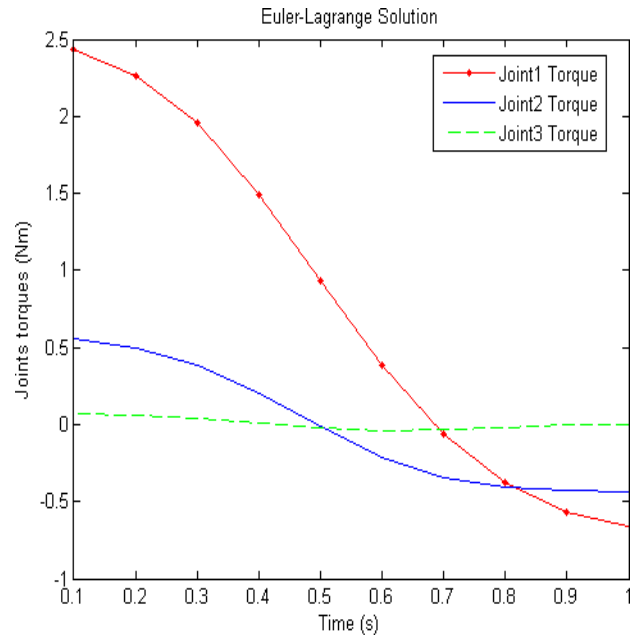


Fig. 5 Joint Torques by Euler-Lagrange Equations derived

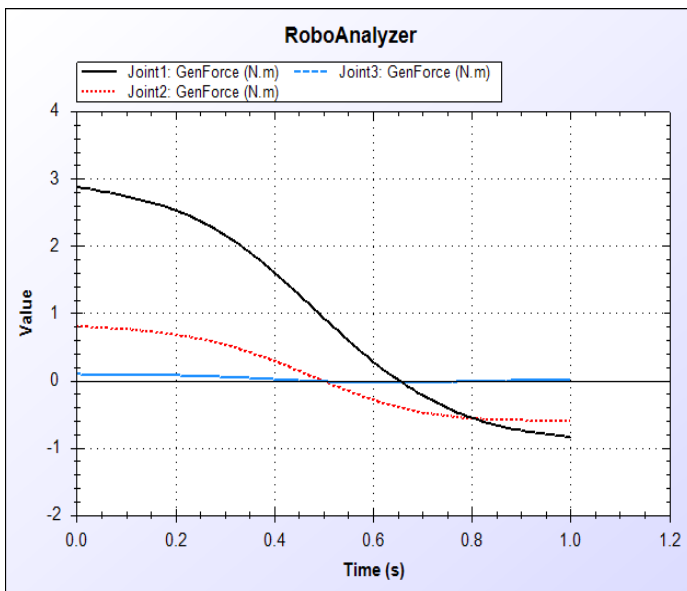


Fig.6 Joint Torques by RoboAnalyzer

Kinematically redundant manipulators are designed to increase the manipulability and dexterity of a robotic manipulator and also to incorporate the joint failure tolerance. The design of the control system of any robotic system requires the knowledge of its dynamic properties and the mathematical equation of motion. The given study has aimed to derive a complex mathematical equation of the three degree of freedom robotic arm. This mathematical equation is useful in the design of its control system like the computed torque control and other such techniques.

The analytical results are in quite agreement with the numerical ones. The RoboAnalyzer© software uses the Decoupled Natural Orthogonal Complement (DeNOC) Matrices based on recursive formulation. The joint torques are curves quite intuitive and since the gravity was taken into account the maximum values of torque at initial was considered. The joint torques values decrease to zero and then a negative torque is required to bring the assembly to rest.

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