OPTIMIZATION OF PID CONTROLLERS FORTHREE LINK ROBOT MANIPULATORS USING PSO

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Abstract— In robotics, a manipulator is used to manipulate materials without any direct physical contact by the operator. This project aims to present method to model and control the mechanics of Robot manipulator. The arm and the body of a robot are used to move and position parts or tools within a work envelope. They are formed from three joints connected by large links. The three- link robot arm is modelled and simulated using MATLAB/Simulink SimMechanics tool box. This model is implemented with PID controllers and the gains of the PID controller are tuned with Particle swarm Optimization Algorithm (PSO). The results of the simulation show that SimMechanics tool box can be used to model the mechanics of robot and the better performance can be obtained with PSO tuned PID controllers.

I. INTRODUCTION (ROBOT MANIPULATOR MECHANICS)

In the realm of robotics, manipulators play a pivotal role in facilitating the precise manipulation of materials and objects without direct physical contact by human operators. The inherent versatility and efficiency of robotic manipulators have led to their widespread use across various industries, ranging from manufacturing and logistics to healthcare and space exploration. These mechanical marvels are capable of executing intricate tasks, including the movement and precise positioning of parts or tools within predefined work envelopes. This review paper delves into a comprehensive exploration of methodologies for modelling and controlling the mechanics of robot manipulators, with a particular focus on athree-link robot arm.

Robot manipulator mechanics encompasses the study of the physical structure and behavior of robotic arms or manipulators. It is crucial for the design and operation of robots across various industries. Understanding the background and context of this field is essential as automation and robotics continue to play a vital role in modern industries.

Significance of Robot Manipulators:

Robot manipulators are invaluable tools for industries, research, and various applications. Therefore, understanding their mechanics is pivotal for the design, control, and operation of these robotic systems.

3R Articulated spatial robot

A 3R articulated spatial robot is a type of robotic mechanism characterized by its specific arrangement of joints and links, enabling it to move and operate within a three- dimensional space. The term "3R" signifies the configuration of the robot's joints: it has three revolute joints, each of which allows rotation around an axis. These joints provide the robot with three degrees of freedom, allowing it to move in a varietyof ways.

The term "articulated" in this context refers to the robot's structure, where its links (rigid components) are connected by joints, allowing relative motion between them. The use of revolute joints means that the robot's links can rotate around their connecting axes, enabling the robot to move its end- effector (the tool or device attached to the robot's last link) invarious directions and orientations.

The phrase "spatial robot" signifies that the robot can navigate and manipulate objects in a full 3D environment. Unlike planar robots that are constrained to a two-dimensional plane, a spatial robot can move and interact freely in all threedimensions—X, Y, and Z.

A 3R articulated spatial robot is often used for tasks that require intricate manipulation, precision positioning, and interaction with objects in 3D space. Its ability to rotate its joints and move in various directions makes it suitable for applications such as assembly, material handling, pick-and-place operations, and tasks that demand dexterity in multipledimensions.

II. Modelling Robot Manipulators

SimMechanics is an essential and advanced tool in the field of robotics engineering, offering a versatile platform for creating precise virtual models of robot manipulators. These manipulators can vary widely in design and complexity, and SimMechanics provides a robust framework for representing their mechanical components, joints, and control systems in a simulated environment.

One of the key advantages of SimMechanics is its ability to accurately capture the dynamic and kinematic behavior of robot arms. It allows engineers and researchers to visualize how these machines move, react, and respond to external forces or control inputs. This is critical in understanding and optimizing the performance of robotic systems for various applications, such as industrial automation, medical robotics, or autonomous vehicles.

SimMechanics simplifies the complex task of modeling by offering an intuitive interface for specifying the physical properties of robot components. Users can define parameters like mass, inertia, and geometry, and then connect them through joints with various degrees of freedom, enabling a faithful representation of the robot's mechanical structure.

Moreover, SimMechanics is an indispensable tool for controller development and validation. It facilitates the integration of control algorithms into the simulation environment, allowing engineers to assess how well these algorithms perform under different conditions. This process helps in refining control strategies, which is crucial for the precision and safety of robot manipulators.

A. Overview of Robot Manipulator Components

Robot manipulators are intricate systems characterized by a synergy of multiple critical components. The mechanical structure, often arranged in a series of interconnected links and joints, forms a kinematic chain that determines the manipulator's range of motion and workspace. These mechanical elements lay the foundation for the manipulator's physical capabilities.

Actuators serve as the muscle of the system, responsible for generating motion and applying the necessary forces to execute tasks. They act in response to control signals, propelling the manipulator's movements with precision and strength. Sensors, on the other hand, play a crucial role in collecting data from the environment and the manipulator itself. This feedback is indispensable for monitoring and adjusting the robot's actions in real-time, ensuring that it operates accurately and safely.

The controller is the brain of the manipulator, responsible for orchestrating its movements and actions. It interprets data from sensors, processes it, and generates commands for the actuators to achieve the desired tasks. This intricate coordination and control are essential for the manipulator to perform tasks with the required precision and efficiency.

In essence, comprehending the interplay of these components is fundamental to the effective design, construction, and operation of robot manipulators. It is the synergy of these components that empowers robots to perform tasks across various domains, from manufacturing and logistics to healthcare and research, making them invaluable tools in modern technology and industry.

B. Types of Robot Manipulators

- Articulated Robots: These robots have rotary joints similar to human arms and are highly versatile, making them suitable for tasks requiring a wide range ofmotion.
- SCARA Robots: SCARA (Selective Compliance Articulated Robot Arm) robots have rigid arms with two parallel rotary joints and are commonly used in assembly and pick-and-place operations.
- Cartesian Robots: Cartesian robots move in three linear axes (X, Y, Z), making them ideal for tasks requiring precise positioning, such as CNC machining.
- Delta Robots: Delta robots are parallel manipulators with high-speed capabilities, often used in tasks like pick-and-place in the food industry.
- Cylindrical Robots: These robots have a combination of rotary and linear motion, making them suitable for applications like welding and material handling.
- Polar Robots: Polar robots have a single rotary joint at the base and a telescoping arm, enabling them to perform tasks in a spherical work envelope.

C. Joints, Links and Work Envelope:

In the realm of robot manipulators, the concept of joints and links is fundamental to the very essence of how these machines operate. Joints are the pivotal hubs of articulation or rotation, serving as the vital connection points that bring the links together. The links, in turn, are the solid, unyielding segments forming the skeletal framework of the robot's physical structure.

Understanding the various types of joints, such as revolute (rotational) and prismatic (linear), is crucial for grasping the intricacies of a robot's kinematics and dynamics. These joint types dictate how the robot's components move, rotate, and extend, playing a pivotal role in its overall behavior and capabilities.

The work envelope, an equally critical concept, defines the spatial domain within which a robot can effectively navigate, reach, and manipulate objects. It is a three-dimensional realm shaped by the combined interplay of joint motions and link lengths, determining the extent of a robot's operational reach. In the world of practical applications, this concept becomes a linchpin in the selection of the most suitable robot for a specific task, ensuring that it can precisely access all the necessary positions and orientations to perform its designated functions with precision and efficiency.

III. CONROL SYSTEEM FOR ROBOT MANIPULATORS

Control systems are at the core of robot manipulators, governing their every move and interaction with the world around them. These intricate systems encompass a myriad of elements, including sophisticated algorithms, an array of sensors, and responsive feedback mechanisms that collectively harmonize to deliver precise and coordinated motion. Whether the task at hand is about following a predefined trajectory, adeptly navigating around obstacles, or managing force and pressure during an operation, control systems are the linchpin ensuring that robot manipulators execute their functions with utmost accuracy and efficiency.

Their indispensable role extends across various sectors, ranging from manufacturing processes that benefit from increased automation and consistent quality to healthcare applications where precision and reliability are paramount.

In these industries and many others, control systems act as the backbone of innovation, consistently improving productivity and expanding the horizons of what robot manipulators can achieve.

A. *Introduction to SimMechanics Toolbox*

The SimMechanics toolbox is a robust and indispensable resource within the realm of robotics and control system design. Its significance lies in its capacity to empower engineers and researchers, offering them a versatile platform for modeling and simulating the intricate mechanical facets of robot manipulators. Notably, it seamlessly integrates with MATLAB, which opens up a world of opportunities for users to create dynamic, real-world models of robot systems with remarkable ease and precision.

SimMechanics plays a pivotal role in bridging the gap between theoretical design and practical application. It allows for the representation of the mechanical structure, the configuration of joints and links, and the orchestration of their dynamic interactions in a virtual environment. This capability significantly aids in the development, analysis, and optimization of control strategies, ensuring that they perform optimally and reliably in the real world. In essence, SimMechanics serves as a critical tool for exploring and comprehending the intricate behavior of robot manipulators, enabling engineers to refine their designs and strategies long before physical prototypes are constructed, thus saving valuable time and resources in the development process.

B. *Modelling Process of Robot Manipulators*

The modeling process of robot manipulators is a profound endeavor that involves encapsulating the complex physical attributes and dynamics of these machines into a structured and comprehensive mathematical framework. At its core, this process commences with the fundamental task of defining the robot's structure, which entails specifying the number and arrangement of joints and links, essentially laying the groundwork for the machine's mechanical composition.

Beyond this initial structural delineation, the modeling process delves deeper into the heart of the robot's behavior. It encompasses the derivation of both kinematic and dynamic equations that intricately describe how the robot moves, as well as how it responds to external forces and interactions with its environment. These equations serve as the bridge between the mechanical components and the mathematical representation, giving insight into the robot's capabilities and limitations.

Furthermore, modeling extends its reach to encompass the integration of essential components, such as sensors, actuators, and control algorithms. Sensors are vital for data acquisition, allowing the robot to perceive its surroundings and itself. Actuators are the agents of motion, translating control commands into physical movements. Control algorithms are the intelligence behind orchestrating these actions, ensuring the robot's precision and efficiency.

In essence, the culmination of this comprehensive model, which encapsulates the robot's physical characteristics, dynamics, and the interplay of various components, serves as the bedrock for subsequent stages in the engineering process. This foundation facilitates simulation, analysis, and control design, enabling engineers to predict, assess, and optimize the behavior of robot manipulators in a myriad of scenarios, ultimately advancing the field of robotics and its diverse applications.

C. *Assumptions in modelling*

In the intricate process of modeling robot manipulators, a set of carefully chosen assumptions plays a pivotal role. These assumptions, while necessary for simplifying the mathematical representation and facilitating analytical solutions, introduce a level of abstraction that must be considered with vigilance. One commonly made assumption is the neglect of friction in the system. While this simplification eases the mathematical complexity, it bypasses the reality that friction exists and can significantly impact the manipulator's behavior. Friction can affect the accuracy and repeatability of movements and should be taken into account in specific applications where precision is critical.

Another common assumption is the consideration of rigid bodies. This simplifying assumption assumes that the robot's links and components do not deform under load, which may not hold true in some practical situations. The flexibility or compliance of materials used in the robot's construction can influence its behavior and accuracy. Treating joints as ideal without backlash or play is yet another simplification. In the real world, joints may exhibit a degree of clearance, backlash, or compliance, which can affect the robot's performance and control. Ignoring these factors may lead to suboptimal outcomes in practical applications.Engineers and researchers must maintain a balanced perspective when employing these simplifications. While they expedite the modeling process and offer analytical advantages, they should always be evaluated against the specific requirements of the application. Testing, experimentation, and validation of the model against real-world data become paramount to ensure the accuracy of control system design and the robot's performance in diverse and complex scenarios. The balance between mathematical abstraction and practical reality is key to producing effective and reliable models for robot manipulators.

IV. OPTIMIZATION ALGORITHM IN ROBOTICS

Optimization algorithms play a crucial role in robotics by enabling robots to make intelligent decisions, plan paths, and optimize various aspects of their behavior. These algorithms are used to solve complex problems such as motion planning, trajectory optimization, and task scheduling. For instance, in motion planning, optimization algorithms can find the most efficient path for a robot to navigate through obstacles while minimizing energy consumption or time. These techniques are vital in making robots more autonomous, efficient, and adaptable to real-world environments.

A. *Control Systems in Robotics*

Control systems serve as the fundamental infrastructure that underpins the realm of robotics, holding the pivotal role of orchestrating how robots navigate and interact with their surroundings. At the core of this multifaceted domain, control systems expertly manage the motors and actuators, translating electrical commands into physical motion, a critical process that drives the robot's every move. Incorporating a network of sensors, control systems provide robots with a sensory perception of their environment and internal state. These sensors act as the robot's "eyes" and "ears," capturing valuable data that is continuously processed and interpreted to enable the machine to understand and adapt to its surroundings.

The scope of control systems' responsibilities is extensive and spans an array of essential tasks. They are instrumental in ensuring the robot's stability, a fundamental prerequisite for safe and efficient operation. Whether the task involves maintaining an upright posture, a steady trajectory, or precise alignment during an operation, control systems are at the helm, guaranteeing the robot's equilibrium and accuracy. These systems also play a pivotal role in trajectory tracking, allowing robots to follow predefined paths with precision and reliability. Furthermore, control systems exhibit their mettle when responding to unforeseen events, harnessing their adaptability to navigate unexpected obstacles and challenges that may arise during tasks. With their advanced designs and algorithms, control systems provide robots with the capability to perform tasks autonomously and with impressive accuracy. This remarkable autonomy expands the potential applications of robotics across a diverse spectrum of industries, from the precision and efficiency of industrial automation to the innovation and safety of autonomous vehicles. In essence, control systems are the digital nervous system of robots, the invisible force that empowers them to perform tasks with grace, intelligence, and ingenuity in the modern world.

B. Role of PID Controllers

PID (Proportional-Integral-Derivative) controllers stand as a cornerstone in the realm of control systems for robotics, playing a crucial role in orchestrating the movements and behaviors of robots with remarkable precision. Their widespread usage in robotics stems from their ability to maintain control over a wide array of tasks, ensuring that robots execute their actions in accordance with desired trajectories or maintain specific states.

The underlying principle of PID controllers lies in their adeptness at continuously fine-tuning the control inputs of a robot. This is achieved by evaluating the error, which is the difference between the desired state and the actual state of the robot. The three components of a PID controller each serve a distinct purpose:

1. The Proportional component responds to the current error, providing a corrective input proportional to the present deviation from the desired state. This component ensures that the robot is constantly being nudged back towards the target, preventing large deviations and oscillations.

2. The Integral component takes into account past errors, enabling the PID controller to address any accumulated error over time. It is particularly useful in scenarios where the robot may have a steady-state error or bias that needs correction.

3. The Derivative component, on the other hand, anticipates future errors by examining the rate of change of the error. It dampens rapid changes and overshoots, thus enhancing the stability and responsiveness of the system.

These three components work in harmony to provide robots with a fine balance of stability, precision, and responsiveness. This makes PID controllers indispensable for a plethora of tasks in the realm of robotics, including position control to achieve specific spatial orientations, velocity control to manage how fast the robot moves, and overall stability in various applications. Whether it's guiding a robot arm through precise manoeuvres in manufacturing, ensuring a drone maintains steady flight, or guaranteeing that a self-driving car remains on a designated path, PID controllers remain a linchpin for the seamless execution of tasks in the vast landscape of robotic applications. Their adaptability and effectiveness contribute significantly to the advancement and widespread integration of robotics across a multitude of industries and domains. applications.

C. Implementation of PID Controllers for RobotManipulators

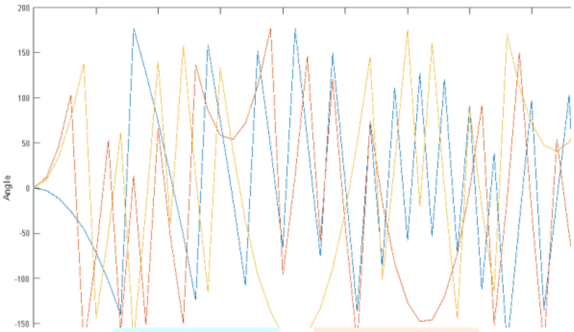
The application of PID controllers in robot manipulators is a strategic and widely used approach for the precise regulation of a robot's motion. Particularly, PID control finds significant utility in scenarios requiring tight position control, where the controller adeptly manages the motor commands to guide the robot's end-effector to a specified location with a high degree of accuracy. The heart of PID control is the meticulous configuration of its key parameters, known as the PID gains. These gains are tuned to establish a harmonious balance between the proportional, integral, and derivative components of the controller. This fine-tuning process is essential to ensure that the control system behaves as desired. By adjusting the gains, engineers and roboticists aim to achieve optimal control performance, where the robot responds swiftly to deviations from the desired position, minimizes steady-state errors, and exhibits resilience in the face of disturbances or uncertainties.

The advantages of properly configured PID controllers extend beyond just precise control of robot manipulators. These controllers offer the virtue of a fast response, ensuring that the robot can swiftly reach its target position with minimal delay. Furthermore, they effectively reduce steady-state error, enhancing the overall accuracy of the robotic system. The ability of PID controllers to maintain stability and robustness in the presence of external forces or perturbations makes them an appealing choice for controlling robot manipulators across a diverse array of applications. From the bustling assembly lines of manufacturing plants where they enable robots to execute precise pick-and-place operations, to the research and development labs where they are used for exact positioning in experimental setups, PID controllers prove their mettle in a multitude of domains. Their versatility and efficacy make them an indispensable tool in the toolkit of robotics engineers, continually advancing the capabilities and applications of robot manipulators in the modern world.

V. Result and Analysis

This section of the document likely focuses on the culmination of the research effort - the analysis and its results. It describes the analysis methodology, detailing the software tools, parameters, and scenarios used in the study. The section may also discuss the expected outcomes, based on the chosen analysis setup. While the actual results may not be presented, the discussion likely revolves around the implications of the expected outcomes, their significance, and how they align with the research objectives. This section forms the core of the study, shedding light on the effectiveness of the chosen methodologies and algorithms.

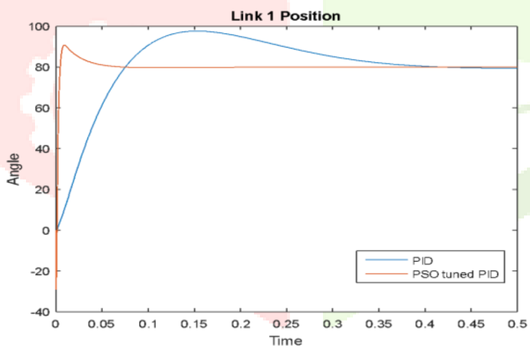
A. Open loop response



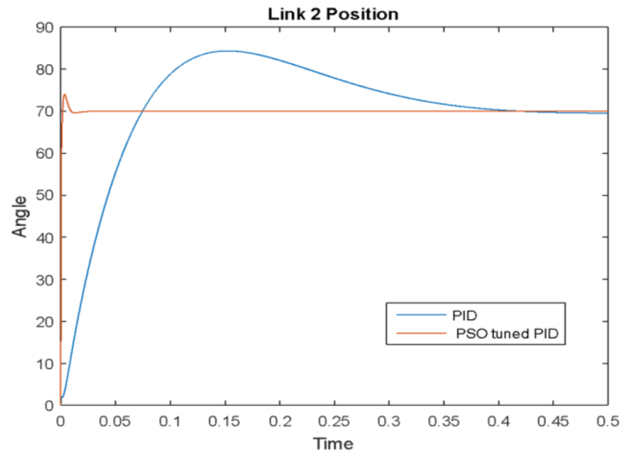
Position of link 1, 2 and 3 in Open loop

In Open loop, the control action from the controller is independent of the "process output". Since it is an open loop, the links will be moving in a random manner and there would be no control over the links. Therefore, we move to PID controller for Robot manipulator.

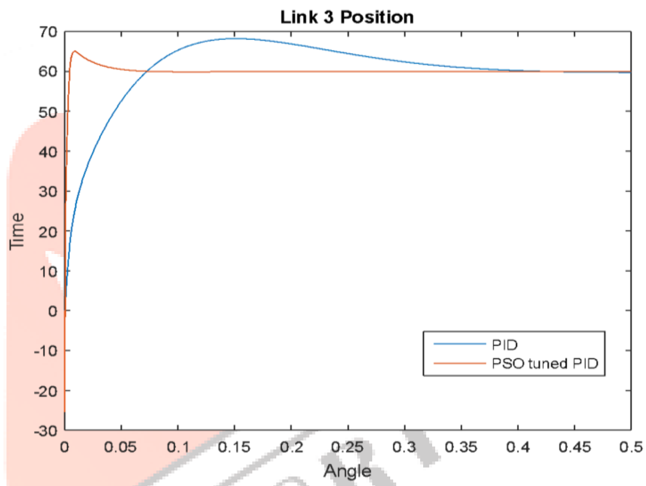
B. Comparison of response of PID Controller with PSO tuned PID Controller



It is inferred that for link 1 the Settling time of PSO-PID is less compared to the conventional PID and also the Rise time of PSO tuned PID is less compared to conventional PID.

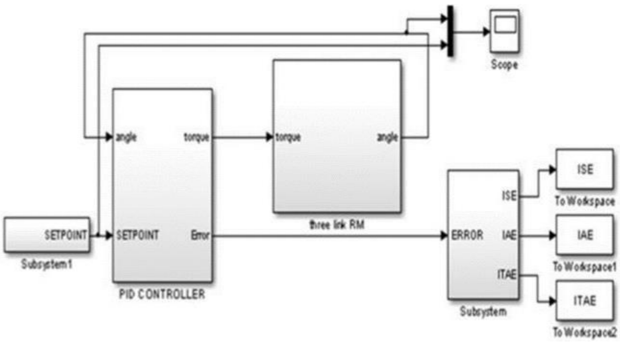


It is inferred that for link 2 the Settling time and the Rise time of PSO tuned PID is less compared to conventional PID. Hence the performance of PSO-PID is better when compared to conventional PID.



Settling time is better in PSO-PID and hence the performance of PSO tuned PID is better when compared to the conventional PID.

C. Analysis using Evaluation criteria



The PSO-PID is better when compared to Conventional PID in the Integral square error, Integral absolute error and Integral time absolute error analysis.

	ISE	IAE	ITAE
PID	1530	62.70	156.6
PSO Tuned PID	565.20	18.59	13.21

VI. CONCLUSION

The conclusion section serves as the culmination of the research effort, summarizing key findings, insights, and implications based on the simulation setup and expected results. It may discuss how the research objectives were addressed, highlighting the significance of the study in the context of robotics and control systems. Additionally, the section may touch upon the broader implications of the research and potential areas for further investigation.

REFERENCES

[1] A. Said, A. Khalil, R. Petra, S. Yunus, A. S. Peng and S. Khan, "PID Controller Optimization of Teleoperated 2DOF RobotManipulator Using Artificial Bee Colony Algorithm," 2019 IEEE 6th International Conference on Engineering Technologies and Applied Sciences (ICETAS), Kuala Lumpur, Malaysia, 2019, pp. 1-6, doi: 10.1109/ICETAS48360.2019.9117457.

[2] L. Qiang, S. Xuhua, L. Ting, C. Xiaoxia and Z. Jianpei, "Multi- objective Optimization Based Self Tuning Robot Manipulator Controller," 2019 Chinese Control And Decision Conference (CCDC), Nanchang, China, 2019, pp. 2593-2598, doi: 10.1109/CCDC.2019.8832358.

[3] Helon Vicente Hultmann Ayalaa, Leandro dos Santos Coelho, “Tuning of PID controller based on a multiobjective genetic algorithm applied to a robotic manipulator,” Expert Systems with Applications, 2012.

[4] Le Tien Dung, Hee-Jun kang and young shick Ro, “Robot manipulator modelling in matlab-Simmechanics with PD control and online gravity compensation,” International Forum on Strategic Technology (IFOST), 2010.

[5] Arturo Zavala-R´ıo, Marco Mendoza, V´ıctor Santib´an˜ez, Fernando Reyes, “An Output-Feedback PID-type Global Regulator for Robot Manipulators with Bounded Inputs,” 2015, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd.

[6] C. Hoffmann, S. M. Hashemi, H. S. Abbas, and H. Werner, “Benchmark Problem — Nonlinear Control of a 3-DOF Robotic Manipulator,” 52nd IEEE Conference on Decision and Control, December 10-13, 2013. Florence, Italy.

[7] Frank L.Lewis , Darren M.Dawson and Chaouki T.Abdallah, Robot Manipulator Control Theory and Practice, second edition, Prentice Hall, 2006.