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Enhancing Teaching of Fundamentals of Robotic Technology with Assistance of Maple Platform

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Abstract: This study investigates the integration of Maple software as a powerful tool to improve methods of instruction in robotics education. It discusses frequent issues encountered in teaching robotics, like the complexity of mathematical equations, difficulties in visualizing, time-consuming manual computations, programming complexities, challenges in analyzing control systems, and the necessity for good simulation and testing. By leveraging Maple's symbolic algebra abilities, visualization tools, automation characteristics, programming efficiency, and simulation abilities, teachers may address these difficulties properly. Maple enables the simplification and solution of challenging equations, the visualization of complex ideas, the automation of manual calculations, the development of algorithms, the analysis of control systems, and the simulation of robotic systems. Through the integration of Maple into robotics education, students acquire a greater awareness of theoretical principles, practical abilities in robotics, and the ability to develop and solve real-world issues related to robotics.

1. Introduction

Robotics is a dynamic and multidisciplinary field that comprises numerous disciplines, such as mechanical engineering, electrical engineering, computer science, and artificial intelligence. This includes the design, development, operation, and utilization of robots, which range from simple robotic devices to complex autonomous systems. The backbone of robotics is an in-depth understanding of complex mathematical concepts [1], which provides a foundation for developing innovative solutions to practical issues. Between these concepts, the understanding of spatial interactions among a robot's joints and end-effectors is significant [2]. This mathematical framework permits researchers and engineers to reliably determine the position and orientation of the robot's end-effector in three-dimensional space by using the angles or displacements of its joints. Therefore, this basic understanding offers an essential foundation for multiple uses in robotics, especially in the fields of robot manipulation, motion planning, and control. Recent investigations highlight the value of its relevance in numerous fields: Mathematical equations describing the location and orientation of the end-effector are important in robot manipulation operations [3]. They help in designing robust control methods, as stated by Spong et al. [4]. Motion planning algorithms, as stated by LaValle [5], use these mathematical principles to determine collision-free pathways for robots moving through complex environments, permitting autonomous navigation while obeying task requirements and avoiding obstacles. Furthermore, the analysis of spatial interactions in robotics education works as a basic concept, boosting students' comprehension of robotics, as highlighted by Craig [6]. By integrating this basic feature into the educational curriculum and applying novel techniques and algorithms, researchers and engineers constantly expand the boundaries of robotics. This allows robots to undertake more complex jobs with precision and efficiency. However, the mathematical adjustments involved in this area of robotics education can provide significant challenges for students to tackle.

As a mathematic assistance platform, maple has discovered significant use in multiple additional fields. Several studies have shown Maple's effectiveness in areas like mathematics, engineering, physics, and computer science. For example, in mathematics, Maple has been employed for symbolic computation, mathematical modeling, and solving complex equations[7]. Moreover, researchers have employed Maple for system modeling, simulation, and optimization tasks. Hrdina [8] carried out studies with the CAS software MAPLE and discovered it as a powerful tool for solving control problems from both geometric and algebraic aspects. Their findings indicate that Maple is especially proficient at controlling low-dimensional circumstances emerging in varied mechanical systems, such as trident snake robots and 3-link snake robots. Additionally, their study demonstrates the possibility of investigating alternate geometric structures inside these systems, which could offer further insights and establish further limits on the mechanism's movement. This highlights the versatility of MAPLE in learning and optimizing the control of mechanical systems, paving the path for innovations in robotics and related areas. Employing Maple to teach beginner programming skills provides an opportunity to add a greater number of mathematically concentrated programming exercises and problems when compared to common programming courses. This method not only emphasizes basic concepts in programming but also offers practical uses of calculus approaches. Within the dynamic and user-friendly environment of a Computer Algebra System (CAS) like Maple, students can easily comprehend all the key ideas of computer programming and robotics [9]. Furthermore, the inclusion of Maple into programming and robotic instruction enables students to learn about complex mathematical concepts in a hands-on manner, encouraging a greater understanding of both programming and mathematical principles.

The main objective of this paper is to explore how Maple can be integrated into robotics education to enhance students' understanding by bridging the gap between theoretical knowledge and practical application.

2. Main Problems in Teaching Robotics Modeling

2.1 Complex deduction and solution of mathematical equations for robot modelling

Teaching the mathematical principles of robotics, such as kinematics and dynamics, involves interacting with the exceptionally complex equations needed for comprehending how robots behave and communicate with their surroundings. For example, forward kinematics requires students to solve numerous simultaneous equations to figure out the positions and orientations of robot arms, requiring trigonometric functions and homogeneous transformation matrices. As the number of joints grows, the difficulty of these equations expands exponentially, which makes them difficult for students to manage. Inverse kinematics is extremely complex, as it involves identifying the joint parameters that yield an ideal end-effector position and orientation. This problem demands solving non-linear equations that may include different solutions or require iterative computations for approximation. Understanding the Jacobian matrix and dealing with singularities where solutions become undefined increases additional complexity.

Dynamics, dealing with forces and torques, contains deriving and solving second-order differential equations from Newton-Euler or Lagrangian mechanics. These equations characterize the relationship among applied forces/torques and subsequently accelerations of the robot's joints, demanding students to grasp complex ideas like inertia, Coriolis forces, and potential and kinetic energy. The sheer sophistication of these equations could intimidate students, hindering their ability to understand key concepts effectively.

Calculations performed manually for robotic systems, specifically those needing numerous degrees of freedom, are both time-consuming and prone to errors. This concern is particularly crucial in educational environments where time is constrained. Students often spend much of their study time carrying out repetitive operations, such as solving kinematic chains or integrating dynamic equations, instead of concentrating on developing the underlying principles. This repetitious effort can lead to frustration, poor engagement, and diminished learning efficiency. Errors in manual computations are prevalent and can cascade through successive phases, resulting in inaccurate findings and misconceptions. These errors not only disrupt the learning process but additionally prevent students from connecting thoroughly with the subject matter. As stated by Ruta Desai [10], integrating computational tools can substantially decrease the time spent on manual calculations, enabling students to quicker learn and apply theoretical ideas in actual situations. This move may encourage learning efficiency while enhancing students' overall knowledge of robotics.

2.2 Difficulty in mastering of concepts and simulation

Many topics in robotics, including the movement of robotic arms, trajectories, and workspace analysis, are complicated and hard for students to understand. Without appropriate tools for visualization, students might be unable to comprehend how various variables affect robot performance. For instance, illustrating the workspace of a robot or the path it takes to reach a desired point may significantly improve understanding. When students understand how joint angles and link lengths affect the robot's reach and mobility, they build an expanded understanding of kinematic and dynamic principles. Similarly, displaying trajectories helps students understand how robots organize and carry out moves to prevent obstacles and optimize pathways. These visuals help bridge the gap between theoretical equations and real-world applications, making it simpler for students to recognize the practical implications of their studies while encouraging a more spontaneous grasp of complicated robotic behaviors.

Programming robots for mastering the concepts includes developing complicated algorithms that control the robot's movements and responses, which can be challenging for students unfamiliar with programming or robotics. Using these algorithms from the beginning requires not just acquiring the syntax and logic of computer languages but also transforming theoretical concepts into functional code. This method requires incredible intellectual effort and may provide trouble for students with understanding complex concepts and implementing them properly. Furthermore, debugging and testing such algorithms adds an additional level of complexity, leading students to detect and repair issues in their code, which could be time-consuming and difficult. Consequently, students might become overwhelmed by the complexity of programming and algorithm development, obstructing their ability to entirely grasp and use the fundamentals of robotics.

Robot simulation and testing are vital aspects of robotics education, allowing students to verify their designs and algorithms in a controlled, virtual environment prior to implementing them. However, the procedure of setting up and carrying out these simulations may be challenging and resource-intensive, usually requiring professionals' software and hardware. Students must learn to manage these technologies, which can be challenging without enough guidance and support. Furthermore, evaluating the findings of simulations to make educated judgments for design modifications and algorithm enhancements demands an excellent grasp of both the simulation environment and the underlying robotic concepts. The complex nature of such tasks can be an important barrier to effective learning, as students may struggle with the technicalities of simulation software, detracting from concentrating on basic robotics standards. Integrating user-friendly and accessible simulation tools within the curriculum might help reduce these issues, giving students practical experience in a controllable and instructional context.

3. Usage of Maple platform for teaching

To address these problems, the complex computational software Maple can be applied. Maple encompasses wide features for symbolic and numerical computation, making it an optimal resource for understanding and illustrating challenging mathematical issues. With Maple, students can directly investigate forward kinematics equations, experiment with different parameters, and notice the resulting transformations, consequently improving their understanding and expertise in robotics mathematics. Furthermore, Maple's user-friendly interface and numerous documentations offer crucial assistance for students as they navigate through the nuances of forward kinematics and other mathematical concepts used in robotics teaching. Although Maple software might not have been substantially used in solving issues associated with robotics education, after studying all the above problems that learners undergo, we suggested use of Maple software in different aspects as the main solution. The example for transformation matrix in forward kinematics through maple software platform is presented below in Fig. 1. With the platform, it is obvious the relationships among parameters of the kinematics equation can be indicated in the teaching.

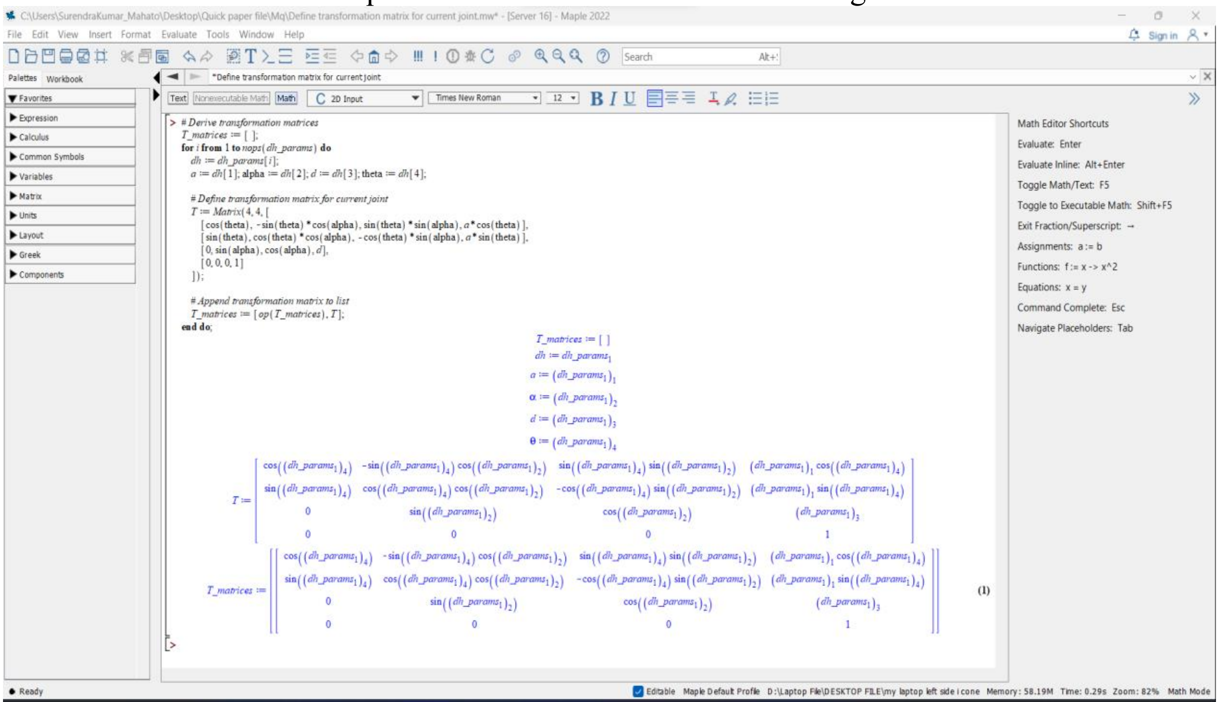

Fig. 1 Transformation matrix in forward kinematics in Maple platform

For efficient use of this software, one needs to get familiar with the many tools provided by Maple. It is akin to having an exceptionally intelligent assistant for mathematics and scientific subjects. With Maple, you can solve complex equations without breaking a sweat. Plus, it's amazing at showing you what's going on using great visuals and graphs. There are all sorts of essential tools for robotics, like techniques to solve hard equations, work with numbers, and even produce 3D representations of robots and their actions. Maple's powerful tools makes teaching and learning robotics easier. The implementation process with the assistance of Maple can be followed by that indicated in Fig. 2. Teachers must determine which aspects of robotic modeling will contain ideas that will be enhanced by applying Maple's computational features. This entails identifying how the students' learning objectives could be matched with the curriculum and creating assignments and activities using Maple to supplement examples to be taught and encourage the practice of concepts learned. When Maple is adopted as a learning tool, teachers can ensure that knowledge delivery is complemented by a dynamic application that exhibits preliminary classes, simulations, and models.

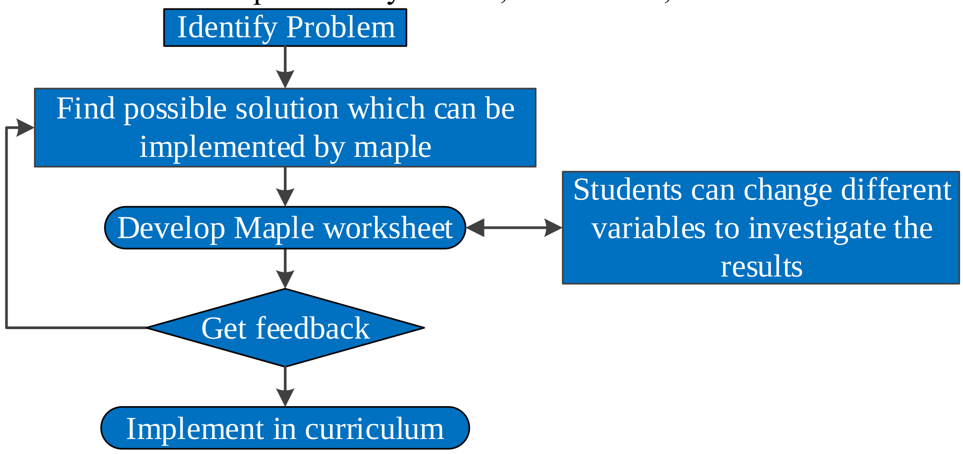

Fig. 2 Implementation process with assistance of Maple

4. Implementation of Maple assistance for curriculum teaching

To deal with the problems in teaching robotics employing Maple software, we can implement an extensive strategy that utilizes Maple's capabilities to make complex mathematical equations easier, visualize complex concepts, figure out manual calculations, improve programming and algorithm development, analyze robot control systems, and conduct robot simulation and testing. The following is a possible solution for the existed problem in the curriculum teaching.

4.1 Sequential mathematical equations support in teaching

Maple's symbolic algebra expertise provides an impressive toolset for reducing and solving complex equations found in numerous fields of robotics, including forward and inverse kinematics, dynamics, and trajectory planning. By utilizing Maple's capabilities, teachers may break down challenging formulas into small steps, providing students with an understanding of the fundamental concepts in mathematics. Maple worksheets permit teachers to develop interactive demonstrations, enabling students to get involved with the topic and explore different possibilities. Through Maple's plotting functionalities, teachers may illustrate the solutions to equations, assisting in understanding geometrical connections while improving students' visual analytical abilities. The step-by-step explanations offered throughout Maple worksheets assist students' journey over the complexities of robotic mathematics, urging a greater understanding of the subject matter. By bringing Maple into the curriculum, teachers may successfully address the issue of complex mathematical equations in robotics education, enabling students to investigate complex concepts with ease.

Maple's programming features allow instructors to simplify repetitive manual calculations in robotics by developing scripts and functions that perform tasks such as solving kinematic equations, deriving Jacobian matrices, and integrating dynamic equations of motion. By giving Maple worksheets with developed templates and algorithms for usual robotic calculations, instructors can simplify the learning experience and reduce the load of manual calculations on students. These Maple worksheets may be used as interactive learning tools, enabling students to investigate multiple scenarios and variables while Maple executes the computational components in the background. Through the automation of repetitive calculations, students may concentrate their attention on understanding the fundamental ideas and concepts of robotics rather than being slowed down by individuals' calculations.

4.2 Visualization of complex concepts

Maple's apps with interaction and visualization features allow lecturers to illustrate complex concepts in robotics education, such as robot trajectories, workspace analysis, and configurations, in a simple and engaging way. Utilizing Maple's plotting capabilities, teachers can generate dynamic 2D and 3D visualizations of robot movements, routes, and workspaces, delivering students with an explicit understanding of spatial relationships and geometric boundaries. Through interactive demonstrations and simulations created with Maple, students may examine the influence of different variables on robot behavior and performance, increasing their understanding of complex robotic issues. Maple's user-friendly interface enables teachers to develop visualizations and simulations based on individual learning objectives, adapting to the various needs and preferences of students.

Maple's programming capabilities provide a diverse platform for teaching students about programming and algorithm development in the field of robotics. Teachers may offer coding examples and exercises in Maple to clarify how concepts in robotics, like control algorithms, motion planning strategies, and path optimization approaches, can be understood in functional code. Maple's interactive interface allows students to experiment with code snippets, edit settings, and see the results of their changes in real-time, urging an active learning experience. By utilizing Maple's troubleshooting capabilities, students may identify and troubleshoot bugs in their code more efficiently while gaining helpful insights into the debugging process. Through hands-on programming tasks in Maple, students may acquire practical skills in algorithm development for robotics, improving their capacity to create, implement, and refine algorithms for robotic systems.

MapleSim's unique multi-domain modeling and simulation tool provides a strong platform to develop dynamic models of robotic systems and their surroundings. Teachers can build Maple worksheets involving simulation models of robots, sensors, actuators, and control systems, enabling students to explore and engage with virtual robotic systems. MapleSim's simple interface allows students to simulate multiple situations, test different control methods, and analyze the behavior of robotic systems in real-time. Using Maple's analytical features, students may review simulation results, examine system performance, and propose areas for improvement or optimization.

5. Conclusion

The integration of Maple software provides an innovative method for robotics education, providing an integrated solution to the challenges encountered in teaching robotics. Through Maple's broad variety of tools and functions, teachers can go beyond traditional teaching approaches, providing students with engaging educational experiences that connect theory and practice. By utilizing Maple's capabilities, students are encouraged to learn complex mathematical concepts, visualize complex theories, and establish advanced algorithms with ease and knowledge. Moreover, Maple's user-friendly interface and interactive features encourage active participation and experimentation, urging a culture of curiosity and creation among growing roboticists. As technology keeps evolving, Maple remains unchanged in its commitment to promoting robotics education, pushing growth, and cultivating supremacy in the next generation of engineers and researchers.

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