Research on the Optimization Strategy of Mechanical Design and Programming in FTC

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Abstract: In FTC (FIRST Tech Challenge), mechanical design and programming are two essential components that significantly influence the team's overall results. By analyzing FTC's requirements and scoring standards, this paper examines how to integrate mechanical design innovation with programming optimization strategies to enhance the performance of robots. This paper begins by discussing the basic principles and innovative mechanical design methods and analyzes effective programming practices, including algorithm optimization, code reconstruction, and system testing. This study combines case analysis with a comprehensive strategy that integrates mechanical and program optimization. The goal is to provide a system framework for the FTC team to enhance the robot's overall performance. In the FIRST Tech Challenge, mechanical design innovation and programming efficiency are the keys to winning the competition. The strength of mechanical design is its ability to directly influence the physical performance of robots, including speed, stability, and task execution accuracy. Effective solutions require an in-depth understanding of the seasonal tasks, clear design goals, and rapid iteration and testing using modular design ideas. Additionally, the reliability and maintainability of the robot are crucial factors in the design, as they determine the robot's continuous combat capability in fierce competition.

1. Introduction

FIRST Tech Challenge is a robot design and programming competition participated by teenagers worldwide. The goal is to inspire enthusiasm for science and technology through hands-on activities while fostering teamwork, problem-solving skills, and innovation. Participants in the FTC (FIRST Tech Challenge) must design, build, test, and program robots to accomplish complex tasks and collaborate and compete with other teams during the competition. Efficient mechanical design and accurate programming are the cornerstones of success in the competition. The team requires more in-depth research and optimization in mechanical design and programming strategies as competition levels continue to rise. An excellent robot design needs to perform tasks quickly and accurately while being stable and reliable in a competitive environment. Similarly, programming requires ensuring that robots respond accurately to the operator's commands while optimizing algorithms and program logic to improve performance during the autonomous phase.

This paper discusses effectively integrating innovative mechanical design concepts and advanced programming technology in FTC to form a comprehensive optimization strategy. First, this study reviews FTC rules and scoring criteria and discusses the role and importance of mechanical design and programming in FTC. By analyzing success cases and best practices, this study proposes specific design and programming recommendations to help FTC teams achieve better competition results [1].

2. Key Elements of Mechanical Design in FTC

2.1 Basic Principles of Robot Structure Design

The design of the robot structure needs to focus on the competition task to ensure the stability and strength of the structure. Moreover, it pursues lightweight to improve mobility. The basic principles involve the following. The first is the low center of gravity, which can improve stability and avoid

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overturning in fierce competition. The second principle is to distribute the load evenly to ensure the robot's maneuverability and stability in all directions. The third principle is simplifying the design to minimize failure points and ease maintenance. The fourth principle is modular design, which facilitates rapid iteration and replacement of damaged components [2].

2.2 Optimization of Power System and Drive Mode

The power system is the "heart" of the robot, and its performance is directly related to the speed and strength of the robot. The choice of the motor must account for torque and speed, balancing them with the appropriate gear ratio configuration. In addition, the choice of driving mode (such as an omnidirectional wheel, tracked wheel, or standard wheel) directly affects the robot's maneuverability and passing rate. Some teams may opt for Mecanum or omnidirectional wheels to enhance control and movement, enabling seamless omnidirectional movement without dead ends.

2.3 Selection and Configuration of Sensors and Actuators

Correct selection and configuration of sensors and actuators are very important for performing complex tasks. Sensors, such as encoders, gyroscopes, and distance sensors, are convenient for updating environmental information and robot status and help robots locate and perform tasks more accurately. Actuators, including servo motors and cylinders, are utilized to control robot movements accurately. According to the task's needs, selecting appropriate sensors, actuators, and fine configuration will greatly improve the robot's performance.

2.4 Design Adjustability and Fault Tolerance

In designing, it is necessary to consider the various uncertainties the robot may face in the competition. Therefore, the adjustability and fault tolerance of the design become essential. The robot's structure and system should be designed for quick on-site adjustments to accommodate the varying conditions of competition venues and rules. Additionally, the design should incorporate redundancy and fault tolerance to ensure the robot can still complete its tasks, even if some systems are damaged.

2.5 Challenges and Solutions in Mechanical Design

The common challenges in mechanical design include limited design time, resources, and technical expertise. In response to these challenges, the team can adopt the following strategies: using 3D printing and rapid prototyping technology to accelerate the iterative process; Open-source resources and community design sharing can provide inspiration and solutions for the team; The effective distribution of coach and tutor resources is helpful to improve the team's ability to cope with technical challenges [3].

3. Synergy Between Mechanical Design and Programming Optimization

3.1 Interaction between Mechanical Design and Programming

Mechanical design lays a strong foundation for programming, while programming maximizes the potential of hardware. For example, fine-tuned mechanical structures can reduce programming complexity and streamline control algorithms. On the other hand, efficient programming compensates for the shortcomings of mechanical design and can also achieve functionalities that mechanical systems lack through software, such as utilizing software filtering technology to enhance the stability and accuracy of sensors.

3.2 A Close Fit between Mechanical Design and Control Strategy

Mechanical design and programming must be closely coordinated for the robot's control strategy. For instance, implementing a PID control loop is crucial for maintaining the robot's speed and direction stability. The choice of hardware, such as different types of motors and sensors, should be consistent with the requirements of the control algorithm. An appropriately matched control system can improve the robot's accuracy when performing tasks [4].

3.3 Process Optimization and Resource Integration

The team must prioritize process optimization and resource integration in design and programming to achieve optimal performance. The process is not only about optimizing the workflow of a single component but also about integrating all parts in the whole system to use time and resources with high efficiency. For instance, using version control tools in the integrated development environment (IDE), team members can work on different modules simultaneously and finally integrate them seamlessly.

3.4 Adaptability between Modular Design and Software Modules

Modular design is the key to modern engineering practice. It enables mechanical components and software modules to be developed, tested independently, and integrated into a complete system. Therefore, it ensures that each part can be quickly replaced or upgraded when needed so as not to affect the stability of the whole system. For software, modular programming enhances code clarity, maintainability, and scalability.

3.5 Optimization of Feedback Mechanism and Adjustment Strategy

An effective feedback mechanism is essential for continuous improvement of programming and mechanical design. Using the data provided by sensors, the team can analyze the robots' real-time performance and identify and correct problems. In programming, software can record and analyze data, optimize control strategies, and reduce system errors. On the hardware side, creating a standardized test program is essential for improving competition performance by verifying the robot's capabilities across various aspects.

4. The Challenges of Mechanical Design and Programming Optimization Strategy in FTC

4.1 Design Complexity and Resource Constraints

FTC teams frequently encounter significant challenges when designing and building robots, such as complex designs and limited resources. The robot designs often require careful refinement to accomplish a range of intricate and innovative tasks. This necessity for refinement can lead to an increase in design complexity. However, the participating teams are strictly limited in time, money, and manpower. It means that while pursuing design innovation and complexity, we must effectively manage and allocate limited resources to ensure the practical feasibility of the design. It is essential to make careful calculations and make rational use of resources on the premise of ensuring the performance of the robot. It requires team members to have superb design skills and acquire excellent resource management and project management capabilities to ensure that innovative and practical robots can be built under limited resources [5].

4.2 The Balance between Power System and Control Precision

In FTC, selecting and building the robot's power system is crucial. The performance of the power system directly influences the robot's speed and strength, while control accuracy determines whether the robot can complete tasks effectively. High-power motors can provide great power and speed. However, it is often difficult to control accurately. On the contrary, a system with high control accuracy may be unable to complete some tasks due to insufficient power. Therefore, finding the best balance between the power system and control accuracy is a big challenge for the participating teams. The team must conduct thorough investigations and testing when selecting motors, sensors, and control systems to ensure that the chosen components meet power demands and achieve precise control. In addition, the power system needs to be finely tuned to ensure the robot can perform at its best in the competition.

4.3 Requirements for Real-time and Stability in Programming

FTC has very high requirements for robot programming, particularly regarding real-time performance and stability. In an unmanned environment, robots need to complete specific tasks autonomously, so programming is required to be highly real-time and can respond to sensor inputs quickly and make accurate control outputs. Moreover, programming stability is crucial, as minor errors can cause the robot to fail its task or even malfunction. Therefore, developing an efficient and stable control algorithm has become a big challenge for the participating teams. The programming team must continuously optimize the algorithm to enhance code execution efficiency. In addition, the reliability and stability of the code need to be guaranteed. It is necessary to test the robot fully to verify the real-time programming stability and ensure it performs well in the competition [6].

4.4 Multi-sensor Data Fusion and Processing Difficulties

To improve the ability of robots to perceive, FTC often uses various sensors, such as cameras, lidar, gyroscopes, etc. However, the format and accuracy of data generated by sensors are different. Effectively fusing and processing data to provide accurate information for robots operating in complex environments has become an urgent problem that needs to be addressed. The complexity of data fusion arises from potential conflicts and redundancies among data collected from different sensors, necessitating careful screening and integration [7]. Additionally, real-time sensor data processing also challenges the programming team, as robots need to process and make decisions about large amounts of data quickly. Therefore, developing efficient data fusion algorithms and real-time processing systems has become one of the important tasks of the participating teams. It requires team members with profound programming and data processing skills to ensure that robots can accurately perceive the surroundings environment and make correct responses during competitions.

4.5 Compatibility between Hardware and Software Debugging

The interaction between hardware systems and software applications can lead to unforeseen problems, such as interference among electronic components and unexpected program behaviors. These issues may not emerge until the system is integrated, requiring the team to be ready to quickly diagnose and resolve interdisciplinary problems and perform debugging and compatibility testing.

To address these challenges, FTC team members must fully use system engineering principles for overall planning and management. Effective strategies may include using an iterative design method, actively utilizing simulation software for pre-testing, reasonably assigning tasks, and encouraging teamwork. Continuous practice, testing, and experience accumulation are essential for the team's responsiveness to challenges in design and programming. By overcoming these key challenges, the team can create a competitive robot and gain valuable engineering practice knowledge in the process.

5. Cooperative Optimization Strategy of Mechanical Design and Programming

5.1 Interaction between Mechanical Design and Programming

Mechanical design influences programming, which in turn enhances mechanical design functions. An innovative mechanical structure may not perform well due to the lack of elaborate control procedures, and vice versa. Designers and programmers must collaborate closely to establish a design plan and programming approach. By breaking down disciplinary barriers and exploring interdisciplinary solutions, the overall performance of robots can be significantly enhanced.

5.2 Strategies for Process Optimization and Resource Integration

The concept of resource integration entails the optimization of resource utilization, encompassing human, time spent, and material resources. Process optimization involves the smooth connection between design and programming. Team members should adopt an agile development framework, which allows for iteration and improvement throughout various design and programming stages. By having regular meetings and program reviews, we can identify problems in advance and develop effective solutions. A version control system helps teams manage software changes, preventing conflicts and data loss.

5.3 Synergy of Mechanical Design and Control Algorithm

The development of a control algorithm should be based on mechanical design characteristics. An accurate mathematical model can predict and simulate robot behavior, and actual test data can be used to correct the model. For example, if the robot's motion depends on complex physical dynamics, the algorithm designer must understand these dynamics to write efficient code. It is imperative for mechanical designers to comprehend the constraints imposed by the control algorithm, including its processing speed and feedback delay, to ensure the viability of the design in conjunction with the control algorithm.

5.4 Adaptability between Modular Design and Software Modules

Modularity is of paramount importance in the fields of mechanical design and programming. From a mechanical standpoint, this concept signifies that each constituent component can be developed, tested, and replaced in an autonomous manner. On the software level, each functional module should be self-enclosed and reusable. Modularization of software and hardware simplifies the design and maintenance process and accelerates the iterative process. It is very important that software and hardware modules are compatible and dock seamlessly. They are extremely important to maintain flexibility and stability of the entire system.

5.5 Optimizing Feedback Mechanism and Adjustment Strategy

Effective feedback is the core of continuous improvement. People get information from sensors and user input, and use the information to adjust the behavior of robots. Programming teams need to implement data recording and performance analysis tools so that they can assess the power of the robot after each test. Furthermore, designers continue to optimize their mechanical structures according to this data. It is necessary to ensure that there is a fast and reliable feedback loop so that the team can understand the problem in time and formulate solutions.

Continuous communication and cooperation are extremely important for design and programming. Transparent workflows allow each member to understand the latest status and requirements for a project, allowing them to respond quickly and adapt to changes. Regular team meetings, code reviews, and design evaluations ensure that all members possess a comprehensive understanding of the robot system. The implementation of a strategy of short-period iteration in R&D enables the team to respond flexibly to changes in competition rules, facilitating the timely adjustment of mechanical design and programming strategy to meet new requirements.

6. Conclusion

This paper discusses the optimization strategy of mechanical design and programming in FTC and analyzes how to support each other and work collaboratively to achieve optimal performance in competition. Mechanical design lays the physical basis for robots, and effective programming makes intelligent operation possible. Collaborative optimization of the two can achieve the best performance of robots in competitions. This study summarizes the key elements for successfully implementing mechanical design and programming strategies in FTC: First, careful management and integration of resources ensure effective coordination of design and programming work. Second, precisely matching the mechanical system with control logic guarantees the smooth operation of the whole. Third, modular design and software development are integrated to enhance system maintainability and flexibility. Additionally, timely and effective feedback and adjustment mechanisms ensure continuous performance improvement.

Faced with design complexity, resource constraints, and system reliability challenges, FTC teams must adopt a systematic approach to design and programming. Through close mechanical design and programmatic cooperation, team members build competitive robots that meet competition requirements and learn and acquire innovative solutions in interdisciplinary collaboration and technical practice. FTC is a competition for teenagers' technical skills, and it also facilitates students' practice and improvement of their communication, teamwork, and complex problem-solving skills. These skills will have a profound positive impact on their future careers. To succeed in FTC, teams must continually explore and implement collaborative optimization strategies for mechanical design and programming, which will be crucial for future success.

References

[1] Liu X J, Zou W R. Multi-dimensional innovation ability training mode in mechanical college students 'discipline competition under the integration of micro-innovation and Internet [J]. China Educational Technology and Equipment, 2018, (04): 40-41+46.

[2] Lu W X. Design and assembly of FTC robot [J]. Science and Technology Innovation Herald, 2017, 14 (32): 123-124.

[3] Liu T S. Application of 3D Printing Technology in Mechanical Innovation Competition of Vocational School [J]. Laboratory Science, 2017, 20 (02): 232-235+237.

[4] Diao Xingling. Qualcomm Hou Jilei: Artificial intelligence will be applied to various types of terminals [J]. Telecom World, 2016, (08): 41.

[5] Zheng Qingfei. Design and assembly of a FTC robot [J]. Electronics World, 2015, (15): 128-129.

[6] Alamr M A, Gomaa M R. A review of parabolic trough collector (PTC): application and performance comparison[J]. environment, 2022, 2: 5.

[7] Ault H K, Fraser A. Use of technology solutions to improve CAD instruction[J]. The Engineering Design Graphics Journal, 2012, 76(3).