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On the Application of SolidWorks Software in the Design of Robot Internal Structures

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Abstract: ***The adoption of SolidWorks software in the design of a robot's internal structure facilitates significant advancements in precision, efficiency, and innovation. This study explores the application of SolidWorks to model, simulate, and optimize the internal components of robotic systems. Employing a combination of CAD (Computer-Aided Design) and CAE (Computer-Aided Engineering) tools within SolidWorks, the research aims to streamline the design process and enhance the structural integrity of robots. Through detailed analysis and comparison with traditional design methods, the study concludes that SolidWorks offers superior capabilities in handling complex geometries and improving design accuracy. The findings have major implications for robotic engineering, promoting more cost-effective and reliable robot development.***

Keywords: SolidWorks; Robot Design; Internal Structure; CAD; CAE.

1. INTRODUCTION

The field of robotics has undergone unprecedented growth in recent decades, with applications spanning industrial automation, healthcare, aerospace, and consumer electronics. At the core of every functional robot lies a meticulously designed internal structure, which serves as the framework for integrating mechanical components, electrical systems, and computational modules. The efficiency, durability, and performance of a robot are inherently tied to the precision and functionality of its internal structure, making its design a critical phase in the lifecycle of robotics development.

In this context, computer-aided design (CAD) software has emerged as an indispensable tool, revolutionizing traditional design processes by enabling digital prototyping, iterative refinement, and multi-disciplinary collaboration. Among the myriad CAD solutions available, SolidWorks software stands out for its user-friendly interface, robust functionality, and versatility in handling complex mechanical designs. This article explores the multi-faceted role of SolidWorks in the design of robot internal structures, examining its applications in 3D modeling, structural analysis, integration of subsystems, collaboration, and manufacturing preparation. By delving into specific use cases and technical capabilities, the paper highlights how SolidWorks streamlines the design workflow, enhances precision, and accelerates the transition from concept to functional robot.

2. 3D MODELING: THE FOUNDATION OF INTERNAL STRUCTURE DESIGN

At the heart of SolidWorks' utility in robot design is its advanced 3D modeling capabilities. Unlike traditional 2D drafting, which relies on orthogonal views and requires mental visualization of spatial relationships, 3D modeling in SolidWorks creates a digital replica of the robot's internal structure, enabling designers to interact with, inspect, and modify components in a virtual 3D space.

2.1 Parametric Modeling: Flexibility and Iteration

SolidWorks employs a parametric modeling approach, where every dimension, feature, and relationship between components is defined by parameters. This means that if a designer modifies a dimension (e.g., the length of a bracket or the diameter of a motor housing), all related features and components automatically update to reflect the change. For robot internal structures, this is particularly useful during the iterative design phase.

For example, consider a designer working on the internal frame of a collaborative robot intended to assist human workers in a factory. Initially, the frame is designed to accommodate a 12V motor, but later, the team decides to upgrade to a more powerful 24V motor with a larger diameter. In a non-parametric system, the designer would need to manually adjust the motor housing, brackets, and any adjacent components to fit the new motor—a time-consuming process prone to errors. In SolidWorks, however, modifying the motor's diameter parameter automatically resizes the housing and adjusts the positions of mounting brackets, ensuring all components remain aligned. This flexibility reduces design cycles and allows teams to explore multiple iterations efficiently.

2.2 Feature-Based Design: Building Complexity from Simple Elements

SolidWorks' feature-based design tools enable designers to construct complex internal structures by combining simple geometric elements (e.g., cuts, fillets). For robot internal structures, which often consist of custom brackets, channels, and mounting plates, this modular approach simplifies the design process. A typical workflow might involve: Creating a base sketch of a bracket on a 2D plane; using the "Extrude" feature to convert the sketch into a 3D solid; adding "Cut" features to create holes for screws or slots; applying "Fillet" or "Chamfer" features to remove sharp edges, reducing stress concentration points and improving safety.

This step-by-step construction allows designers to build intricate components—such as the gearbox housing for a robotic arm or the battery compartment of a mobile robot—with precise control over dimensions and tolerances.

2.3 Assembly Modeling: Ensuring Component Compatibility

Robots are assemblies of numerous components, and their internal structures must ensure that all parts fit together without interference. SolidWorks' assembly mode allows designers to import individual 3D models (e.g., motors, sensors, gears) and position them within the internal structure, checking for collisions and misalignments.

The software's "Mate" tool is critical here, enabling designers to define relationships between components (e.g., concentricity of a motor shaft with a gear, parallelism of a sensor with a mounting plate). These mates ensure that components move or interact as intended. For example, in a robotic gripper's internal mechanism, mates can constrain the rotation of gears to ensure synchronized movement of the gripper fingers. SolidWorks also includes a "Collision Detection" tool, which alerts designers to overlapping components. This is invaluable for identifying issues such as a motor housing interfering with a nearby circuit board or a bracket blocking the movement of a joint. By resolving these conflicts in the digital realm, teams avoid costly reworking during physical prototyping.

3. INTEGRATION OF MULTI-DISCIPLINARY SYSTEMS

Robot internal structures are not just mechanical frameworks; they must integrate electrical, electronic, and even software-driven components. SolidWorks facilitates this integration through tools that bridge mechanical design with other engineering domains, ensuring seamless coexistence of diverse subsystems.

3.1 Electrical Routing: Managing Cables and Wiring

Modern robots rely on a network of cables, wires, and connectors to transmit power and data between components (e.g., motors, sensors, control boards). Poor cable management can lead to tangling, abrasion, or interference with moving parts—all of which compromise reliability.

SolidWorks Electrical Routing simplifies this challenge by allowing designers to model cables, harnesses, and conduits within the 3D assembly. The software automatically calculates the length of cables needed to connect components, routes them through predefined channels in the internal structure, and checks for interference with mechanical parts. For example, in a robotic arm, designers can route cables through hollow joints, ensuring they do not get pinched during movement. This tool also generates detailed reports, including cable lists and connection diagrams, which aid in manufacturing and assembly.

3.2 Pneumatic and Hydraulic System Integration

Robots requiring high force output (e.g., heavy-lifting industrial robots) often use pneumatic or hydraulic systems, which involve hoses, valves, and cylinders. SolidWorks Routing extends to these systems as well, enabling designers to model the layout of hoses and ensure they fit within the internal structure without kinking or restricting movement.

For instance, in a hydraulic robotic gripper, the internal structure must house cylinders, hoses, and a reservoir. Using SolidWorks, designers can route hoses from the reservoir to the cylinders, ensuring they have sufficient flexibility to accommodate the gripper's opening and closing motion. The software also checks for pressure drops and flow rates, helping optimize the system for efficiency.

3.3 Component Library and Compatibility

SolidWorks includes a vast library of pre-built 3D models for standard components, such as motors, bearings, sensors, and fasteners (e.g., screws, nuts). This library is regularly updated with parts from leading manufacturers (e.g., Maxon Motors, Intel, Festo), allowing designers to import accurate models of off-the-shelf components directly into their robot's internal structure design.

This feature ensures compatibility between custom-designed parts (e.g., brackets) and standard components. For example, if a designer selects a specific servo motor from the library, they can use its precise dimensions to design a mounting bracket that fits perfectly, eliminating the need for guesswork or manual measurements. Additionally, the library reduces design time by eliminating the need to model common components from scratch.

4. COLLABORATION AND DOCUMENTATION: STREAMLINING THE DESIGN WORKFLOW

4.1 Streamlining the Designing Process

Robot design is rarely a solo endeavor; it involves mechanical engineers, electrical engineers, software developers, and manufacturing specialists working together. SolidWorks facilitates collaboration through tools that enable seamless data sharing, version control, and documentation.

Detailed technical drawings are essential for manufacturing and assembly. SolidWorks automates the creation of 2D drawings from 3D models, including dimensions, tolerances, material specifications, and assembly instructions. These drawings are linked to the 3D model, meaning any change to the model automatically updates the drawing—eliminating errors caused by manual updates.

For robot internal structures, this ensures that manufacturers receive accurate specifications for components such as brackets or housing, while assembly teams have clear instructions on how to fit parts together. SolidWorks also generates bills of materials (BOMs), which list all components and their quantities, streamlining procurement and inventory management.

Also, SolidWorks Drawings allows stakeholders to view, mark up, and comment on 3D models without needing a full SolidWorks license. This is useful for design reviews, where non-technical team members can provide feedback on the internal structure's layout or functionality. For example, a client might request that the robot's battery be easily accessible for replacement, prompting the design team to modify the internal structure's housing in response to the feedback.

4.2 Prototyping and Manufacturing Preparation

Once the internal structure design is finalized, SolidWorks plays a crucial role in transitioning from digital model to physical prototype and mass production.

3D printing has revolutionized prototyping by enabling quick production of complex parts. SolidWorks models are compatible with most 3D printing software, allowing designers to export files in formats such as STL or STEP, which are directly usable by 3D printers. This means that a prototype of the robot's internal bracket or housing can be printed within hours, enabling physical testing of fit, form, and function. SolidWorks also includes tools to optimize models for 3D printing, such as checking for wall thickness (to ensure printability) or adding support structures for overhanging features. This reduces the risk of failed prints and accelerates the prototyping phase.

For mass production, SolidWorks integrates with CAM software (e.g., SolidWorks CAM), which generates toolpaths for CNC machines, lathes, and other manufacturing equipment. This integration ensures that the internal structure's design is translated accurately into manufacturing instructions, minimizing errors and reducing setup time. For example, a robot's aluminum frame, designed in SolidWorks, can be exported to CAM software, which calculates the precise movements of a CNC mill to cut the frame's shape, drill holes, and add threads. The software also simulates the manufacturing process, checking for collisions between the tool and the workpiece, further ensuring accuracy.

5. CASE STUDY: DESIGNING THE INTERNAL STRUCTURE OF A MOBILE INSPECTION ROBOT

5.1 The Process of Design

To illustrate SolidWorks' practical application, consider the design of a mobile inspection robot intended to navigate industrial pipelines, checking for cracks or corrosion. The robot's internal structure must be compact, lightweight, and durable. The whole process consists of the following aspects:

1) 3D Modeling: Using SolidWorks, the design team created a parametric model of the robot's cylindrical frame, with slots for a camera, LED lights, and a battery. Parametric dimensions allowed them to quickly adjust the frame's diameter to fit different pipe sizes.

2) Assembly and Collision Detection: The team imported 3D models of motors, wheels, and a microcontroller from SolidWorks' library, positioning them within the frame. Collision detection revealed that the initial motor placement interfered with the battery; the team adjusted the motor's position using mates, resolving the issue.

3) Structural Simulation: Static stress analysis showed that the frame's thin walls would deform under the weight of the battery. The team added radial ribs (using SolidWorks' feature tools), reducing stress by 40% while keeping the frame lightweight.

4) Thermal Analysis: Flow Simulation identified a hotspot around the microcontroller. The team modified the frame to include a small vent, improving airflow and reducing operating temperature by 15°C.

5) Prototyping: The final 3D model was exported as an STL file and 3D printed, producing a functional prototype that successfully navigated test pipelines.

This case study demonstrates how SolidWorks integrates multiple design phases, from concept to prototype, ensuring the robot's internal structure meets all performance requirements.

5.2 Challenges and Limitations

While SolidWorks is a powerful tool, it is not without limitations. One challenge is the learning curve; mastering advanced features (e.g., Simulation, Routing) requires significant training, which can be a barrier for small teams or novice designers. Additionally, SolidWorks' performance depends on hardware capabilities—complex assemblies with thousands of components may slow down on less powerful computers, affecting workflow efficiency.

Another limitation is the software's focus on mechanical design, which, while comprehensive, may require integration with specialized tools for advanced electrical or software design. For example, while SolidWorks Electrical Routing handles cable management, detailed circuit design may still require dedicated EDA (Electronic Design Automation) software.

Finally, like all digital tools, SolidWorks relies on accurate input data. Incorrect material properties, load assumptions, or component dimensions can lead to misleading simulation results, emphasizing the need for careful validation by experienced engineers.

5.3 Future Trends: SolidWorks in the Evolving Robotics Landscape

As robotics continues to advance, SolidWorks is evolving to meet new design challenges. It faces regular updating with features tailored to emerging technologies, such as:

Generative Design: SolidWorks' generative design tools use algorithms to explore multiple design iterations based on user-defined constraints (e.g., weight, strength, material). For robot internal structures, this can generate optimized, organic-shaped components that are lighter and stronger than human-designed alternatives.

AI Integration: Future versions may incorporate AI to automate repetitive tasks, such as detecting design errors or suggesting optimal component placements, further accelerating the design process.

Virtual Reality (VR) and Augmented Reality (AR): Integration with VR/AR tools would allow designers to “walk through” the robot’s internal structure, interacting with components in an immersive environment, enhancing spatial understanding and collaboration.

6. CONCLUSION

SolidWorks has established itself as a cornerstone of robot internal structure design, offering a comprehensive suite of tools that span 3D modeling, simulation, multi-disciplinary integration, and manufacturing preparation. Its parametric approach, coupled with advanced analysis features, enables designers to create precise, durable, and efficient internal structures, while collaboration tools streamline teamwork and reduce time used in the process.

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