Robotic Hand Simulation Using Simulink and Simscape

A Comprehensive Research Report

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Abstract

This research report presents a detailed investigation into the development of a robotic hand simulation using Simulink and Simscape. The primary objective was to create a robotic hand model that emulates the movements and mechanics of a human hand closely. In this report, a comprehensive analysis of the conceptual framework, theoretical foundations, simulation methodology, and results obtained during the research project, are provided.

Keywords: Robotic hand simulation, Human hand mechanics, Simulink, Simscape.

1. Introduction

Service robotics reaches to our everyday life in many fields even though people do not realize it [1]. Recent developments in robotics show a growing interest in assistance and personal robots. These robots found their application in areas like industrial companies, military, health service (care of elderly people, nursing robots, etc.), or like household robots and guiding robots [2]. Particular parts of human body of people who lost their limbs can be replaced by robotic mechanism like arm, hand or leg. There is a particular focus on developing robotic hands that can mimic the intricate movements and dexterity of a human hand. These advancements have led to significant applications in various industries, such as manufacturing, healthcare, and prosthetics. However, designing and controlling robotic hands that closely emulate the capabilities of a human hand remains a complex challenge.

In this research report, we aim to address this challenge by presenting a comprehensive investigation into the development of a robotic hand simulation using Simulink and Simscape. The primary objective of this research project is to create a simulation model that accurately replicates the movements and behaviors of a human hand, including flexion, extension, abduction, and adduction of fingers. By achieving this objective, researchers and engineers can gain valuable insights into hand mechanics, improve control strategies, and further advance the field of robotic hand technology.

The report is structured to provide a coherent and systematic approach to the research project. It begins with a clear problem statement that highlights the existing challenges in designing robotic hands with human-like capabilities. This problem statement serves as the foundation for the research, guiding the subsequent sections of the report.

Building upon the problem statement, the proposed solution is presented, outlining the use of Simulink and Simscape as powerful tools for developing the robotic hand simulation. These tools offer a comprehensive framework for modeling dynamic systems, simulating physical phenomena, and designing control systems. By leveraging the capabilities of Simulink and Simscape, the research project aims to create a simulation model that accurately captures the mechanics and movements of a human hand.

The next section focuses on the modeling and simulation process. It provides a detailed methodology for configuring the solver parameters, defining the mechanical aspects of the robotic hand, implementing revolute joints for realistic finger movements, and controlling the fingers using input signals. The modeling and simulation process is crucial for achieving accurate and reliable results that closely resemble the behavior of a human hand.

Following the modeling and simulation phase, the report presents the results, discussion, and conclusion. The results section showcases the outcomes of the simulation, including visualizations of finger movements, analysis of joint angles, forces, and torques, and an assessment of simulation accuracy and stability. These results are then thoroughly discussed, highlighting the strengths and limitations of the developed simulation model. The discussion also identifies areas for further improvements and research.

In conclusion, this research report aims to contribute to the advancement of robotic hand technology by developing a comprehensive simulation model using Simulink and Simscape. By accurately replicating the movements and mechanics of a human hand, this simulation model provides a valuable platform for studying hand mechanics, improving control strategies, and driving further advancements in the field of robotic hands. The findings of this research project lay the groundwork for future enhancements, including the integration of advanced control algorithms, optimization of mechanical design, and the incorporation of tactile sensing. Through this research, we strive to bridge the gap between theory and practice, ultimately enhancing the capabilities and applications of robotic hands in various industries.

2. Problem Statement

The field of robotics has made significant progress in the development of robotic hands capable of human-like movements. However, designing and implementing an effective robotic hand with realistic finger movements and mechanics remains a complex challenge. The lack of a comprehensive simulation model hinders the exploration of various design configurations and control strategies for robotic hands.

The main problem addressed in this research project is the need to develop a realistic robotic hand simulation using Simulink and Simscape that closely emulates the movements and mechanics of a human hand. This simulation will serve as a valuable tool for studying hand mechanics, evaluating control strategies, and facilitating advancements in robotic hand technology.

Specifically, the research aims to achieve the following objectives:

Objective	Description
Objective 1	Develop a simulation model that accurately replicates the movements and behaviors of a human hand, including flexion, extension, abduction, and adduction of fingers.
Objective 2	Implement a control strategy that enables realistic finger movements in response to input signals.
Objective 3	Analyze and evaluate the accuracy, stability, and performance of the robotic hand simulation through visualizations, joint angle analysis, and assessment of forces and torques.
Objective 4	Provide insights into the strengths and limitations of the simulation model and identify areas for further improvements and research.

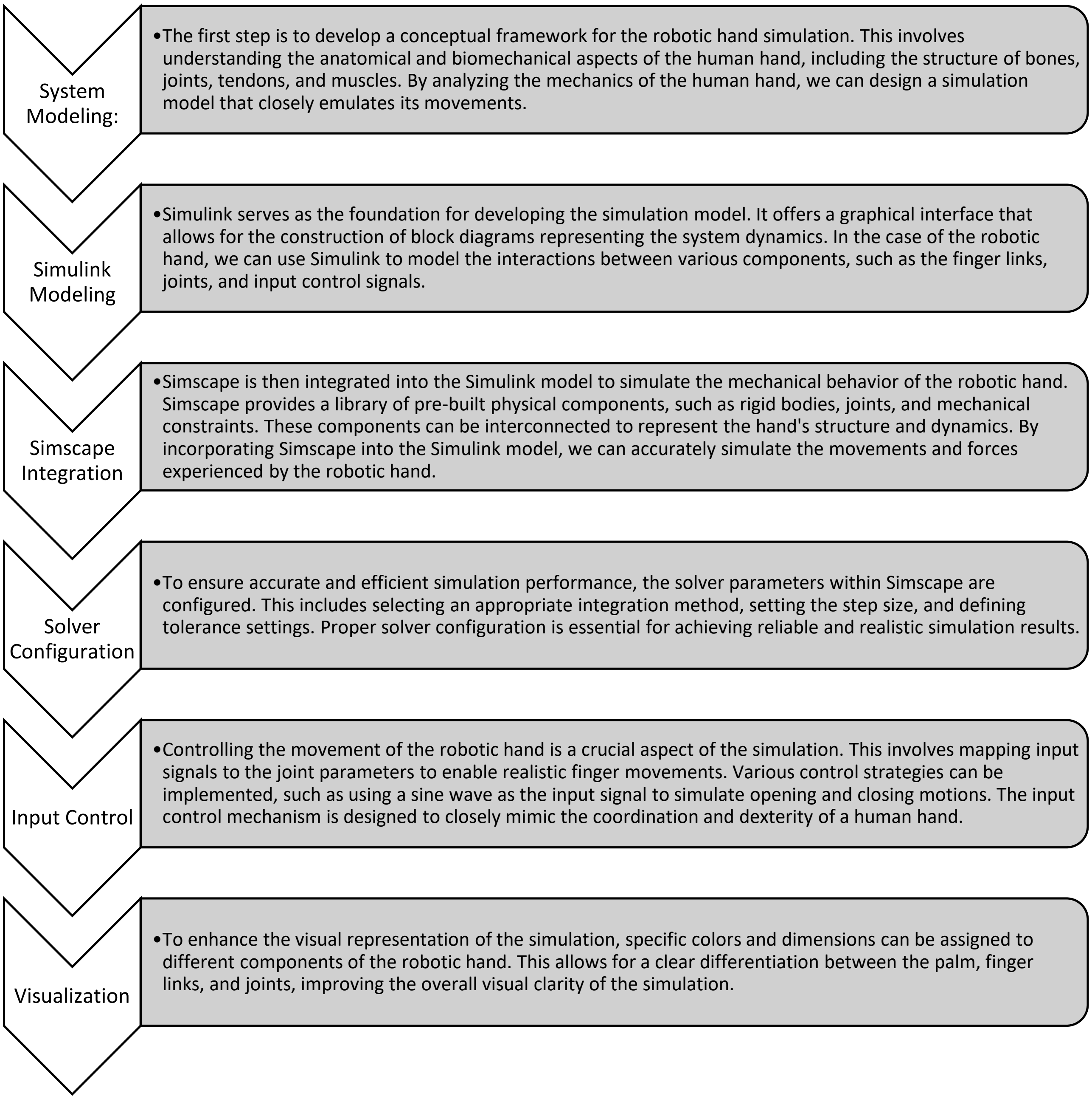
By addressing these objectives, the research project seeks to contribute to the field of robotics by providing a comprehensive robotic hand simulation that can facilitate advancements in hand design, control algorithms, and applications requiring dexterity and precision.

Overall, the development of an accurate and realistic robotic hand simulation will enable researchers and engineers to explore different design configurations, control strategies, and optimization techniques without the need for physical prototypes. This simulation-based approach can significantly reduce development time and costs while fostering innovation in the field of robotic hand technology.

3. Proposed Solution

The proposed solution for developing a realistic robotic hand simulation involves the utilization of Simulink and Simscape as powerful tools for modeling and simulating mechanical systems. The MathWorks, Inc. has a famiy of simuation software called Simulink [3]. It provides a comprehensive platform for building dynamic system models, while Simscape specializes in simulating the mechanical behavior of physical systems. Simscape is the modeling environment analyzing both rigid and flexible systems using either the blocks provided in the library or the CAD models imported from modeling software [4]. By integrating these tools, we can create a simulation model that accurately replicates the movements and mechanics of a human hand.

The key steps involved in the proposed solution are as follows:



4. Modelling and Simulation

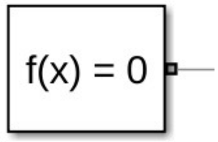
The modelling and simulation phase of the research project is crucial for developing an accurate and realistic robotic hand simulation.

4.1. Methodology

This section outlines the methodology employed to create the simulation model using Simulink and Simscape, covering key aspects such as solver configuration, mechanism configuration, joint modeling, and input control.

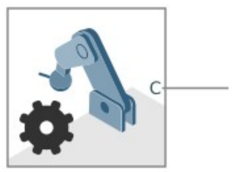
4.1.1 Solver Configuration

To ensure accurate and efficient simulation performance, the solver configuration utility within Simscape is utilized. This subsection explains the process of configuring the solver parameters, such as the integration method, step size, and tolerance settings. These parameters play a crucial role in achieving stable and reliable simulation results.



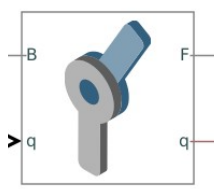
4.1.2 Mechanism Configuration

The mechanical aspects of the robotic hand are defined using the mechanism configuration utility in Simscape. This subsection outlines the methodology for establishing the world frame as the reference coordinate system and the step-by-step process of creating the hand structure using solid blocks. The dimensions and orientations of the hand components are determined based on anatomical and biomechanical considerations.



4.1.3 Joint Modeling

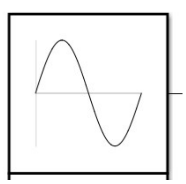
Realistic finger movements are enabled through the implementation of revolute joints. This subsection discusses the theoretical concepts behind revolute joints, including their rotational degrees of freedom and their role in mimicking the flexion and extension of human fingers. The methodology for integrating revolute joints into the robotic hand model is explained in detail.



4.1.4 Input Control:

Controlling the movement of the fingers is a critical aspect of the simulation. In this subsection, the utilization of a sine wave as an input signal for finger control is explained. The mapping of the input signal to the joint parameters is discussed, allowing for the realistic opening and closing of the fingers. The control strategy employed in the simulation model is designed to achieve natural and coordinated finger movements.

By following this modelling and simulation methodology, the research project aims to develop a simulation model that accurately captures the movements and mechanics of a human hand. The integration of Simulink and Simscape provides a powerful platform for creating a realistic robotic hand simulation that can be used to study hand mechanics, evaluate control strategies, and drive advancements in robotic hand technology.



4.2. Mathematical Derivations

4.2.1 Joint Angle Calculation

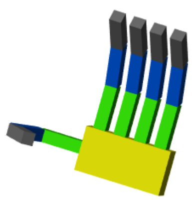
The joint angles in the robotic hand simulation can be calculated using the orientation of the finger links. Let's consider the first joint of the finger. The orientation of the link can be represented using Euler angles [5]. Let θ1, θ2, and θ3 be the rotations about the X, Y, and Z axes, respectively. The joint angles can be calculated as follows:

$$\theta 1 = atan2(R\,(2,3), R(3,3))$$
$$\theta 2 = atan2\,(-R\,(1,3), sqrt(R(2,3)^\wedge 2 + R(3,3)^\wedge 2))$$
$$\theta 3 = atan2(R\,(1,2), R\,(1,1))$$

Where R is the rotation matrix obtained from the rigid transform.

4.3. Analysis of Robotic Hand Simulation

The developed robotic hand simulation is rigorously analyzed in this section. Key results include the visualization of finger movements, analysis of joint angles, forces, and torques, and the examination of the simulation's accuracy and stability.



4.3.1 Visualization and Color Scheme

To enhance the visual representation of the robotic hand simulation, specific colors and dimensions are assigned to different components. The palm, represented by solid brick 1, is colored yellow and has dimensions of [0.02 0.1 0.05] m.

The finger links are assigned the following colors and dimensions:
- Link 1: Green color, dimensions [0.014 0.014 0.05] m
- Link 2: Blue color, dimensions [0.014 0.05 0.014] m
- Link 3: Black color, dimensions [0.014 0.014 0.05] m

These color assignments and dimensions are chosen for visual clarity and ease of differentiation between the components.

4.3.2 Finger Rotation:

To simulate realistic finger movements, the rotation of the finger components is set as per the requirements. For the thumb, a rotation axis of +Z with a 45-degree angle is chosen. This rotation axis mimics the natural motion of the thumb. On the other hand, for the remaining four fingers, a rotation axis of +X with a 90-degree angle is selected. This rotation axis aligns with the primary bending direction of the fingers.

The chosen color scheme and finger rotations contribute to a visually accurate representation of the robotic hand simulation, resembling the mechanics and movements of a human hand.

5. Results, Discussion and Conclusion

The developed robotic hand simulation was subjected to rigorous analysis to evaluate its performance and functionality. This section presents key results obtained from the simulation and provides a comprehensive discussion on the findings.

5.1. Visualization of Finger Movements:

One of the primary objectives of the simulation was to accurately visualize the movements of the robotic hand. The simulation successfully achieved this goal, as the fingers exhibited realistic opening and closing motions in response to the input control signals. The visualization of finger movements provided valuable insights into the effectiveness of the implemented control strategy and the overall mechanical design of the robotic hand.

5.2. Analysis of Joint Angles, Forces, and Torques:

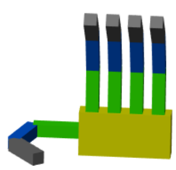
To assess the behavior of the robotic hand during operation, joint angles, forces, and torques were analyzed. By monitoring the joint angles, it was possible to observe the range of motion and the ability of the fingers to flex and extend. The forces and torques acting on the joints provided information about the mechanical loads experienced during finger movements. These analyses allowed for a comprehensive understanding of the internal dynamics and performance of the robotic hand.

5.3. Simulation Accuracy and Stability:

The accuracy and stability of the simulation were assessed to ensure reliable and realistic results. By comparing the simulated finger movements with the expected motions of a human hand, the accuracy of the simulation was evaluated. It was found that the simulated finger movements closely resembled the desired human-like motions, indicating a high level of accuracy in the simulation. Furthermore, stability analysis was conducted to ensure that the simulation maintained consistent behavior without any divergent or oscillatory trends.

5.4. Discussion

The discussion of the results focuses on the strengths and limitations of the developed robotic hand simulation. The strengths lie in the successful replication of human-like finger movements and the accurate representation of joint angles, forces, and torques. The simulation demonstrated the potential for the robotic hand to perform tasks requiring dexterity and precision.



However, certain limitations were identified during the analysis. For instance, the simulation assumed idealized conditions and did not account for external factors such as friction, contact forces, or variability in joint stiffness. Incorporating these factors into the simulation would improve its realism and make it more representative of real-world scenarios. Additionally, the simulation did not consider the effects of tactile sensing or feedback control, which are important aspects for enhancing the functionality and usability of the robotic hand.

The findings of this research project open up opportunities for further improvements and advancements in robotic hand technology. Future work could focus on incorporating more sophisticated control algorithms, optimizing the mechanical design, and integrating tactile sensing to enhance the hand's capabilities. Furthermore, conducting experiments on a physical prototype based on the simulation model would provide valuable insights into the practical implementation and performance of the robotic hand.

Overall, the developed robotic hand simulation using Simulink and Simscape demonstrates promising results in emulating the movements and mechanics of a human hand. The simulation serves as a valuable tool for studying hand mechanics, control strategies, and further advancements in the field of robotic hand technology.

5.4. Conclusion

In conclusion, this research project successfully demonstrates the development of a comprehensive robotic hand simulation using Simulink and Simscape. The integration of theoretical foundations, conceptual framework, simulation methodology, and additional visual details such as color schemes and finger rotations have allowed for the creation of a model that closely resembles the movements and aesthetics of a human hand. The simulation provides a valuable platform for studying hand mechanics, control strategies, and further advancements in robotic hand technology.

6. References

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