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Executive Summary of the Thesis

Methods for Comparative Analysis of the Robotic Arms

Laurea Magistrale in Mechanical Engineering - Ingegneria Meccanica

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1. Introduction

Industrial automation has become a critical aspect of modern manufacturing processes, revolutionizing the way industries operate and enhancing productivity, efficiency, and safety. Robotic arms play a pivotal role in industrial automation, offering versatility and precision in various applications such as pick-and-place operations, material handling, and assembly tasks[2]. As the demand for automation continues to grow and many solutions produce with different options, it is crucial to evaluate and compare the performance of different robotic arm models to identify the most suitable solution for specific industrial requirements.

In the present era, the vast variety of robot models and types for industrial usage has engendered complexity in comparing their respective features. This task requires considerable effort due to the absence of a well-defined and straightforward methodology. For instance, determining the optimal mechanical design to achieve optimum performance, identifying the most suitable programming and software features, and prioritizing crucial aspects such as accuracy and performance for specific tasks become formidable.

The research discusses the industrial revolution and its impact on adopting robotic arms in manufacturing. This background provides a contextual understanding of the benefit of robots in the industrial world and the important aspects of robots and the trends of their change.

Hence, this thesis aims to introduce novel methods that simplify and structure the process of comparing robot features in various aspects. To have a better view of these methods and their usage in real applications, the methods will be employed to evaluate the Fruitcore H900, a new robotic arm, against other similar robots in the market, with a particular focus on the physical characteristics, mechanism design, software capabilities, and performance attributes of the robot mentioned above.

Subsequently, the report delves into a detailed examination of the robotic arms' mechanism design and will explore their unique physical features and their usage and advantages for different tasks.

From a software perspective, it is essential to consider the appropriate features that significantly impact operators and programmers. Similarly, a comprehensive evaluation and comparison of the key software features of the H900 robotic arm with other robotic arms are conducted.

In the comparison procedure, a custom software tool was developed to monitor the robot's status and command it to perform specific tasks for feature testing and improving the usability of the robot in an automatic union. It enhances the usability and efficiency of the Fruitcore H900 and lets it communicate with external devices for different purposes.

To evaluate the performance of the Fruitcore H900, a complete demo task is designed to assess its programming capabilities and overall performance. The robotic arm's repeatability and cycle time variation is also evaluated using the photogrammetry method[4] and custom-designed application to provide insights into its precision. Additionally, a comparison is made between the Fruitcore H900 and a Mitsubishi RV-5AS robot in terms of cycle time and repeatability at different speeds to compare the new H900 robot to a traditional one.

The findings of this thesis summary report contribute to the existing body of knowledge by providing comparison methods for robotic arms. This thesis provides valuable insights for industry professionals adopting robotic arms, aiding in application decision-making.

2. Key Hardware Aspects of Robotic Arms

In this section, a comprehensive overview of the main components and units of the robotic arm is presented. These components possess unique characteristics and features that are vital for ensuring the proper functioning of the robotic arm. Moreover, these features significantly influence the decision-making process when selecting a robotic arm solution.

The arm with motors serves as the skeleton and muscles of the robotic arm, enabling movement and manipulation. In industrial applications, robotic arms predominantly adopt three main designs: serial, parallel, and delta mechanisms. Each design offers distinct advantages and is suited for specific use cases. For instance, serial robots exhibit high flexibility and possess a wide working space, making them suitable for tasks requiring versatile movement. On the other hand, parallel mechanism designs excel in handling heavy payloads, while delta robots are known for their speed and accuracy.

The end-effector unit, located at the end of the robotic arm, functions as the robot's hand. It allows for the attachment of different units to perform various actions and interact with diverse objects. The use of standardized end-effectors facilitates the easy interchangeability of units to adapt to different tasks and requirements.

The controlling unit serves as the brain of the robotic arm, overseeing the precise control of each motor and sensor. This unit is responsible for executing programmed tasks and ensuring optimal performance. Tasks are designed or sent to the controlling unit, which then orchestrates the individual rotations of the motors accordingly.

Furthermore, the controlling unit provides an interface for users to initiate commands and modify the robot's status. It incorporates software for programming and controlling the robot, along with input and output ports for seamless interaction with external devices.

In conclusion, a thorough understanding of the components and units of the robotic arm is crucial for informed decision-making. During this thesis, for a better understanding of the methods and ideas presented, the mentioned components for the new Fruitcore H900 are discussed and compared to ABB IRB 2400 and Mitsubishi RV-5AS in the following sections.

3. Kinematic and Kinetostatic Analysis

This section focuses on the mechanical comparison of the robotic arms, especially Fruitcore H900 to Mitsubishi ABB RV-5AD and IRB 2400, shedding light on their unique features and capabilities. The H900 is designed to attach various tools, allowing for a wide range of tasks and applications. This versatility enables users to connect different tools and accessories to the robot, enhancing its functionality and adaptability in industrial settings.

One of the key mechanical aspects of the H900 is its parallel linkage design. This design offers advantages in terms of lifting heavier loads compared to serial robots[3]. While the H900's payload capacity may not be as high as some other parallel robots available in the market, its parallel linkage mechanism notably improves lifting capabilities.

Furthermore, the H900 incorporates a unique linkage design for its second joint movement for design purposes, as shown in Figure 1. However, parallel robots have limited working angles and space in comparison to serial robots.

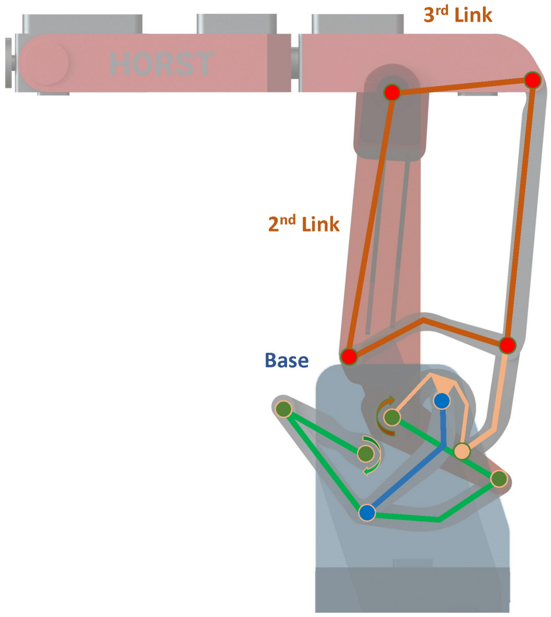


Figure 1: Schematic view of mechanism design of H900

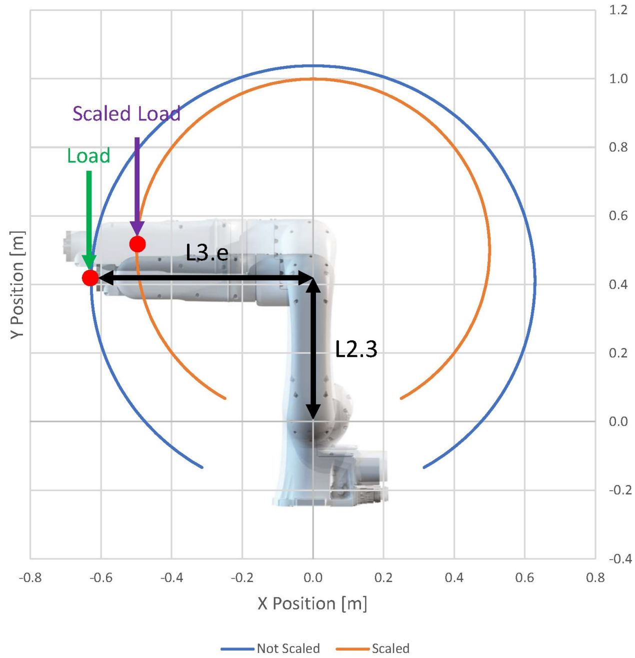


Figure 2: End-effector point variation with scaling method for RV-5AS

A novel method was introduced to assess the working space comparison of different robots to see the design effect on the working space. Different robots have various linkage sizes that directly affect the working space. In other words, by comparing the real and original working spaces of different robots, the advantageous mechanism design can not be discussed solely.

In this method, with the help of geometrical and force equations, the effective linkage length and loading position is scaled and repositioned to make the system invariant of the linkage length and loading position. The graphical representation of this method is as Figure 2 for Mitsubishi RV-5AS serial robot.

By comparing the scaled working space of H900 with Mitsubishi RV-5AS and ABB IRB 2400 in a 2D plane, shown in Figure 3, it revealed that the workspace of serial robots, like ABB and H900, is heavily reduced because of the physical limitation of the parallel mechanism. Also, the unique mechanism design in H900 reduces the working space even more.

By calculating the scaled working space area in the 2D plane and scaled payload of each robot, as in Table 1, it will be concluded that although the parallel mechanism reduces the working space of the robots, it will help them to raise a heavier load.

It is important to note that the limitation in the working space of the H900 should be carefully considered when planning tasks and operations. While the H900 may not be suitable for applications that require extensive reach or access to large work areas, its compact design and enhanced load-carrying capabilities make it well-suited for tasks that involve precision movements within confined spaces.

In summary, the mechanical characteristics of the robotic arms showcase their adaptability through compatibility with different end-effectors. The parallel linkage design enhances the load-carrying capabilities, while the complex linkage design enables precise and flexible movements. The comparison of the parallel robots' working space reveals its limitations compared to serial robots, but different mechanism designs can vary the working space significantly and it should be considered in the decision-making process. These comparison attributes make the H900 a compelling option for applications that prioritize compactness, precise movements, and handling moderate loads within confined workspaces in comparison to the other two robots.

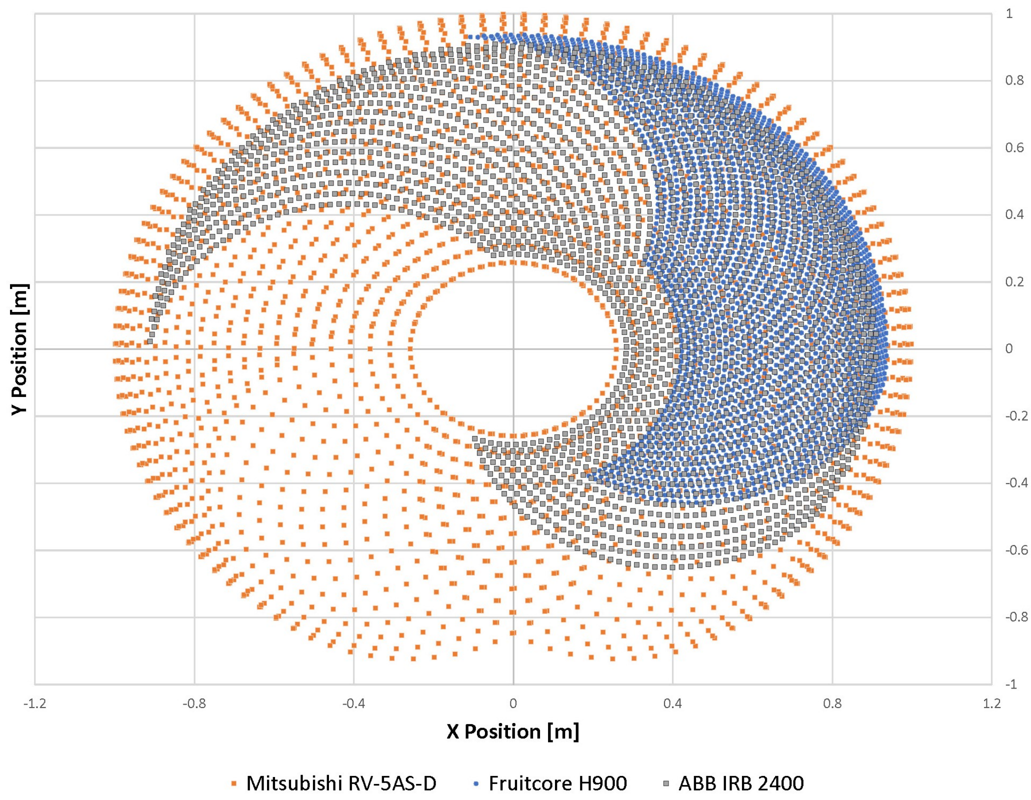


Figure 3: Scaled working space of H900, IRB2400, and RV-5AS in 2D plane

4. Controller and Software Features

This section focuses on the key points of the software and programming language of the robotic arms. For this purpose, the Fruitcore H900 robot is considered as an example unit with the key features highlighted and explained on it.

The H900 stands out with its compact controller, user-friendly interface, and versatile programming capabilities. HorstFX, the software interface of the H900, provides a graphical and textual coding environment, enabling users to program the robot using their preferred method. The interface also offers a simulation and virtual dual of the robot's movements and tasks, making help the user easily debug the program beforehand. The textual code representation allows for more advanced programming, giving users finer control over the robot's actions and enabling complex task execution.

One of the notable advantages of the H900 is its compatibility with different communication protocols. These protocols allow the robot to communicate with external systems and devices, facilitating seamless integration into existing industrial setups and external systems. To leverage capability, a custom program was developed specifically for the H900, enabling the extraction of status information from the robot and providing a means to send commands to the robot from an external system. The software opens up possibilities for advanced automation and integration scenarios, enhancing the overall flexibility and functionality of the H900 in industrial applications, and it is used for the tests in the following section.

However, it is essential to note that while the software of the Fruitcore H900 offers significant benefits, certain complexities are associated with specific commands in the textual programming. Although users can add the standard commands used in graphical programming, taking advantage of all capabilities may require a deeper understanding of the programming language and syntax, posing a learning curve for users new to the system. Nonetheless, with adequate training and experience, users can effectively harness the power of the software and exploit the full capabilities of the H900.

In summary, the software comparison high-

Table 1: H900, IRB2400, and RV-5AS payload comparison

Manufacturer	Fruitcore	ABB	Mitsubishi
Robot Model	H900	IRB 2400/16	RV-5AS-D
Reachable Range [mm]	905	1550	910
Scaled Reachable Range [mm]	930	910	1000
Payload [kg]	5	16	5
Scaled Payload [kg]	5.15	9.46	3.98
Covered Area [M^2]	0.97	5.80	1.94
Scaled Covered Area [M^2]	1.23	2.05	2.89

lights the strengths of the Fruitcore H900 robotic arm, including its compact controller, user-friendly interface, and versatile programming capabilities. Integrating the Modbus communication protocol enhances connectivity and enables seamless collaboration with external systems which plays a crucial role in the interaction of the robot to automatic systems. While some complexity may be associated with specific commands in comparison to RV-5AS, the overall software package offers a robust platform for controlling and commanding the H900, making it a valuable asset in various industrial applications. The results for H900 can be easily applied to any robot and it will help the decision-making procedure.

5. Real World Performance Comparison

This section summarizes the performance evaluation conducted on the Fruitcore H900 robotic arm. The evaluation aimed to assess the robotic arms' programming capabilities, real-world performance, repeatability, and cycle time variation.

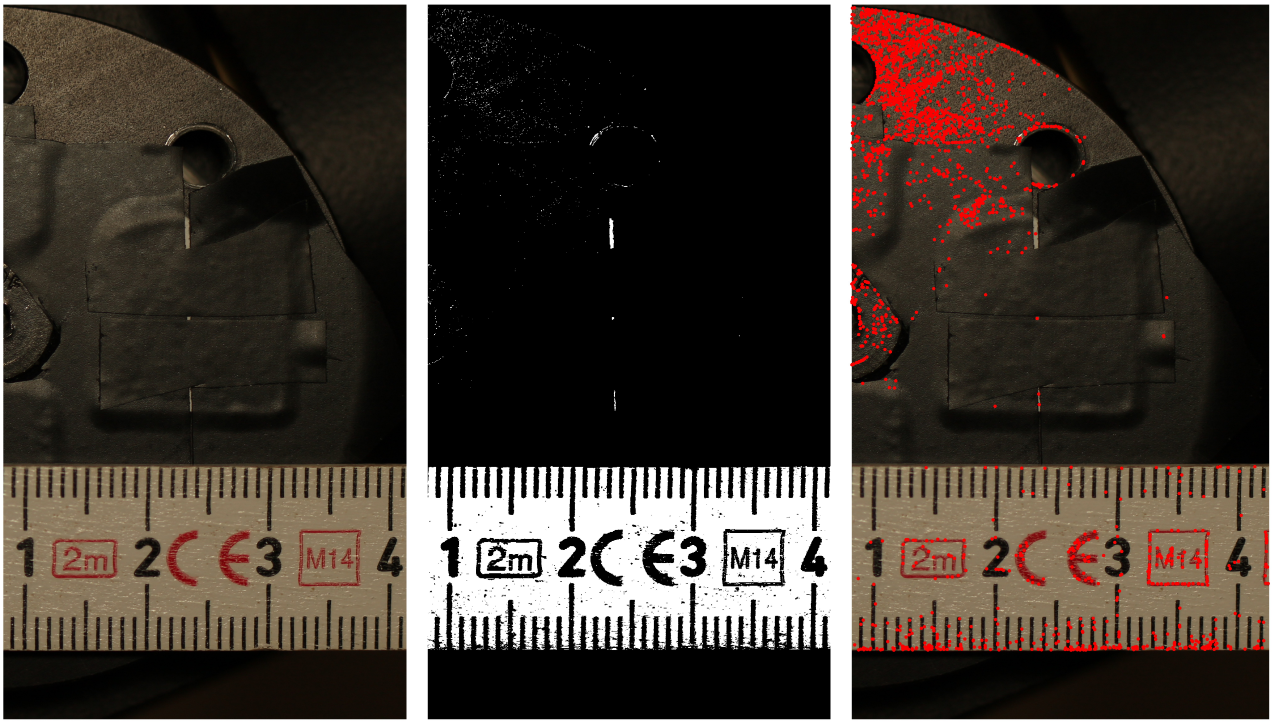
To evaluate the programming complexity and capability of the robot, a demo was designed involving the pick and placement of cubes in specific positions to form logos. This task allowed for an examination of the robot's ability to execute precise movements and complex commands. The programming process was analyzed to identify any challenges or complexities encountered and to evaluate the overall programming efficiency.

Furthermore, the performance of the H900 in real-world scenarios was assessed. The robot's behavior and speed were analyzed during the execution of the demonstration task. This evaluation provided insights into the robot's performance and suitability for real-world applications.

In addition to the designed demo, some tests were done for comparison of Fruitcore H900 and Mitsubishi RV-5AS. In these tests, the repeatability and cycle time variation of these robots were compared to each other to understand better the performance of the new H900 to another well-established industrial robot.

The repeatability and cycle time of the H900 were measured using the photogrammetry method. This approach allowed for a quantitative assessment of the robot's repeatability, which is a crucial factor in industrial applications requiring consistent and accurate movements in a fast and cheap method. The cycle time measurement provided insights into the robot's controlling unit behavior.

For the photogrammetry method for measuring the repeatability performance of the robots, a DSLR camera was placed close to the robot's end effector, and attached to a tripod over solid ground. In the test, the robots will do the same cycle consisting of movement between five points and returning back in front of the camera. In the position in front of the camera, the robot rests for a few seconds to remove the vibration effect and image capturing process. After taking an image, the robot starts the same cycle. The test was done with different robot speeds to see the repeatability variation by changing the robot's speed. As mentioned in the previous section, all of the processes were done automatically with the software designed for the robot. Also, the software was modified



(a) Original (b) After Filtering (c) After processing

Figure 4: The steps of point tracking in the image processing

in a way to control and trigger the camera capturing moment. This software also records all of the robot's status and the status used for the cycle time variation test.

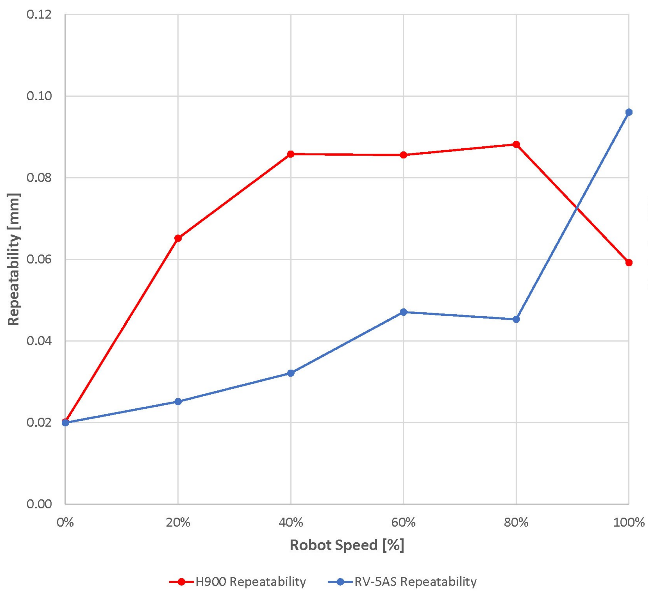
on the robot's end-effector, two small points were placed, as shown in Figure 4.a, to check the variation of the position of these points in each cycle and a reference dimension placed in the image to have the dimension in each image.

The images were analyzed with a MatLab code, applying different filters to the image as shown in Figure 4.b, and the position of the mark was recognized from the filtered image. As shown in Figure 4.c, the different positions found with the code, and the user should specify the preferred point for the analysis, in this case, the small white point in the middle of black tapes, and the code checked the variation of the specified point in the test automatically.

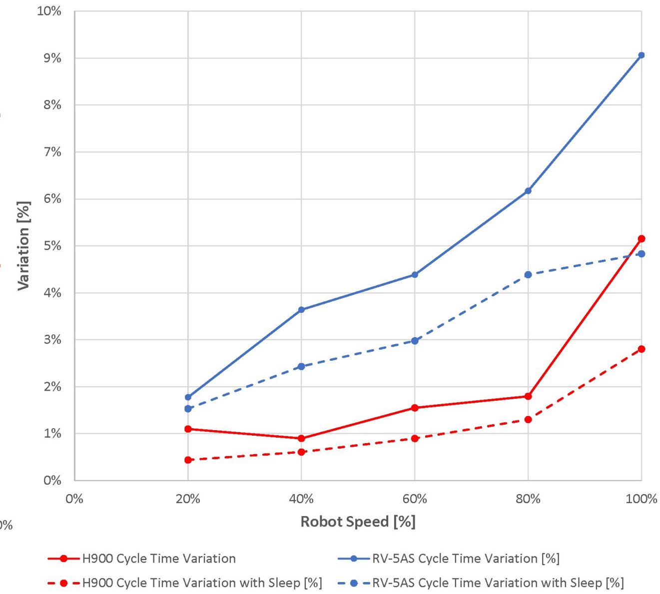
The repeatability and cycle time variation results are shown in Figure 5. As expected from the robot's specification, with 0.05mm accuracy for H900[1] and 0.03mm for RV-5AS[5], RV-5AS has a better performance in the repeatability test. It constantly degrades performance by increasing the robot's speed, but H900 changes its controlling strategy to have better performance at a higher speed after 60% of the speed.

From the cycle time variation point of view, H900 performed better than RV-5AS. In industrial usage, these robots need feedback on the cycle that they are working on because their cycle time can vary and may get in sync with other systems. The variation is more significant without considering the rest times in front of the camera for the photo-capturing process. In this rest time, the robots tried to recover some of this variation, especially for RV-5AS.

In the comparison of the performance between the two robots, notable variations and differences have been observed. The final data obtained from the cycle time and repeatability tests provide valuable insights into the expected performance of the robots. Specifically, for tasks requiring high precision, the repeatability of the robot at various speeds becomes a critical factor. This information allows the reader to make informed decisions regarding adjusting the speed and production rate to align with the robot's performance. Conducting a simple and cost-effective test enables the assessment of whether the robot is the optimal solution for achieving



(a) Repeatability Vs robot's speed



(b) Cycle time variation Vs robot's speed

Figure 5: H900 and RV-5AS repeatability and cycle time variation comparison

the desired speed and efficiency.

Furthermore, in situations where the robot is not synchronized with other machines in the system, the level of variation in the cycle time becomes significant. Any inconsistencies in the cycle time can disrupt the smooth flow of the machines and impact overall productivity. Therefore, understanding the amount of variation in the cycle time aids in evaluating the compatibility and integration of the robot with other components within the system.

6. Conclusions

In this thesis, the methods and key points for a comprehensive analysis of robotic arms were conducted, focusing on three key aspects: mechanical characteristics, software comparison, and performance evaluation. The results can give a better insight and can help the reader in the decision-making process for finding the best solution among various models of robotic arms.

For a better understanding of the process, the new Fruitcore H900 robot was compared with some well-established robots, like Mitsubishi RV-5AS and ABB IRB 2400, in some of the characteristics.

The mechanical design of a robotic arm plays a crucial role in determining its versatility and adaptability to various tasks. The Fruitcore H900's unique physical design allows for the connection of different end-effectors, enabling a wide range of applications. Its parallel linkage design enhances the robot's ability to handle heavier loads compared to serial robots. However, it should be noted that the H900's payload capacity is relatively lower compared to some other parallel and serial robots available in the market. Evaluation of the working space using an innovative method reveals that serial robots offer higher flexibility compared to parallel robots due to their design characteristics.

From a software perspective, the Fruitcore H900 demonstrates several notable advantages over the compared robots. Its compact controller and user-friendly graphical and textual interface facilitate efficient programming and control of the robot. This feature enables users in the industry to easily understand its operation and make modifications and programming more easily and quickly. The development of a custom software program further enhances the robot's capabilities by enabling real-time status information extraction and seamless integration with external systems through different communication methods. The availability of standard communication methods or the ease of developing translator middleware plays a significant role in decision-making, particularly in automatic systems where synchronization with other devices is crucial.

Performance evaluation of robotic arms is a critical aspect of assessing their real-world capabilities. A designed demo task effectively demonstrates the programming complexity and capability of the Fruitcore H900 robot, highlighting its effectiveness in executing precise movements and complex commands. Repeatability and cycle time tests, conducted using photogrammetry and data analysis methods, provide quantitative measures of the robot's repeatability, consistency, and operational speed. The comparison between the H900 and RV-5AS robots yields valuable benchmarking data that can be extended to other robotic arms for better insights into their expected performance.

Overall, the Fruitcore H900 emerged as a competitive option in the industrial robotics landscape. Its software capabilities, mechanical characteristics, and performance showcased its suitability for a range of applications. However, it is important to consider the observed limitations, such as the complexity of certain commands, the limited payload capacity compared to other parallel robots, and the constrained working space. The observations can help the reader to have a clearer expectation about the use-case suitability of the H900.

The insights and findings from this thesis contribute to informed decision-making for industry professionals seeking to adopt robotic arms. The research methodology was systematic and objective, enabling comprehensive evaluations and comparisons. Further research could expand upon this study by exploring additional performance metrics, conducting comparative studies with a larger sample of robots, and assessing the applicability of each robot in specific industries.

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