A Study on Improving Efficiency and Reliability of Automated Connector Testing for Aerospace Applications

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Abstract. Automation is crucial for the future of the industry as it enhances efficiency, quality, and accuracy while reducing operating time and the occurrence of human errors. Establishing an automated factory requires significant resources, including robot installation, worker training, program development, and ensuring quality and safety measures. This paper presents a study on automating the testing process for an aerospace company aiming to enhance productivity and minimise errors. The study aimed to achieve full task automation using a Universal Robotics Arm (UR5), which undertook the tasks of retrieving, inserting, securely locking, and removing the six connectors into the equipment, effectively executing the entire process. In initial trials, wireless connectors exceeded expectations, achieving 16 cycles in 2 hours. The inclusion of cables brought about significant challenges, particularly in terms of cable entanglement and concerns regarding the durability of connectors. Proposed solutions include improving the rack system and refining the gripper's functionalities. This highlights the project's potential for transformative advancements in aerospace manufacturing.

1 Introduction

In a dynamic industrial environment fuelled by a constant pursuit of efficiency, companies are modifying their production plants to incorporate the principles of Industry 4.0. [1]. In this context, the aerospace industry faces continuous need for improving processes. Due to the highly competitive nature of the aerospace industry, even minor mistakes can have significant repercussions for companies. Therefore, it is crucial to thoroughly test various equipment and products to identify hidden errors and improve the sophistication of the equipment. A prominent British aerospace company is currently involved in manually testing their flight stick. This study aimed to automate the process using a six-degree-of-freedom robotic arm [2]. The testing protocol of the standard flight stick, shown in Fig. 1 (a), requires an operator to be physically present in the designated testing area. The operator is responsible for manually connecting and disconnecting six cables to the flight stick. The manual technique is ineffective due to the diversion of the operator's attention from evaluating test

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findings to the procedural work of manipulating cables. Therefore, this manual operation creates inefficiencies in the company, which may affect the strict deadlines for delivering test results. The continued reliance on manual testing operations increases the temporal and financial burden.

a b

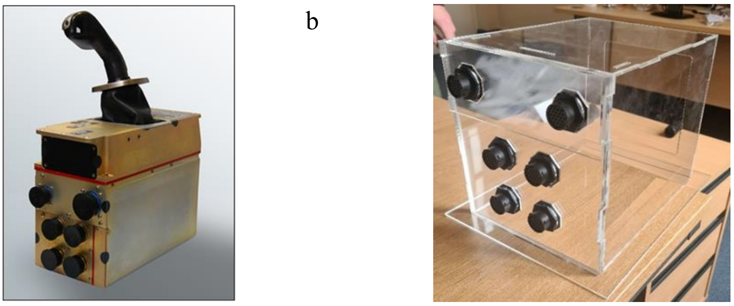

***Fig. 1**. Comparative Illustration: Flying Sticks - (a) Commercial and Military Use [3], (b) Initial Replica Prototype*

Given these circumstances, automating the cable connection process is crucial for its undeniable importance in achieving operational efficiency, precision, and speed. The aerospace industry has successfully integrated cyber-physical systems due to their proven benefits. Moreover, the decreased costs of robotic technology have made it more accessible for organisations to utilise them in low-volume tasks, such as testing procedures[4], [5]. Robotic Process Automation requires careful attention to detail due to the delicate nature of the equipment involved, which must be protected from any potential harm. The main goal of this research was to align with the operational needs of the aerospace company. This involved achieving smooth and uninterrupted connection and disconnection of ten consecutive flight sticks without human intervention. A detailed set of components was carefully designed to accomplish this ambitious objective. This involved designing and quickly creating necessary equipment, including replica flight sticks customised for the connectors, a rack to manage unused connectors efficiently, and a table with secure clamping for all elements. The robotic arm's programming was crucial for achieving perfect connector connections. This highlights the close relationship between programme and equipment development, carefully planned to improve operational efficiency according to the company's high standards.

2 Equipment and Program

As previously mentioned, incorporating a Universal robotic arm, particularly the UR5 model, played a crucial role in the experimental procedures. The robotic arm demonstrated the capacity to detect contact forces of up to 200N, reducing the likelihood of equipment damage and protecting the operator's safety [2], [6]. Although the operational velocity of the system did entail a degree of risk, it did not sufficiently warrant the erection of a protective cage. The robot demonstrated a significant capability to bear loads, as it can handle things weighing up to 5kg, which exceeds the demands of the specific use case. Due to the exorbitant cost and the fact that it is a private piece of intellectual property, using a real flying stick in the experiments was impossible. The utilisation of a replica facilitated the execution of essential tests, hence avoiding the financial burden and any legal consequences connected with using authentic equipment. Considering the limitations, a customised variety of tools was developed: a replicated flying stick, a specialised connectors rack, and a tailored workspace environment. The previous elements were carefully designed to minimise mistakes and enhance operational efficiency, with the goal of optimising time utilisation.

During the design process, a significant choice was taken to depart from replicating the original flight stick's shape. Instead, a practical approach was used, creating a box featuring socket placements on all its faces. The decision to deviate from the initial design, which had sockets on just one side as shown in Fig. 1 (b), was driven by the need to avoid any potential setbacks caused by the need to readjust the flying stick throughout the experiment process. The prioritisation of efficiency in the design was considered to be of utmost importance. To enhance the accuracy of the robot's activity, it was necessary to establish predetermined sites to install connectors. The aim of the connector rack was designed with the intention of accommodating six connections, and it is constructed using many pieces of acrylic that are layered. While installing the connector in this particular form required significant effort, it effectively eliminated the possibility of rack damage. Further improvements were made by including rubber pieces to boost grip and dividing the structure into two portions to simplify cable management. Table 1 provides a comparative study of different gripper prototypes that were evaluated for the project. It outlines essential characteristics such as grip type, load capacity, weight, cost, and force applied. Each gripper model was evaluated to assess its appropriateness for accurately manipulating connections inside the automation process. The assessment of several gripper types played a crucial role in this research, to determine the most appropriate gripper for accurately joining connections while maintaining their structural integrity. The study conducted a comparative analysis of several grippers that were available on the market. Each gripper was examined based on its unique features and capabilities. The solutions assessed were soft grippers with actuation mechanisms, which were recognised for their ability to conform to a wide range of item forms. Although they demonstrated proficiency in jobs requiring a solid grasp, their ability to perform accurate locking actions was limited due to intrinsic design constraints.

Table 1. Comparative analysis of grippers

PoC	**Gripper Name**			
	Qb SoftHand	***OnRobot RG6***	***Robotiq Hand-E***	***OnRobot Soft Gripper***
				
Type of grip	Soft finger	Parallel	Parallel	Adaptive
Load Capacity (kg)	2	6	4.7	1.5 to 2.2 (Shape Dependant)
Weight (kg)	1	1.25	1	0.77
Cost (€)	8000	5500	4500	3800
Force (N)	27 to 40	25 to 120	20 to 185	380

Another candidate gripper has shown potential in applying consistent pressure for secure connection retention and possible locking. Nevertheless, several limits emerged, such as the lack of autonomous control over individual components and insufficient force for the necessary rotations. Following this, a shift to an alternate gripper was executed. Its alignment with the robotic arm, user-friendly interface, and proven effectiveness across various materials influenced the decision. The iterative process of selecting and refining the gripper played a crucial part in optimising the process of connecting connectors. Upon considering the shape of the connection, the possibility of utilising a soft gripper equipped with actuation mechanisms emerged organically [7]. The adaptability of soft grippers to various object shapes made them adept at gripping duties but potentially less so for locking. The OnRobot Soft Gripper had notable dexterity in grabbing items in different orientations. However, the gripper's physical structure constrained its effectiveness in performing precise locking actions. The Qb SoftHand Industry is characterised by its adaptability and incorporates soft fingers that were specifically designed to enclose connections, hence applying consistent pressure [8]. The proposed design incorporated a three-fingered technique to firmly grasp the connection, with the remaining two fingers responsible for executing the required rotations to activate the locking mechanism. Nevertheless, several operating limitations became apparent due to the lack of autonomous finger control and inadequate actuation force for connection-locking rotations. Moreover, the inherent accuracy limits of the soft hand hindered the constant alignment of connectors.

As a result, a shift to use a parallel gripper, notably the Rg6 type manufactured by OnRobot, became imperative. The decision was based on the alignment between the arm and gripper, a user interface that is easy to use and understand, and the proven effectiveness of the Rg6 on different types of materials [9]. While serving their purpose, the initial gripper tips demonstrated reduced gripping capabilities due to inconsistencies in their compatibility with the curved surfaces of the connections. The constraint mentioned above led to the development and production of specialised curved tips. However, their original version, created through 3D printing, was found to be too smooth. A practical resolution was discovered by implementing a foam layer to enhance traction, yet its temporary characteristic required a shift towards a sturdier stamping rubber. Adding a rubber layer to the gripper tips was a critical improvement, effectively increasing the strength of the grasp while reducing the potential for harm to the connections. Given the equipment's operating environment, it was crucial to have a sturdy support structure that could withstand the forces created by the robot without compromising accuracy [10]. Given this recognition, we decided to replace the hardwood surface of an existing table with metal bars and T-slots, enhancing its structure and allowing for versatile component securing while maintaining structural integrity. Once the table, shown in Fig. 2, was constructed, the placing of elements became quite flexible. The flight stick replica was substituted at this critical stage with the defined cube. The subsequent version of the flying stick replica used a cube-like structure, which was intentionally engineered to provide multiple points of attachment along its surfaces. This design thoroughly examined connector connections from various angles and orientations, allowing for extensive testing. The table's construction represented a noteworthy milestone in the project's advancement.

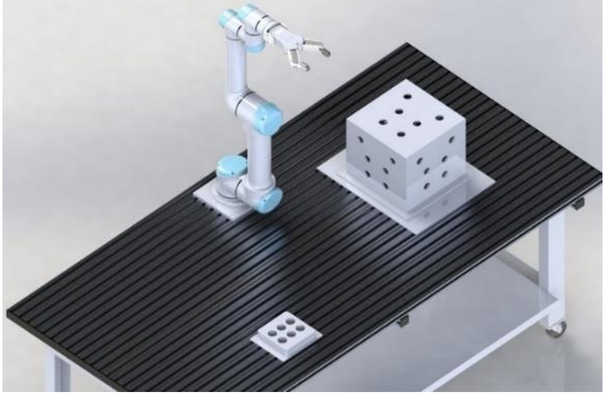

Fig. 2. *3D model of the experiment environment*

The UR5 robotic arm's operational program comprises four key components, each vital for coordinating the intricate tasks of selecting and placing connectors. An indexer guides the robot in retrieving and placing connections onto the correct sockets with precision and attention to detail, ensuring collision avoidance. Once a connector is picked, the robot aligns directly over the designated socket and begins the insertion process with high precision. The gripper adjusts the connector's position until contact is established, indicating accurate alignment. After insertion, the robot releases its grip to engage the locking mechanism, securing the connection in place with a regulated spin. Challenges may arise during insertion due to connection design, prompting the use of a timer to regulate the locking process. Once all connectors are fastened, the robot removes them by gently disengaging the connections and returning them to the rack, following directions from the indexer for each step. This sequence repeats for all six connections, with the indexer resetting the process after each cycle to mimic real-world conditions.

3 Test and Results

Once the optimised workspace was established, testing processes were commenced. Two separate tests were scheduled: one test focused on wireless connections, while the second test involved connectors with wires. The main aim of the study was to evaluate the performance of the robotic arm in terms of its capacity to sustain cyclic endurance until task failure, therefore assessing the repeatability of the process. The effectiveness of automating an activity would be compromised if it required frequent human interaction. The primary objective of the original experiment, including wireless connections, was to do a series of 10 consecutive cycles, which aimed to simulate the expected requirement of the firm to connect and disengage the flight stick ten times during a typical workday. The outcomes exceeded anticipated levels to a noteworthy degree. During the 120-minute testing session, the robotic system successfully completed 16 consecutive operating cycles without any problems, Significantly, this achievement demonstrated the possibility of further iterations. The corporation mainly relies on cable connections, so the current results fall short. Trying to execute ten cycles with additional wires caused various complications. When functioning wirelessly, the centre of gravity of the connection was positioned within the cables, ensuring their retention upon insertion. Nevertheless, the introduction of cables caused a disturbance in this balance, leading to the dislodgement of connections when released by the gripper. Moreover, the incorporation of cables presented difficulties for the rack system since the increased load resulted in connections becoming dislodged. The cable management issue has become a significant consideration, primarily because of the proximity of power outlets on the faces of the cube, leading to the entanglement of several wires. Therefore, it was crucial to choose the indexer to avoid any potential wire entanglement carefully. Furthermore, the rack was partitioned into two distinct portions, with each section capable of supporting three connectors. These connectors were placed on opposing sides of the cube to optimise the cables' separation. Tension was induced, and excessive movement was restricted by attaching weights to the end of each cable. Although there were occasional disruptions throughout the insertion and locking process, caused mainly by difficulty in managing the cables, the robot demonstrated its capacity to manoeuvre through these problems, leading to successful connector insertion. Some suggested changes involve combining gripper tips with lateral claws to enhance the gripping mechanism and creating self-retracting cable mechanisms. In addition, the installation of cable suspension structures is intended to reduce collisions and improve cable organisation. These initiatives strive to tackle issues regarding connector stability and cable management, ultimately enhancing the dependability and effectiveness of rack systems.

4 Conclusions

This research highlighted the significant impact of automation on the trajectory of industrial processes, providing advantages such as increased efficiency, enhanced accuracy, and less dependence on human interaction. The aerospace industry places great importance on ensuring high-quality standards, making it imperative to adapt to the advancements of

Industry 4.0. The examination of the flight stick, as exemplified in the case study, highlighted the presence of inefficiencies in the manual testing procedure, which might hinder the prompt interpretation of test outcomes. This research showcased the possibility for attaining complete job automation by integrating a Universal Robotics Arm, emphasising the need of selecting suitable equipment and developing appropriate programming. The thorough assessment of many gripper prototypes was essential in enhancing the efficiency of the connection manipulation procedure. The iterative procedure resulted in the identification of a gripper that achieved a harmonic equilibrium between accuracy and grip capacity. Adding a rubber layer to the gripper tips had emerged as a crucial improvement, effectively enhancing grip strength while protecting the connectors' integrity. Although wireless connections have shown impressive performance, the introduction of wires has presented issues that require further improvement. Potential solutions, such as enhancing the rack system and boosting gripper functions, have shown promise in addressing these challenges. Furthermore, using novel strategies in cable management is necessary to attain smooth and efficient operations.

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