sciendo
LOGI – Scientific Journal on Transport and Logistics
Vol. 16 No. 1 2025 DOI: 10.2478/logi-2025-0004

Technical and Economic Analysis of a Robotic Station for Assembling the FPV Drone Body

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Received: 9 October 2024; Revised: 21 October 2024; Accepted: 30 October 2024; Published: 21 January 2025

Abstract: The current technological progress is possible due to automated assembly and transport operations, and the increasing use of robotic cells. This article presents a robotic station for assembling the body of an FPV drone. The article uses analyzes and simulations as well as the results of simulation studies. The research has shown that the robotic station significantly increases the efficiency of the assembly process compared to traditional methods, shortening the unit production time by approximately 30-50%. The economic analysis has shown that despite higher initial costs, the investment in a robotic station pays off in approximately 3.3 years, which results from lower operating costs and the elimination of some labor costs. Moreover, the automation of assembly processes not only contributes to financial savings, but also to the improved quality of the final product. The future research should focus on further optimization of robotic stations, in particular on increasing their flexibility and adaptability in dynamic production environments.

Keywords: Automation, industry 4.0, robotics, internal transport, air transport

1. Introduction

Practically, in all areas of life, there has been a huge development conditioned by technical, technological and economic progress. One of the factors that influence the economic development is the development of energy, because all economic branches need energy resources. Within the framework of sustainable energy, the so-called energy mix, i.e. the share of various fossil energy sources and the energy from renewable sources, is quite important [1]. The sector that needs large and diverse energy resources is transport [2].

One of the most important areas behind the development is the progress in materials engineering. Thanks to modern materials, it is possible to implement advanced technologies, and design new structures based on modern materials. Among these materials, it is worth mentioning the widely studied and widespread polymer materials [3,4] and composite materials [5,6], improving traditional materials such as steel [7] or improving properties through modern materials and alloy additives [8]. A good example of development is the production of materials using additive techniques. In this area, a lot of scientific research is being undertaken, today not only polymer filaments are available, but it is also possible to print metal or concrete [9,10]. Additive techniques have a number of advantages, the most important of which are relatively low production costs, a large share of recycled materials, the possibility of shaping the varied strength of the elements made [8]. The above-mentioned groups of materials can be used in many areas, and this is the most noticeable in the case of various means of transport [11-13], where it is possible to reduce the vehicle's own weight in favor of greater payload [14] or the possibility of obtaining greater strength and durability as in the aviation sector [15-17], or special machines [18,19]. In the literature on the subject of small aircraft, one can also find many important scientific works [20,21], in particular focused on control and monitoring [22,23] or stability [24]. As already noted, the economic development is possible thanks to the technical progress, and new materials and technologies foster the need to assess production possibilities and economic aspects related to the profitability of using a given solution. In the literature, one can find many works on technical and economic assessment [25], user preferences and demand for a given product or service [26]. The pandemic period has shown the weakness of companies in which technological processes were carried out under supervision or exclusively by employees. This experience has forced many entrepreneurs to change their way of thinking and has opened the way to investments in the automation of production processes and a greater than ever interest in industrial and collaborative robots. This is visible in the increasing number of robot sales [27].

In connection with the above, this paper attempts to conduct a technical and economic analysis for the assembly station of the FPV drone body using a robot from Universal Robots compared to traditional assembly performed by personnel. The FPV (first-person-view) drones are a special category of unmanned aerial vehicles that allow the pilot to experience the flight from the perspective of the cockpit. Thanks to the mounted camera and video glasses, the operator feels as if he were on board the drone himself, which provides an extremely immersive experience. These small, agile and efficient machines have found wide application in various fields - from entertainment and sports, through filming and photography, to military operations or technical inspections. Their mobility and ability to reach hard-to-reach places make the FPV drones an increasingly popular tool.

2. Research Object and Methodology

The key element of every FPV drone is a lightweight yet rigid frame, most often made of carbon fiber or durable plastic reinforced with fiberglass. The drone is equipped with brushless electric motors that drive propellers, also made of polymers. (Fig. 1) The most important element of this flying machine is the main board (FC) with an integrated processor, sensors and electronic systems responsible for flight control and stabilization. Other necessary components are engine speed controllers (ESC) and an RC signal receiver. All these elements must be properly integrated and configured to ensure reliable operation of the FPV drone. The robotic station for assembling the drone body is only responsible for the mechanical part of the process.

Fig. 1 The view of the construction of the FPV drone's body. Source: authors

Simulation tests were carried out in the ABB RobotStudio providing an offline and online simulation and the programming environment. A process simulation was carried out to verify the correct operation of the station. To make this possible, a simple station was developed (Fig. 2) consisting of: 1 - UR 16e Robot, 2 - 2F-85 Adaptive Gripper, 3 - Flat Conveyor Belt, 4 - 5-inch drone body assembly table, 5 - SPATZ04 tool station, 6 - SPATZ internal power unit, 7 - SPATZ Encoder, 8 - SPATZ04 tool holder, 9 - Micro HAWK F440-F smart camera.

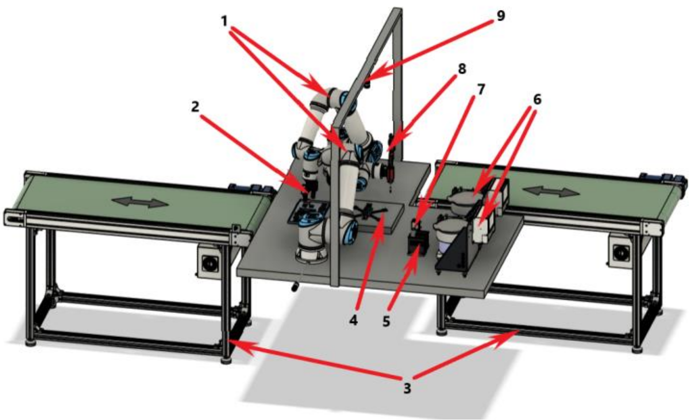

Fig. 2 The photo from Fusion 360 showing the concept of the robotic station for assembling the FPV drone body. Source: authors

In the first stage of the assembly process of the 5-inch drone body, its parts are transported using a flat conveyor belt. Then, the previously prepared drone parts are taken from the box (Fig. 3a), assembled by the first UR16e robot, equipped with the 2F-85 Adaptive Gripper, and then placed on the table in the appropriate place. At the same time, the second UR16e robot, equipped with the SPATZ04 tool holder, places the nuts on the table for assembly of the drone body. After placing the first parts on a specially designed table (No. 4 in Fig. 2), the second UR16e robot changes the tool to SPATZ04 for the screws and tightens the drone parts. This process is repeated until all the drone body elements are completed. After the screw tightening process is completed, the drone goes through quality control using vision systems, using the Micro HAWK F440-F intelligent camera, which allows for immediate detection of any errors during production. After passing the quality control and detecting no irregularities, the first robot transfers the finished element to a conveyor belt, which will enable palletizing.

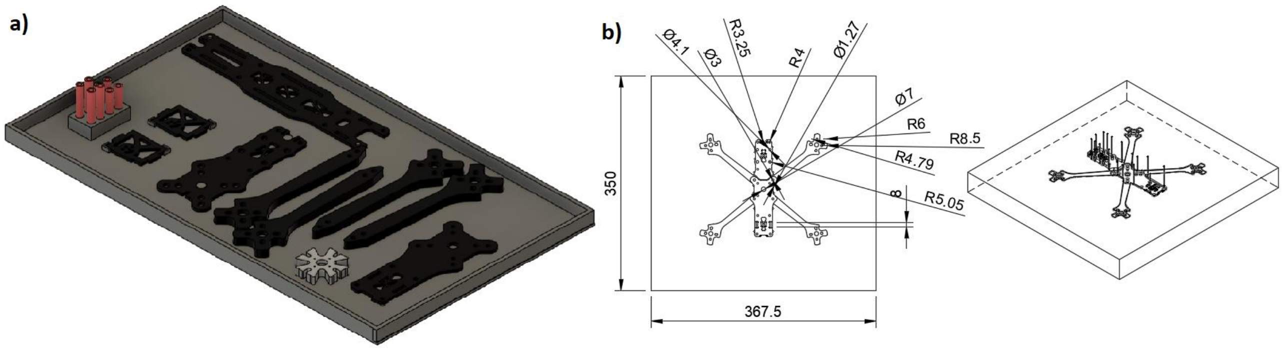

Fig. 3 A box with parts for the FPV drone body – a) 5-inch drone body assembly table - Technical drawing – b). Source: authors

Provided the built-in camera vision system fails the quality control procedures, the automatic system sends a message to the operator and robots to remove the defective body from the palletizing area. Then, the rejected part is inspected by the operator, who assesses the possibility of repairing the damage. If the defect is found to be serious and beyond repair, all components are manually disassembled. Those that still meet quality standards are separated and placed in the right place for reuse. This procedure aims at minimizing defective products and maximizing the use of parts that are still in good condition. This section should include sufficient technical information to enable the experiments to be reproduced. In theoretical papers comprising computational analyses, technical details (methods, models applied or newly developed) should be provided to enable the readers to reproduce the calculations.

3. Results of the Experiments

Using Fusion 360, we managed to develop a fully automated drone body assembly station. This allowed us to compare the simulated speed and cost of the drone assembled by a robotic station and manually assembled by a human. Figure 4 shows the stages of drone assembly using the automatic method without any human intervention. The UR16e robot was selected for the assembly station for the FPV drone body assembly mainly due to its versatility, precision and safety. Although the drone parts are not heavy, this robot is an ideal solution thanks to its high precision and accuracy, which allows the precise assembly of small and delicate components. In addition, the UR16e robot is easy to integrate and program, which allows it to be quickly adapted to different assembly stages. Its advanced safety features ensure safe cooperation with humans, which is crucial in a production environment. With these features, the UR16e robot ensures efficiency, high quality and safety in the FPV drone body assembly process.

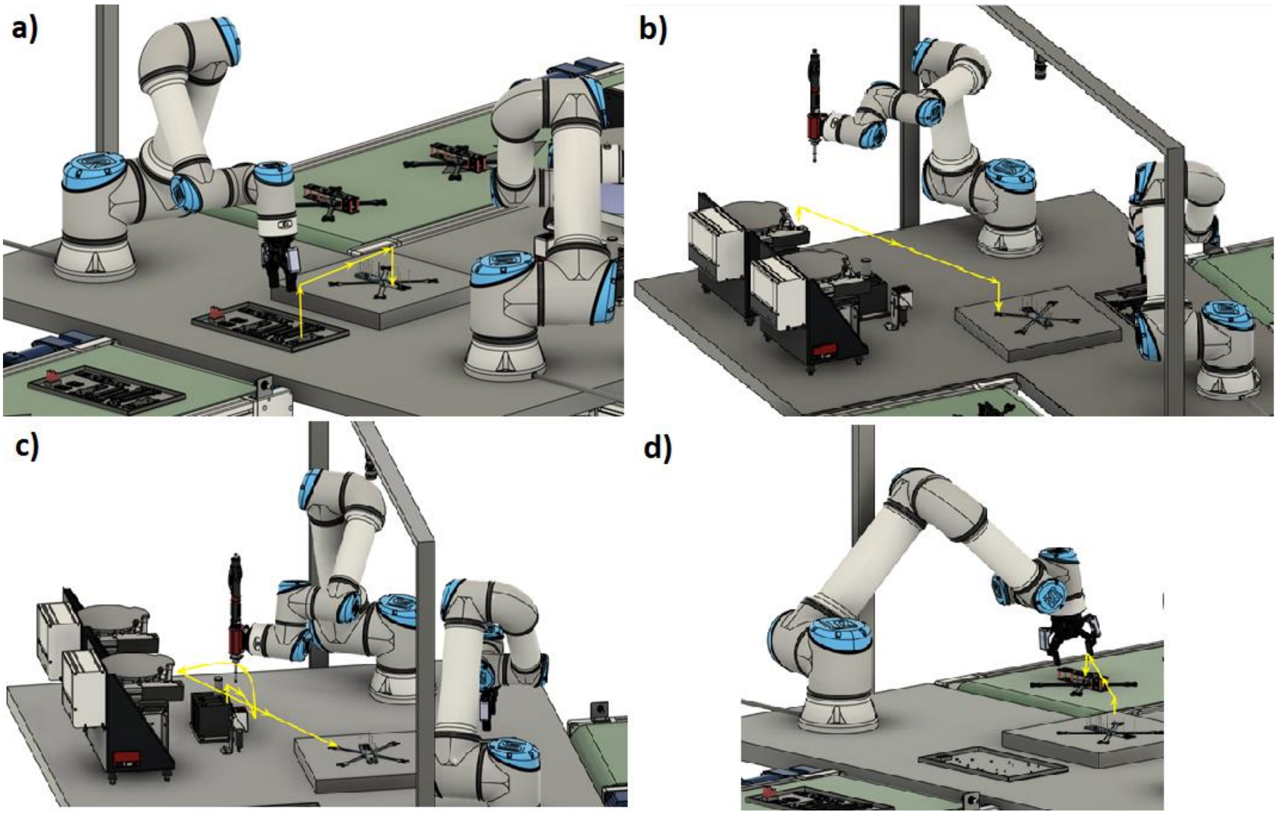

Fig. 4 Assembly process a) transferring FPV drone body parts to the assembly table; b) placing nuts on the assembly table; c) changing the tool and receiving the screw; d) placing the finished drone body on the conveyor belt. Source: authors

4. Discussion

The analysis of the proposed solution in the context of drone body assembly automation shows both significant advantages and certain limitations compared to traditional manual methods. The introduction of a robotic station, as shown in the experimental results, significantly increases the efficiency of the production process, reducing the time of individual assembly and minimizing errors resulting from human work.

4.1 Analysis of the Proposed Solution

Automation allows precise and repeatable assembly operations, which translate into higher quality of the final product and a lower risk of defective components. In addition, decreasing the dependence on labor reduces operating costs, which, in the long term, can lead to significant financial savings. However, the robotic station encounters significant challenges in the context of flexibility and the ability to react to unpredictable events, which is crucial in a dynamic production environment. The lack of adaptive skills that are inherent to human operators makes automation less effective in the event of non-standard situations or changing operating conditions. Robotic systems, despite their technological advancement, still require significant costs for implementation, maintenance and programming, which can be a barrier for many companies.

The simulation shows that the estimated production time of one drone body by the robotic station is approximately 654 seconds, which gives us about 10 minutes and 54 seconds. In the case of traditional manual assembly, the study showed that the assembly time of the drone body was from 15 to 20 minutes. This means that the robotic process is much faster, offering time savings in the range of 30-50% for each assembly cycle. To show the relationship between these two methods, it is assumed that the production of one body by the robotic station takes 11 minutes, and manually 17.5 minutes. Fig. 5 shows the relationship between the robotic station and the manual method by the operator in drone production.

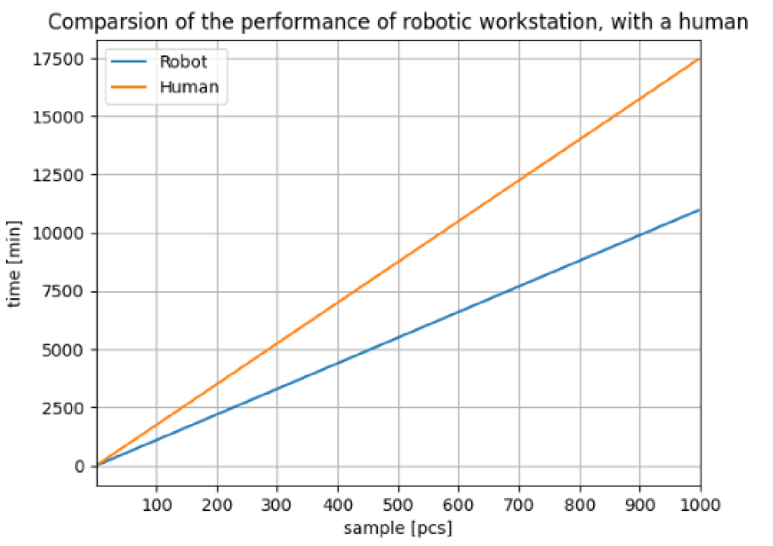

Fig. 5 The comparison graph of robot and human work. Source: authors

Analyzing the data in the graph (Fig. 5), the working time of the robotic station is shorter than the manual assembly, so the robotic station is more efficient. In the case of 1,000 pieces of manufactured bodies, the time saved is 6,500 minutes, which gives a result of 108 working hours per one station. From an economic point of view, the robotic station is associated with higher initial costs related to the purchase and implementation of robots. However, lower operating costs resulting from the elimination of some labor costs mean that significant savings can be achieved in the long term. In turn, the manual station is characterized by lower initial costs, but higher operating costs related to employee remuneration. The cost efficiency of the robotic station is higher because savings on labor costs and increased efficiency lead to lower unit production costs. Table 1 presents a summary of the costs of the robotic station for the production of drone bodies.

Table 1 The cost estimate for the position (Rate as of 08.06.2024: PLN 4.31 = €1). Source: authors

Name	Price [PLN]	Value	Total [PLN]	Total [€]
Robot UR16e	182,300	2	364,600	84,523.39
SPATZ04 Tool Holder	25,000	1	25,000	5,795.63
SPATZ04 Tool	1,000	1	1,000	231.82
SPATZ04 Tool Holder	2,750	1	2,750	637.50
SPATZ Internal Power Unit	18,500	2	37,000	8,577.53
SPATZ Encoder	400	1	400	92.73
2F-85 Adaptive Gripper	20,300	1	20,300	4,706.04
M18 x 1 Inductive Proximity Sensor	300	1	300	69.55
F440-F Smart Camera	3,000	1	3,000	695.48
Module Perfect Ø70mm Signal Tower	350	1	350	81.14
Siemens SIRIUS ACT Safety Switch	400	2	800	185.46
X-GUARD CLASSIC Machine Guard	3,150	7	22,050	5,111.74
Siemens SIRIUS 3SK1111-2AB30 Safety Relay	660	2	1,320	306.00
Total			479,320 PLN	111,118.36 €

In order to assess the economic aspects of both methods, the following issues must be taken into account: the number of working hours per day and the number of working days per year, the cost of maintaining the robotic station, the initial costs associated with implementing the robotic station, apart from the purchase itself, and the expected annual increase in the salaries of production employees, if any. To calculate the period after which the robotic station will become more profitable than a manual station operated by two employees, the following assumptions were made: working time is 8 hours per day, 5 days per week, which is about 250 days per year, and the salary of one employee is PLN 30/h. In addition, various costs borne by the employer are taken into account, which gives a final rate of PLN 36.15/h. The cost of the robotic station is €111,118, and the costs should be added to the employee training of about €5,000 and the annual cost of maintaining the station of €2,000. The inflation of about 3% per year is also assumed. With these assumptions, it is possible to calculate after how many years the robotic work station will become more profitable compared to manual work, and the results are presented in the graph below (Fig. 6).

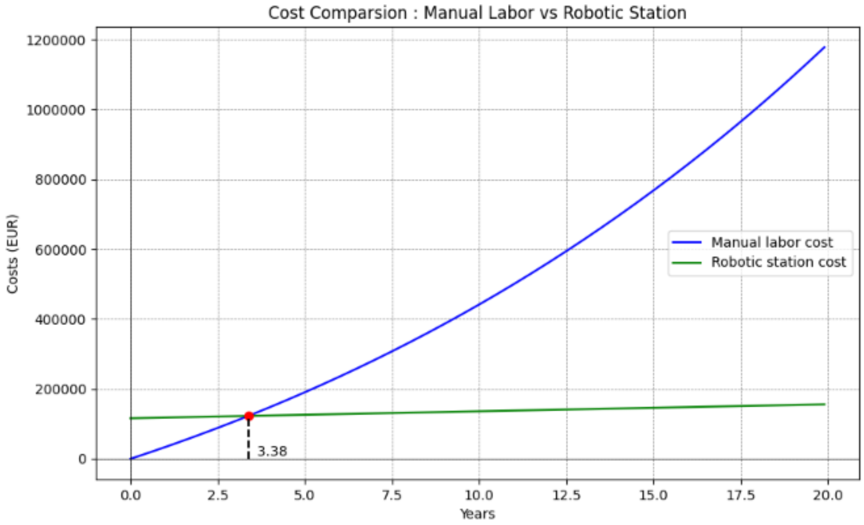

Fig. 6 Comparative graph of the costs of the robotic and manual station. Source: authors

4.2 Disadvantages of a Robotic Station

The changes related to the automation of production often lead to concerns about job losses, especially in sectors where manual work dominates. Employees performing routine and repetitive tasks may feel uncertain about the future of their employment, which may affect their morale and sense of job security. However, the implementation of robots also creates new jobs related to the operation and maintenance of automated systems. Employees, instead of performing long, monotonous and physically demanding tasks, can be moved to more advanced, technical tasks, which contribute to reducing physical burdens. Monotonous manual work is often associated with the risk of musculoskeletal disorders, stress and burnout. The automation of such tasks not only improves work comfort, but also reduces the number of injuries and occupational diseases, which has a positive effect on the health of employees. Thanks to this, they can focus on tasks that require greater intellectual engagement and creativity, which can bring greater job satisfaction [28,29]. Automation can also affect the work culture in the company. Working with robots requires a different set of skills and can lead to reduced interaction between employees. In the case of manual workstations, workers often collaborate and communicate, which builds social bonds and supports teamwork. Robotic work environments can be more isolating, which can affect employee morale and team spirit. One of the main challenges associated with automation is the potential for worker isolation, which can negatively affect morale and team spirit. Workers may experience lower job satisfaction when their social interactions are limited and their role is limited to monitoring and managing machines rather than actively collaborating with colleagues [30,31]. In the context of drone body assembly, robotic workstations often rely on programmed sequences of operations and precisely defined motion trajectories. This methodology works well in stable production conditions, where all variables are predictable and controlled. However, in real production conditions, random events often occur, such as changes in component quality, unexpected tool failures, or differences in component alignment. In such cases, robots show limited flexibility compared to employees who can adapt their actions on an ongoing basis, using experience and intuition to solve technological problems. The inability of robotic stations to respond to random events can lead to serious disruptions in the production process. For example, if a drone component is damaged or incorrectly placed, the robot may continue the assembly according to the programmed scheme, which may result in further damage or even complete failure of the assembled device. A manual employee, upon noticing a problem, can immediately take appropriate corrective steps, such as replacing the faulty component or adjusting the assembly process on the fly, which minimizes the risk of downtime and production losses [32,33].

5. Conclusion

This article presents a robotic assembly station for the FPV drone body, presenting both the research methodology and the results of simulation experiments. The research has shown that the robotic station significantly increases the efficiency of the assembly process compared to traditional manual methods, reducing the unit production time by about 30-50%. In addition, automation minimizes the risk of errors, ensuring high quality and repeatability of the assembled drone bodies. The economic analysis has shown that despite the higher initial costs, the investment in the robotic station becomes profitable after about 3.3 years, which is due to lower operating costs and the elimination of some labor costs. These results suggest that the automation of assembly processes not only contributes to financial savings, but also to the improvement of the quality of the final product. However, the implementation of automation is associated with certain challenges, such as the need for specialist knowledge for programming and maintaining robotic systems and the need to adapt to changing operating conditions. Nevertheless, the benefits of automation, such as increased efficiency, higher quality and work safety, outweigh the potential disadvantages.

The future research should focus on further optimization of robotic cells, in particular on increasing their flexibility and adaptability in dynamic production environments. Developments in this area can bring significant benefits to the manufacturing industry, making automation more accessible and effective. Robotic assembly cells are the future of industrial production, offering numerous operational and economic benefits, but the existing limitations require further research and development to fully exploit the potential of automation in changing production conditions.

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