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Functionality and Reliability Improvement of Lifting Mechanism System in The Drone Docking Station Using TRIZ

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Abstract

Drone docking station (DDS) is a hub designed for drone origin resting that is used for highway surveillance. The studied DDS is purposely for low-cost and locally sourced DDS components used in remote areas to store and protect the drone. This paper aims to select simpler design of lifting mechanism that can improve the functionality and reliability of the DDS by using TRIZ tools. The key solutions are obtained using the Function Analysis (FA) tool and Engineering Contradiction (EC) tool. By utilizing FA tool, functions of all DDS components were identified and it helped to focus on improving the chosen subsystem which is the lifting mechanism. After that, by applying EC tool, a screw type or known as mechanical type lift was chosen as the lifting mechanism for the DDS. The EC tool shows that the mechanical lifting mechanisms have simpler design with no dependency on fluid making it more suitable to be installed inside the DDS. By selecting the mechanical lifting mechanism, the simplicity design relates with easier maintenance and troubleshooting procedures, without risk of fluid-related issues. However, it should be tested in real working environments to find and fix any underlying problems.

1. Introduction

Nowadays drones have become a highlight in the aviation industry as they have numerous benefits that may contribute to certain sectors, especially transportation. People also started to imagine commuting by drones, envisioning urban connecting styles for people and goods [1].

Projek Lebuhraya Usahasama Berhad (PLUS) consolidates all highway concessionaires under a single entity [2]. By leveraging advanced technology in highway patrolling, PLUS used an existing heavy-duty commercial drone to observe traffic surveillance, third-party development, structure monitoring and landslide analysis throughout the highway road. Based on the data taken, the drone can only sustain its operation around a 7 km radius within 30 minutes of take off times. Improvements have been made where the current drones have the capability to return to launch (RTL) from the starting point and continue doing their task repetitively. However, it would be dangerous for the drone if it is not kept safely during the resting mode.

It is vital to have the nearest DDS so that the process of maintaining the drone missions can be achieved. Then, because of the typical problem of power source for drone, it is crucial to have a DDS that would become a place for the drone to charge its battery [3]. Other than that, typical functions of DDS are storage and shelter, origin automated launching and landing, maintenance and inspection, security and access control, data transfer and communication, integration, monitoring, routing and navigation assistance, and automation. These functions enhance the efficiency, safety, and effectiveness of drone operations in various industries including surveillance, logistics, agriculture and more [4]. This paper focused on improving the function of launching and landing drones that are related to lifting mechanisms.

There are many components inside of this station and all the components have their own functions. Thus, it is important to understand the functionality of specific systems so that improvements can be made [5]. The process of selecting suitable lifting mechanism must consider its load capacity, speed, precision, safety, energy efficiency and cost effectiveness [6]. The reason why this DDS has lifting mechanism is to provide shelter to drone from adverse weather conditions. Instead of being a platform for automated battery swapping, space optimization can be achieved where other activities, such as maintenance and inspection or other equipment can be installed inside the DDS too.

There are many types of lifting mechanisms, but the ones discussed in this paper are mechanical types, hydraulic and pneumatic. For mechanical types, typically with simpler designs leads to easier maintenance and troubleshooting procedures. Differ than hydraulic and pneumatic, mechanical types do not depend on fluids. Thus eliminates the need for fluid storage, pumps, hoses, and other related components. This will be proved by utilizing the methodologies in TRIZ (The Theory of Inventive Problem Solving).

The aim of this paper is to improve the functionality and reliability of DDS for its lifting mechanism by using TRIZ tools. Functionality refers to the ability of the lifting mechanism to perform its tasks effectively and efficiently. The aspects to be focused on functionality are lifting capability, providing precise control, and ensuring safety [7]. Reliability is about the consistency of the lifting mechanism in performing its task over time and under various operating conditions. The keys areas of attention for reliability are its durability in terms of moving the lifting link up and down, consistency of the performance, ease of maintenance, and longevity of service [8].

The functionality and reliability of the DDS lifting mechanism are improved using the TRIZ tools which are Function Analysis (FA) and Engineering Contradictions (EC). Then, by improving the lifting mechanism of DDS, it is to ensure that the drone can be lowered and raised smoothly. Firstly, the identification of lifting functionality is done by using FA and then EC. It helps to model the problem of lifting functionality and continue solving problems that arise in designing reliable lifting mechanism in the DDS system.

2. Methodology

The Theory of Inventive Problem Solving, or the acronym in Rusia, TRIZ, is a kind of innovation methodology developed by a Russian engineer and scientist named Genrich Saulowitsh Atshuller [9]. This evolution of technical systems has been developed from a study of more than 40,000 patents [10]. There are four basic concepts of TRIZ which are systems approach, contradiction, ideality, and resources.

This paper focus on the system approach and contradiction of DDS consisting of interrelated and interdependent components such as in Figure 1. In the system approach, complexity in DDS system was analyzed and understood to identify problems. This approach involved examining components within the system, their interactions, and the relationships between each other [11]. The existing DDS subsystem linking mechanism components are constantly influencing one another to maintain their activity to lower and raise the drone. The main product component of the technical system DDS was the drone itself. A detailed explanation of this system approach is discussed in Subsection 2.1 Function Analysis.

There were conflicts or obstacles that existed within components of the DDS system. This can prevent the system from functioning optimally, achieving its desired objectives [12]. Contradictions refer to these insignificant conditions. These ECs often involve conflicting requirements or conditions where improving one parameter of the system worsens another. Overall, the EC in TRIZ serves as an opportunity for innovation and problem-solving by exploring unconventional approaches and inventive solutions to overcome limitations and improve overall system performance. A thorough discussion of this contradiction is discussed in Subsection 2.2 Engineering Contradiction.

2.1 Function Analysis (FA)

In the structure of TRIZ tools, Function Analysis (FA) is one of the tools that is used for problem identification [13]. Understanding functions and functionality is fundamental to the successful application of TRIZ. It employs basic keywords and line types to give hints about functions and how the components are related to each other. Elements inside the FA are Component Analysis (CA), Interaction Analysis (IA), and the Function Model (FM).

From the first element, an inventor must identify components of the system and its super-system. A component is a recognizable object that makes up a part of a system. Whereas super-system components are components that interact with the system but are not part of the system. As for the DDS system, the details list of components and its super-system components are as below in Table 1.

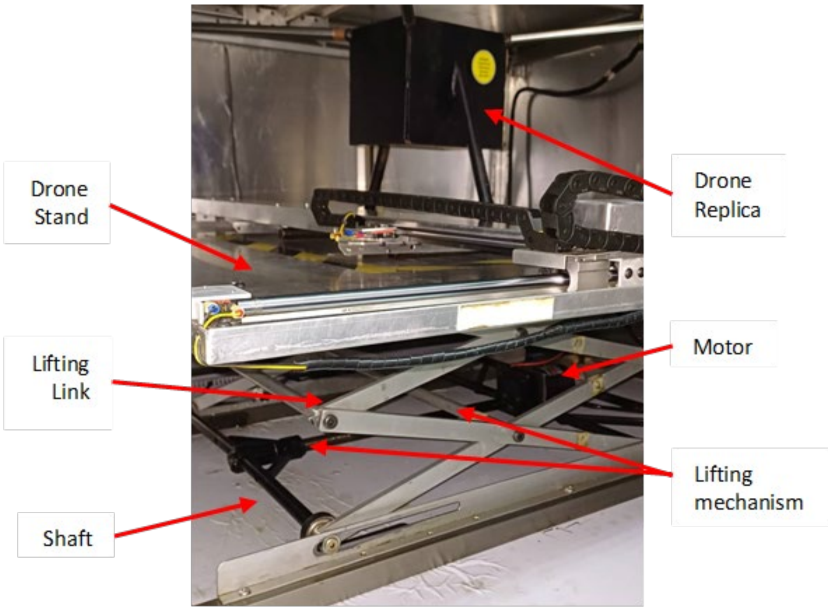

Fig. 1 *Examples of existing DDS components*

Table 1 *Detail list of Drone Docking Station (DDS) components and its super-system components*

Component Analysis	List of Components
Product	Drone
Sub-system Components 1	Body, Stoppers, Legs, Frame Screws, Motors, Trigger/Limit Switch, Lid, Sensors
Sub-system Components 2	Power Source, Server, Indicator, Controller, Motors, Screws, Shafts, Lifting Links, Slide way, Drone Stand
Sub-system Components 3	Body, Battery Holder, Batteries, Connectors, Charger Port
Super-system Components	Wind, Rain, Humidity, Temperature, Ground, Pressure, Lighting, Vibration

Based on list of components in Table 1, components are analyzed by its sub-system and super-system components. The diagram of overall functionality of DDS system is visualized in Figure 5. Example of one sub-system which is the focused sub-system for this study is the lifting mechanism. It consists of a shaft and lifting link that may raise and lower a drone from its drone stand. Then the super-system components that would affect the lifting mechanism is vibration that happened during drone lifting or landing. Those components and the super-system components of the lifting mechanism were analyzed based on its functions.

The main useful functions of components and the super-system component were identified by knowing the interaction between components. Interaction is an analytical tool that identifies and understands the connections between components of a system [14]. This process is the second element in FA which is Interaction Analysis (IA). A function is an action between components. Thus, the lifting link and shaft components interact with one another as a shift mechanism. The lifting link would shift the shaft to raises and lower the drone stand. While vibration affects the lifting link if it happens inside the system. Fig. 2 is an example of simple interactions between components or super-system components.

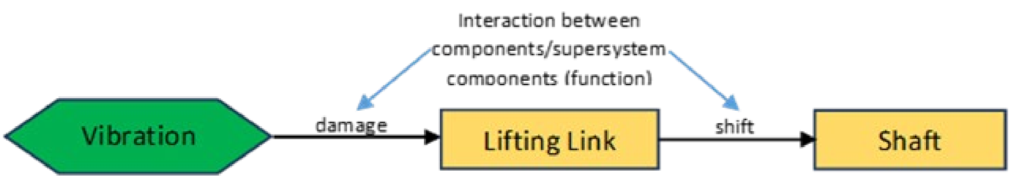

Fig. 2 *Examples of interactions between components or super-system component*

The last element of FA is the Function Model (FM). This element evaluates the interactions between components and super-systems components [15]. It is whether the functions acting on each component beneficial or not. It identifies the advantages and disadvantages of the functions acting on each component. It is done by using different signage lines to represent different types of functions whether useful (in normal, insufficient, or excessive ways) or harmful as per Fig. 3. Thus, as per IA for the lifting mechanism, vibration due to drone landing and lifting is a harmful super-system for the lifting link. Whereas the lifting link is useful in making sure that it can move the shaft in shifting it through the pathway. It can be finalized as Fig. 4. Those steps should be applied to all components of the DDS System Design to make sure the DDS can be enhanced by solving problems around it. Overall FM for the existing DDS system is illustrated in Fig. 5.

Based on the overall steps of FA, this tool helps innovators form a model with a conceptual description of a product. The conceptual description is understood based on the interaction between components that aim to make sure the product is functioning completely. The FA of the linking mechanism to raise and lower the drone inside the DDS system is highlighted in Fig. 5. Intending to enhance the functionality of the linking mechanism, it is suggested to proceed with the next tool which is Engineering Contradiction which generates hypotheses about possible connections between components of related problems.

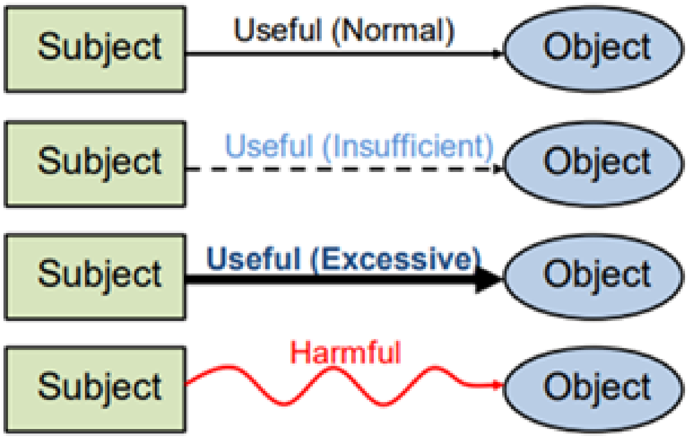

Fig. 3 *Definition of interactions between components*

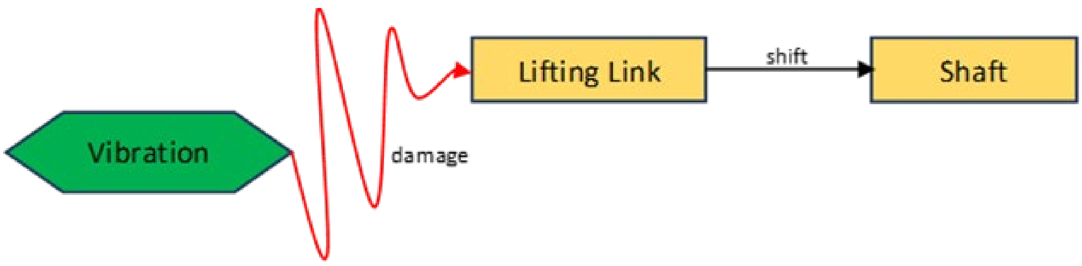

Fig. 4 *Function model of lifting link, shaft, and vibration components*

Typical problem-solving methods avoid conflict or contradiction in their design phase. Regarding TRIZ tools, contradiction is one of its basic concepts and one must always search for contradictions [16]. Contradiction is a combination of statements which are opposed to one another. Resolving those contradictions typically leads to invention which is a must step for the inventor to come up with a new design for a system. The EC happens when the improvement of one component of a system is done which leads to making another component worse. Based on the interaction between components in Fig. 5, focusing on sub-system of lifting mechanism, process of constructing EC is done based on statement below:

Use "If ... (manipulative variable changes) ... then ... (responding variable #1 improves) ..., but ... (responding variable #2 worsens) ..."

A manipulative variable is a variable or component that being changed to see it affects other component. Whereas responding variable is variable or components that being observed in response of changes in manipulative variable [17]. All variables including variable #1 and variable #2 are from components that been analyzed in Subsection 2.1, focusing on lifting mechanism, Sub-system Components 2. Variable #1 would improve based on changes in manipulative variable while variable #2 would worsen. The process of using the EC tool is started by listing the manipulative and responding variables in Table 2 below.

2.2 Engineering Contradiction (EC)

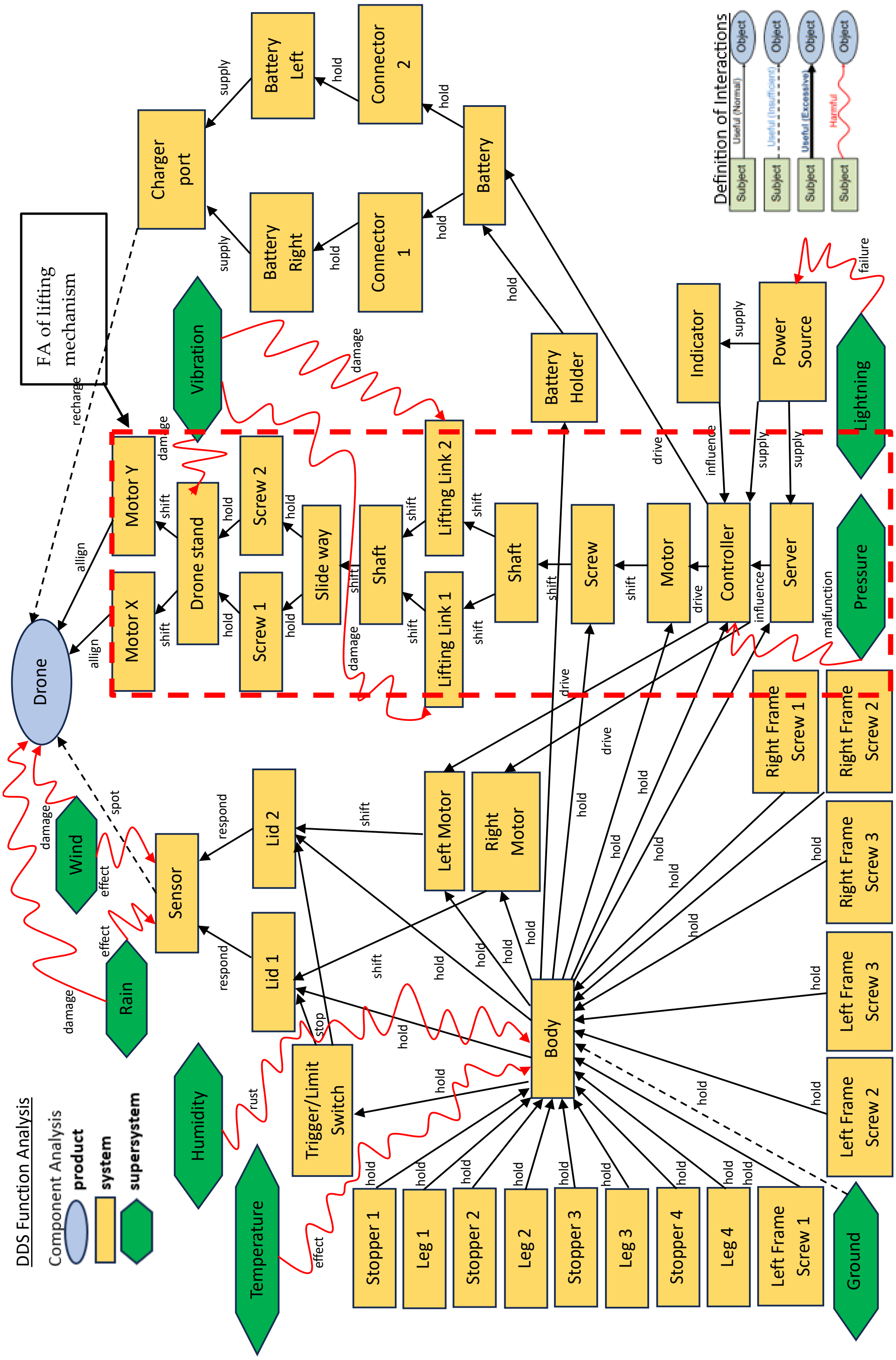

Fig. 5 *Overall function analysis of the DDS system*

This EC is constructed as the example whereas the drone stands as the manipulative mechanism and the lifting mechanism as the responding variable. The function of the drone stand is to shift the motors attached to it in aligning the drone before it is stored inside the DDS. As for the lifting mechanism, this drone stand is connected to it using screws at the slide way which is also one of the components of the lifting mechanism. The functions of each component were analyzed in FA tool. The application of the EC tool is shown in Fig. 6. As illustrated in Fig. 6, hypothesis of EC for the above variables is as below:

"If the drone stand is made of heavy material, then the drone can take off/landed stably, but the lifting mechanism will experience slower lifting speed."

Based on the hypothesis, the drone stand is a manipulative variable that can be change as a light or heavy material. Then based on interaction of the drone stand to hold the drone and lifting mechanism that interact with drone stand to lift or lower it, both becomes the responding variable. Responding variable #1 that improves in above statement is drone can take off or landed stably. However, lifting mechanism as responding variable #2 worsen at its lifting speed if the heavy drone stands affects stability of lifting movements. This process is applied to other components to see the differences of using different types of lifting mechanism to DDS and been discussed detailing later.

Table 2 *Manipulative and responding variables in Drone Docking Station (DDS)*

Manipulative Variable	Responding Variable
Drone Drone stand Shaft	Lid Lifting mechanism

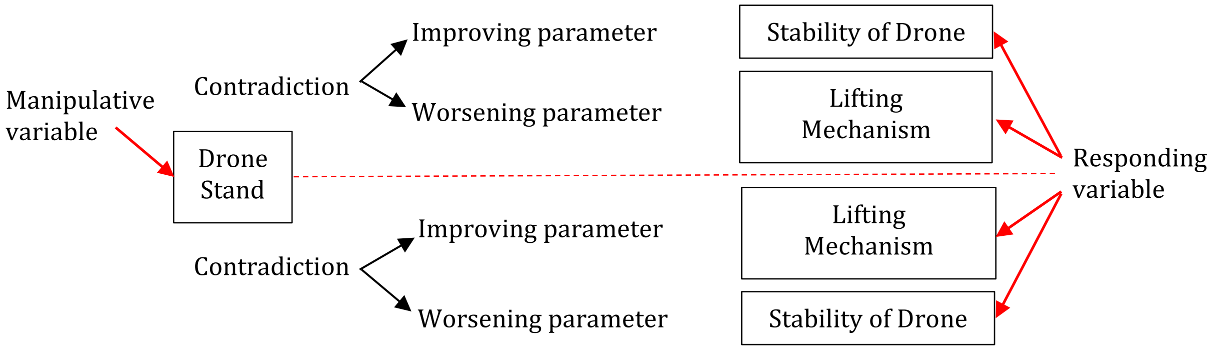

Fig. 6 *Function model of lifting link, shaft, and vibration components*

3. Results and Discussion

The main function of the DDS is to store a drone during its task to monitor highway surveillance in remote areas. It consists of 44 different components and 8 super-system components with different interactions with each other. FA helps in terms of understanding the functions and interactions of all components in the DDS system. However, this paper focuses on the lifting mechanism described as Sub-System Components 2 in Table 1 and highlighted in Fig. 5.

The lifting mechanism in DDS system is focused on this study so that it functions well supporting the drones during the lifting and lowering processes. Besides, the process of storing the drone inside the DDS also becomes smoother by emphasizing the improvement of the lifting mechanism. Consequently, by improving the lifting mechanism, the DDS functionality and reliability can also be improved.

As discussed earlier, engineering contradictions can improve one parameter of the DDS system but may lead to the worsening of another parameter [18]. The list below is ways to evaluate and design the best practices for improving the functionality and reliability of the lifting mechanism of the DDS with low-cost and locally sourced components.

i. If the lifting link is a mechanical type, then it produces a compact and space-efficient solution for lifting or extending applications, but the drone stand may experience issues with stability and rigidity.

ii. If the lifting mechanism is a mechanical type, then it is easy to install, but the cost increases with the need to use a high-efficiency motor.

iii. If the lifting mechanism is a hydraulic type, then a smooth and precise process happens, but creates a noise problem.
iv. If the lifting mechanism is a hydraulic type, then the lifting link would move smoothly, but it has the possibility of fluid leakage if the system is not properly maintained.
v. If the drone stand is made of heavy material, then the drone can take off/land stably, but the lifting mechanism will experience misalignment of components due to the limited precision of the hydraulic mechanism.
vi. If the lid of DDS is designed on the top, then it is easier for the drone to land, but dust, debris, or moisture can enter the body, affecting the lubrication and causing corrosion, especially for hydraulic type mechanism.
vii. If a high-efficiency motor is used, then it increases overall energy efficiency, but it increases the overall cost of DDS.
viii. If a pneumatic lifting mechanism is used, then the drone stand can move rapidly, but it increases noise-sensitive environments.
ix. If the lifting mechanism is pneumatic, then precise positioning is provided, but variations in air pressure or force can lead to inconsistent force output.

Based on the contradictions above, it is suggested that a mechanical type lifting mechanism is more suitable to enhance the functionality and reliability of the DDS system. Besides the mechanical type is more suitable to be employed due to its low-cost and locally sourced components. It is sufficient as the most important function of the DDS is to store, lift, and lower the drone. The pneumatic type lifting mechanism usually has problems with air consumption problems, noise, and vibrations instead of mechanical parts, as the listed EC in viii and ix. Then if using a hydraulic type lifting mechanism, the tendency of problem to occur fluid contamination or leakage due to relying on pressurized hydraulic fluid to operate as per EC numbers iii, iv, v and vi. Then by using a mechanical type of lifting mechanism as the listed EC numbers i, ii, and vii, fewer components usually fail during operations resulting in lower maintenance requirements and decreased downtime.

The main problem that arise in this study is to select a suitable lifting mechanism for the DDS system. For simplicity, the mechanical type lifting mechanism is more suitable to be installed with fewer components involved. Thus, suit for low-cost and locally sourced components for the DDS. The pneumatic and hydraulic lifting systems are more complex and would increase maintenance costs over time [19]. This is due to necessity of relying on fluids that need for fluid storage, pumps, hoses and other related components. Thus, the mechanical systems are less influenced by fluid leakage and contamination due to fluid-based systems making it more environmentally friendly compared to the other types of lifting mechanism. Based on this finding it is confirmed that functionality and reliability of the DDS system to raise and lower the drone can be improved by using the mechanical type system.

In summary, function analysis provides the foundation of identifying and understanding engineering contradictions. Resolving these contradictions often involves the creative application of function analysis principles to find inventive solutions. Therefore, function analysis and engineering contradiction are closely connected in the TRIZ method and can work together to drive innovative problem-solving in engineering and design processes [20]. Based on these outcomes, the application of this approach is suggested to be used for all components in the future design to further enhance the DDS functions.

4. Conclusion

This paper provides an overview of TRIZ Function Analysis (FA) and Engineering Contradiction (EC) processes of identification problems for the existing Drone Docking Station (DDS). By using this FA tool, EC within the DDS focusing on the lifting mechanism have been attempted. Then based on the list of EC tool in Section 3.0, it is proven that mechanical lifting mechanism is more suitable for this low-cost and locally sourced DDS components. The mechanical type system can lift and lower the drone at drone stand effectively with lesser problems related with fluid-based problem. TRIZ method is proven in detailing functionality of studied components then solving technical contradictions, increasing creativity, and opening new possibilities to optimize and improve the design of DDS. By applying those methods, functionality and reliability of the DDS system are improved. The selected lifting mechanism is suggested to be applied under the actual working conditions of the DDS system.

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Conflict of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest on the manuscript.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Rawaida Muhammad, Mohd Azli Salim, Adzni Md. Saad;* ***data collection:*** *Rawaida Muhammad, Mohd Azli Salim, Chonlatee Photong;* ***analysis and interpretation of results:*** *Rawaida Muhammad, Mohd Azli Salim, Mohd Zaid Akop;* ***draft manuscript preparation:*** *Rawaida Muhammad, Mohd Azli Salim. All authors reviewed the results and approved the final version of the manuscript.*

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