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ANALYSIS TO IMPROVE THE PERFORMANCE OF A SIX-AXIS ROBOT

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Abstract. This works on maintenance and real-time diagnosis methods for six-axis robots to ensure their stable operation and production efficiency. Two main areas of maintenance are discussed – software and technical. Software failures can be caused by incorrectly written data, faulty code or poor interface management, which can directly affect the performance of the robot and the quality of production. The technical part analyses the maintenance of spare parts, the optimization of energy consumption and the monitoring of sensors to reduce mechanical and electrical failures. The analysis also highlights the use of real-time sensor data and artificial intelligence algorithms for quick fault detection and preventive maintenance, contributing to the reliability of the system and reducing the risk of major failures.
Keywords: six-axis robot, diagnostic, failure, recommendation

INTRODUCTION

Relevance. As production volumes increase, industrial companies are automating their production system. By automating the production process, engineers aim to save labor, energy and materials and improve the quality of the final product. Automation of the production process includes activities such as: mechanics, hydraulics, pneumatics, electronics and computer-aided design. Automation is very much linked to the science of robotics, where all robots, both hardware and software, can work automatically, without any human assistance.

Problem Statement. Different types of robots are involved in the production process and one of the most popular robots is the six-axis robot, which is better than other multi-axis robots because of its characteristics. A six-axis robot is a type of manipulator that is used to manipulate materials without direct, physical contact with the operator. Because the robot arm is six-axial, it can manipulate six different parts of the robot, allowing it to avoid various obstacles and handle objects from almost any angle. The robot's permissible movement makes it versatile and allows it to be used for a wide range of production processes: assembly, welding, material handling (painting, sandblasting, etc.), packaging, quality control, etc.

With the emergence of automated processes, not only are there failures on the hardware side, but also on the software side. This analysis analyses the most common problems/faults that occur in the operation of a six-axis robot, both from the component and the software side. After analyzing these problems, recommendations are given on how to avoid them and improve the working principle of this robot in order to make the production process more stable.

To achieve the aim of the analysis, the following **objectives** were set:
1. To examine the principles of failures in six-axis robot software systems.
2. To identify failures during the operation of a six-axis robot.
3. To formulate recommendations for improving the performance of a six-axis robot.

RESEARCH METHODOLOGY

A quantitative research method was used to look at data that was put together from different source studies. The topic in question was thoroughly examined as a result of the inclusion of works by foreign authors in the reviewed sources. Research data and theoretical evaluations published in *IEEE* and *Science Direct* were analysed. Titles, abstracts, and full articles of scientific articles were reviewed to determine their appropriateness for analysis. The most pertinent databases, where the findings of studies on the topic were published, were chosen for the systematic and comprehensive literature search.

A literature search was performed using every search word that may be utilised to describe the concept under investigation. 55,677 publications were found based on the keyword combinations used. The table that follows displays the outcomes.

Table 1

Results of the literature search in scientific article databases

Key words	Science Direct	IEEE	Total
Six-axis robot	36,608	341	36,949
Diagnostic	4,459	3	4,462
Failure	10,486	7	10,493
Recommendation	3,773	0	3,773
Total	55,326	351	55,677

Since the data needed for the investigation is available in scientific databases, the study complies with research ethical guidelines.

PRINCIPLES OF FAILURE OF SOFTWARE SYSTEMS IN A SIX-AXIS ROBOT

When automating manufacturing processes with six-axis robots, mechanical engineers need to ensure that the robot is stable, efficient, and safe. Allowing robot movements makes the design complex and the robot itself prone to failure. Unnoticed failures can have serious consequences and can lead to catastrophic consequences (Sabry, Amirulddin, 2024). Unforeseen failures can lead to process stoppages and product damage. Therefore, (Figure 1) shows key motivations for improving efficiency. Failures depend on various aspects such as errors in sensor measurements, engine speedometers, etc., but everything is controlled and monitored by the software system.

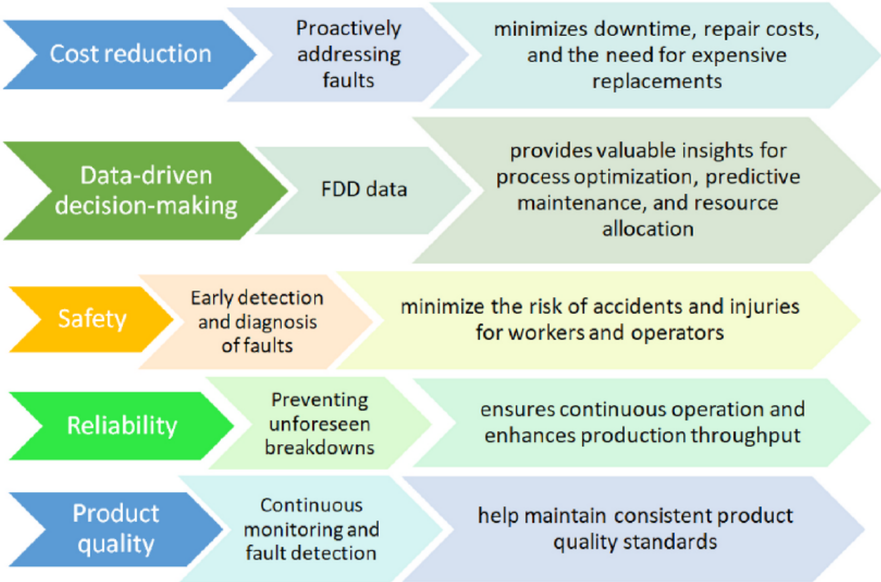

Figure 1. **Key motivations when developing effective FDI techniques**

The system first performs diagnostic operations to detect faults and then compares the properties of the test data with the diagnostic results. These features are fed into a classifier to diagnose robot faults. (Hsu, Ting, Huang et al., 2021). The diagnostic results allow maintenance to be carried out to avoid serious damage. The classifier is trained on historical standard features obtained from the initial diagnosis (Hsu, Ting, Huang et al., 2021). There are several ways to maintain the software system: online and autonomously (on-site maintenance). The principle of diagnostic analysis is dependent on this.

The remote structure consists of three subsystems, whose composition and order of operations are illustrated (Figure 2): fault detection subsystem; fault diagnosis subsystem; condition assessment subsystem.

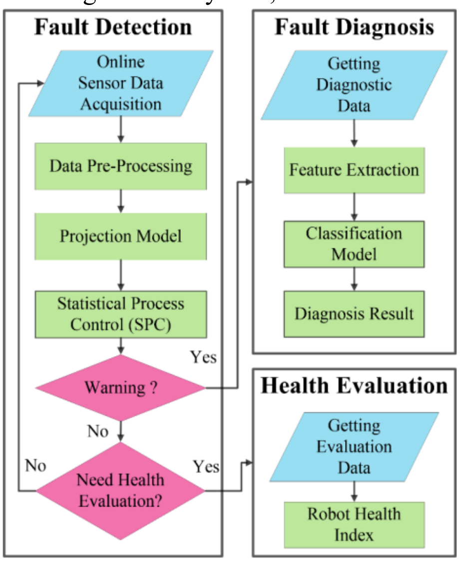

Figure 2. **Intelligent online fault detection, diagnosis and health evaluation system**

When the robot reaches a warning threshold, the fault diagnosis subsystem is triggered when the robot stops the current task. In addition, the data from the existing diagnostics, the projection model and the Statistical Process Control (SPC) control limits are first determined from the historical normal data of the current task. If the warning conditions are not satisfactory, the next step will be to apply the conditions of the evaluation process, which will be determined either by the duration of the job or by the user specification. If these conditions are met, the evaluation subsystem is started when the robot stops its current task. The fault-finding subsystem shall return to the starting point to continue the next cycle.

Before remote maintenance of the system, the subsystem forms the required pre-processing estimates, projection model and SPC bounds from the historical normal data of the current task, as illustrated in (Figure 3). The related parts of the autonomous development process and the remote fault detection process are described below (Hsu, Ting, Huang et al., 2021).

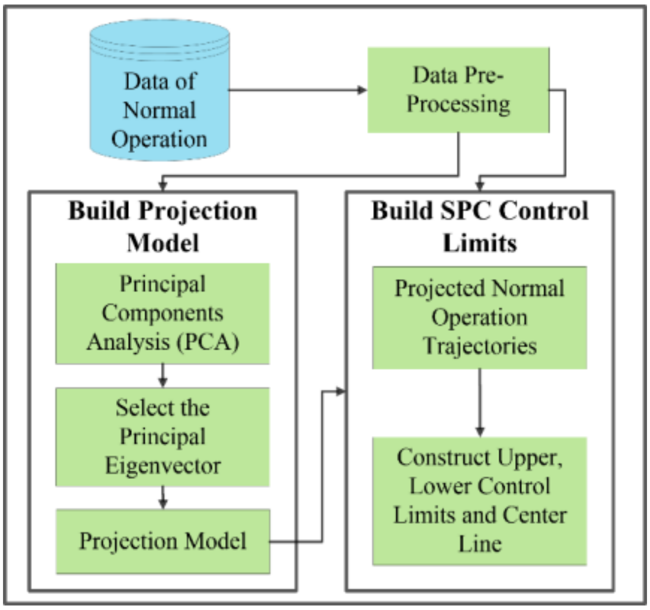

Figure 3. **The offline building process of the projection model and the control limits of the SPC**

Software failures result from a variety of causes, including human factors and equipment malfunctions, such as communication between other systems, sensor data errors or algorithmic errors (Sabry, Amirulddin, 2024), which can be seen in (Figure 4). The causes of software failures can be varied, one of the main errors is software bugs, which can arise from a misconfigured or programmatically corrupted system, which can cause incorrect robot movements. In addition, among the important problems, (Li, Wang, Wang, Duan, 2020) identified that sensor data errors, which arise from environmental disturbances such as moisture or dust, can affect the robot's response, which may cause the robot to perform the wrong motion or turn at the wrong angle.

Control system malfunctions are often caused by human errors in writing the system code, which can be due to algorithms that process motion sequences or real-time signals. Also, (Sabry, Amirulddin, 2024) state that if a six-axis robot uses different versions of software, problems can arise in the communication between components. Other faults can also occur, such as communication glitches, if the robot communicates with other systems, such as control centres or other robots, communication problems can cause synchronisation errors (Sabry, Amirulddin, 2024).

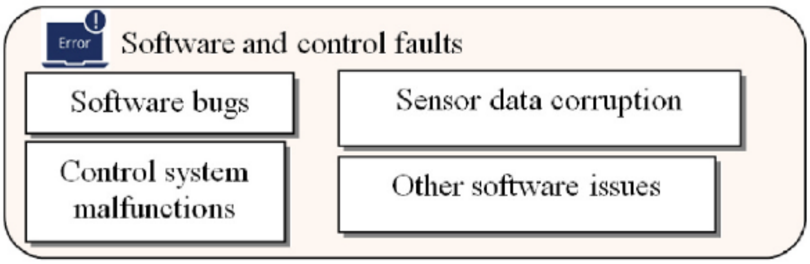

Figure 4. **Categorization of faults in industrial machines**

Improper control can damage the robot and the product (Sabry, Amirulddin, 2024). If the robot is given the wrong data, it may perform incompatible movements. The User Interface (UI) is essential, as a complex or unclear UI can lead to errors that adversely affect the robot's functions. In addition, a lack of maintenance of the software system can lead to errors in sensors, motors or communication. An effective error detection system is essential for robot safety. Human errors in programming and simulation have a significant impact (Figure 5). Incorrectly chosen algorithms or nonoptimised algorithms can lead to slow response times and higher energy consumption. Also, incorrect kinematics or dynamics models can lead to inaccurate movements, and inadequate testing can lead to loss of data.

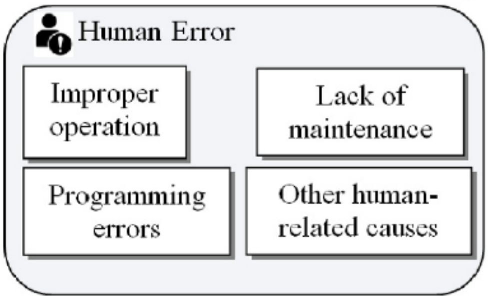

Figure 5. **Categorization of faults in industrial machines**

In general, the principle of a six-axis robot depends on the stability of the software and the efficiency of the sensors, as well as on human responsibility and other factors to keep the robot stable.

SIX-AXIS ROBOT TECHNICAL FAILURE PRINCIPLES

Technical failures also have a significant impact on the performance of a six-axis robot (Sabry, Amirulddin, 2024). Technical failures are separated in different categories, processing related failures, electrical failures, human errors, these categories can be seen in (Figure 6).

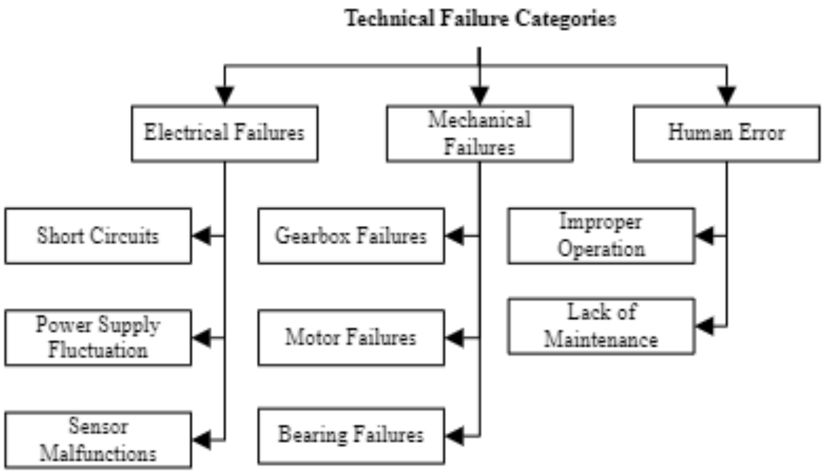

Figure 6. **Technical failure categories**

Gearbox failures are often mechanical problems caused by improper maintenance. Wear and tear and friction build-up cause vibration, noise and heat build-up. Replacement of bearings and seals is necessary and overheating of motors often occurs with incorrectly set loads, causing abnormal acceleration and deceleration (Sinha, Ahmed, Das, 2023). Motor overheating can also be affected by the temperature of the environment in which the robot is operating. At the same time, (Sabry, Amirulddin, 2024) emphasizes that regular maintenance is necessary to keep a six-axis robot at optimum performance and running smoothly for a long time. Such maintenance includes changing belts, monitoring and replenishing the oil level, as well as replacing all intermediate parts, (Morenas, Fernandez, Gomez, 2024). The robot is also a moving object, and the electrical wires that connect to the robot can wear out from the robot's movements, which can cause short circuits, power fluctuations, sensor malfunctions, or no current at all.

Therefore, each of the features discussed in this section has a significant impact on the stability of the robot and directly determines the quality of the product.

RECOMMENDATIONS TO IMPROVE THE PERFORMANCE OF THE SIX-AXIS ROBOT

As factories become more complicated and interconnected, the impact of a single machine failure can bring the production chain to a standstill (Sabry, Amirulddin, 2024). Optimizing settings, software and controls, and preventive maintenance are important to improve their performance. In addition, the increasing complexity of modern machines makes manual fault detection and diagnosis increasingly difficult and time consuming, (Sabry, Amirulddin, 2024). To ensure the safety, reliability and productivity of automated systems, comprehensive fault detection and isolation (FDI) strategies are required, which will be discussed in this section.

SOFTWARE IMPROVEMENTS

One of the means of stable operation of a six-axis robot is continuous monitoring. Continuous monitoring is a real-time monitoring system that collects data from sensors, such as sensors monitoring vibration level, temperature, motor current and other parameters (Sabry, Amirulddin, 2024). Another system that can be applied in robotics is fault diagnosis. This is a set of algorithms and models that can accurately diagnose the root cause of detected faults. Also, to detect faults faster, artificial intelligence can be applied that can learn from previous readings and thus increase the accuracy of the operation. Advance maintenance is also recommended to improve the performance and stability of the six-axis robot. Using sensor data, maintenance or minor repairs can be carried out in a timely manner to avoid major failures that could halt the production process for a long time.

TECHNICAL RECOMMENDATIONS

To keep a six-axis robot stable, the technical part also needs to be improved, so the following criteria must be followed to improve performance. Timely maintenance is essential, which includes replacing spare parts such as bearings, seals, belts, oil, etc. The energy efficiency of six-axis robots is also important, both in terms of reducing operating costs and improving system stability. Improving energy efficiency requires designing an optimal robot trajectory and inputting the right data to the motors to prevent them from consuming too much energy and overheating, which can also cause the robot to stop working. It is also necessary to monitor the technical condition of the sensors, as they can wear out and fail and need to be replaced in time, as well as to ensure that the parameters of these sensors are correctly set so that the system analyses the robot's behavior correctly.

CONCLUSIONS

1. Analysing the failure principles of a six-axis robot from the software side, it can be said that human inattention/error, poorly written code, incorrectly written initial data, improperly updated software, and improper use of the interface program can all lead to robot failures. This depends on how the robot will work, what movements it will use and can affect the output, damage it, cause losses during production or even cause human injury.
2. The six-axis failure principles can technically arise from mechanical failures, processing-related failures, electrical failures and human error. The main components that require more maintenance are the motor, bearings, seals, gearbox and electrical wiring. Failure to carry out regular maintenance can lead to vibrations, overheating, short circuits, etc., which can affect the stability of the robot's operation and directly affect the quality of the product.
3. With the increasing complexity and interdependence of production equipment, the maintenance and fault management of efficient systems is becoming increasingly important to ensure uninterrupted production. The failure of a single component can bring the entire production chain to a standstill, making it essential to invest in optimisation and preventive maintenance. Continuous data monitoring and advanced fault diagnosis systems allow real-time anomaly detection and rapid problem identification, which not only increases system reliability but also efficiency. Strategies such as AI-based diagnostics and early maintenance can reduce the risk of major failures. Finally, technical improvements, including energy efficiency improvements and sensor health monitoring, contribute to the long-term stability and productivity of six-axis robots and other automated systems.

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