CS 687 Capstone Project
Related Work
Improved Predictive Unmanned Aerial Vehicle Maintenance Using Business Analytics and Cloud Services

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Abstract

Demand for Unmanned Aerial Vehicle (UAV) usage in various industries is rapidly increasing from one year to another, but at the same time, there is growing concern about the electrical, mechanical, and system reliability of UAVs. The problem is that those reliability issues will interfere with safe operations and may lead to accidents due to malfunctions during flight. One of the effective ways to solve the issues is to strengthen the existing UAV maintenance method. For that reason, this research paper will review data analytics technologies that are using with existing predictive maintenance in aviation or other industries. Furthermore, this paper explains the strengths and weaknesses of each technology and compares each technology of the existing maintenance methods with a Proposed Maintenance Method (PMM) that uses Microsoft Power BI and Azure to verify which maintenance method is better to improve UAV reliability. Lastly, the paper discusses a limitation of the PPM and other efforts to increase the UAV reliability.

Keywords: Preventive Maintenance, Data Analytics Technology, UAV Reliability, a Proposed Maintenance Method (PMM)

1. INTRODUCTION

Using UAV brings significant benefits to decrease workload and product costs and increase work efficiency and productivity, so companies in several industries are adopting and using it to enjoy those advantages. As associated technologies advance and the growth of UAV demand, it expects that the commercial UAV market is rapidly growing soon. However, studies that research UAV safety and operations with the accident and incident data pose a question of the UAV reliability (Belzer, 2017; Lum & Tsukada,2010; Williams, 2004). Maintenance is one of the significant factors to directly influence UAV reliability, so having an appropriate maintenance method must be premised to improve the reliability for safe UAV operation. Technologies involved in data analytics are widely used to predict part failure accurately in the maintenance industry and help to reduce maintenance efforts, costs, and downtime for repair. Furthermore, it contributes to improving maintenance efficiency and reliability. Therefore, this paper reviews existing data analytics technologies that are recently used for predictive maintenance and compares them with the PPM to propose a suitable maintenance method for improving the UAV reliability. Also, the paper will discuss the limitation of the PPM and other efforts to increase the UAV reliability.

Problem Statement

Existing maintenance in the aviation industry, which is preventive maintenance, regularly performs aircraft maintenance depending on the flight hours, and this method requires downtime, high maintenance efforts, more upfront maintenance costs, the costs for the part inventory management, and intensive labor.

The UAV industry is rapidly growing up as technology advances, and UAVs are utilizing in various industries. But at the same time, the question of reliability in UAV has been continuously rising. Based on the studies, mechanical and system failure are still risk factors (Lum & Tsukada, 2010), and improvement of system reliability and standardization is necessary for safe UAV operation (Belzer, 2017). The purpose of UAV maintenance is to ensure that all components are operating as design for safe operation, but the existing maintenance method does not work properly as its purpose.

Motivation

From a report of the numbers of drones by the Federal Aviation Administration (FAA), 351,244 of 868,838 commercial drones are registered in the United States (FAA, 2021), and the FAA anticipates that the numbers of commercial drones will increase to 1.44 million by 2025 (FAA Aerospace Forecasts, 2020). A number of companies that are operating UAVs are getting an increase, but the existing maintenance method still remains in place without improvement. As a result, there are still issues of UAV reliability.

For that reason, the motivation of the paper is to recommend a way to improve UAV reliability through a PPM that combines data analytics technologies.

Approach

The paper will evaluate each data analytics technology that is utilized in existing maintenance in the aviation and maintenance industry. Furthermore, it looks over the advantages and disadvantages of each data analytics technology of existing maintenance and types of maintenance.

Conclusions

This paper mainly focuses on comparing features of the architecture of existing maintenance methods in aviation and maintenance industry with a PPM to propose which maintenance method is suitable to increase UAV reliability.

2. BACKGROUND

Types of Maintenance

There are many types of maintenance, such as preventive maintenance, predictive maintenance, reactive maintenance, and others. Preventive maintenance is to repair parts at a scheduled interval. On the other hand, predictive maintenance is to repair parts before they fail (Barlow, 2015).

Power BI

Power BI, which is a cloud-based data analysis software, allows users to easily connect to various data sources and processes and visualizes data to discover valuable information (Microsoft, 2021).

Azure Stream Analytics

Azure Stream Analytics is a scalable complex event processing engine and allows users to process high volumes of fast streaming data in real-time from sensors, devices, and other applications (Microsoft, 2020).

Azure IoT Hub

Azure IoT Hub is a managed service that enables connection and communication between an IoT application and devices that are attached to the application (Microsoft, 2021)

3. RELATED WORK

Based on the studies, mechanical and system failures are still risk factors (Lum & Tsukada, 2010), and improvement of system reliability is necessary for safe UAV operation (Belzer, 2017). For that reason, many studies are underway to suggest various maintenance techniques to reduce system or electrical failures and increase system reliability. One of the articles explains that the most modern aircraft is installed a large number of sensors on flight control, engine, and avionic components, so the data that collects through each sensor can use to monitor the status of the components (Oh, 2017). Also, the data may use to identify what components need to replace before they fail. Another study concludes that aircraft health management technology with big data analytics for jet engines improves performance, fuel efficiency, and system safety. Furthermore, it significantly contributes to reducing maintenance efforts (Berbente et al., 2020). An article that accounts for big data analysis and predictive maintenance recommends adopting the integration of cloud-based analytics in the aviation industry so as to improve reliability with less maintenance efforts and low cost (Daily & Peterson, 2017). This article also highlights that information technology, such as the Internet of Things (IoT), big data analysis, and Artificial Intelligence (AI), helps to improve aircraft maintenance by controlling risks in an efficient way for meeting safety standards (Lian, 2021). Furthermore, the article that describes trends and technology of predictive maintenance informs that predictive maintenance with advanced information, computer, and communication technologies can improve reliability, safety, and quality in the manufacturing and service industry (Selcuk, 2017). The article introduces predictive maintenance with a technique that uses Apache Spark, which is a unified analytics engine for large-scale data processing, to detect a sign of Hard Disk Drive (HDD) failure in real-time in the data center before it fails (Su & Huang, 2018). Lastly, the article that makes a suggestion of predictive maintenance using a smart and compact electronic control unit with IoT, AI engine, and cloud claims that it is possible to improve the engine reliability of buses by monitoring engine status and driver behavior (Massaro, Selicato, & Galiano, 2020).

	Su & Yon, 2018	Massaro, Selicato, & Galiano, 2020
Architecture & Technologies	Cloud Computing with Apache Spark On premise computer resources	Raspberry Pi Cloud On premise database
Cost	High	High
Data Visualization & Monitoring	Smartmontool	Graphical dashboard

	Ng, Tang, , & Lee, 2015
Architecture & Technologies	On premise database, Business Intelligence, Key Performance Indicator
Cost	High
Data Visualization & Monitoring	Power BI

4. APPROACH

The PPM that is using the MS Power BI and Azure cloud services compares with existing maintenance methods in the aspect of features of architecture, cost, and data visualization and monitoring to prove that the PPM is an effective way to improve the UAV maintenance and reliability.

Architecture

During the flight, massive data will be generating. For that reason, each architecture needs to have an ability to flexibly respond to the volume of data changes. Therefore, it evaluates features of each architecture and technology to check each architecture's ability.

Cost

Depending on the types of maintenance and architecture, the operating and building costs will be different. For that reason, this paper provides information on a cost-benefit for each architecture.

Data Visualization and Monitoring

Data processing and analyzing are essential to extract valuable information for predictive maintenance, but, likewise, data visualization and monitoring that provide insights from complicated data is important. Therefore, the paper will examine a component of the architecture that is related to data visualization and monitoring.

The paper also provides a demo of the PPM with Microsoft Power BI and Azure. For receiving telemetry data from UAV in real-time, Azure IoT Hub, Stream Analytics, and Power BI are used for processing and visualizing valuable information for predictive maintenance.

5. DATA COLLECTION

Data are mainly collected from published academic articles and technical documentations to compare each architecture that is based on the following criteria.

- Architecture and Technologies
- Cost

- Data Visualization and Monitoring

Architecture

Study #1 recommends a proactive approach using Key Performance Indicator (KPI) with Power BI for an aviation maintenance enterprise. This study explains KPI architecture that is connected with Operational Database Management systems and Power BI software on on-premises infrastructure (Ng, Tang, , & Lee, 2015).

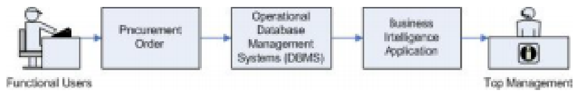

Fig. 1. KPI architecture

Study #2 proposes Predictive Analytic Framework architecture that is designed as a hybrid cloud and consists of three modules that are Extract, Transform and Load (ETL) module, Machine Learning (ML) module, and Prognostics and Health Management (PHM) module. This architecture is developed on the Apache ecosystem including Hadoop and Spark (Su & Yon, 2018).

Fig. 2. PAF Architecture

Study #3 applies an Intelligent Smart Electronic Board for monitoring the vehicle engine and driver behavior for predictive maintenance. The architecture that is using a hybrid cloud is to utilize a Raspberry Pi to receive the data from sensors and sends data to the cloud. Data is processing and analyzing by an AI engine and is visualized and displayed as key performance indicators on a dashboard (Massaro, Selicato, & Galiano, 2020).

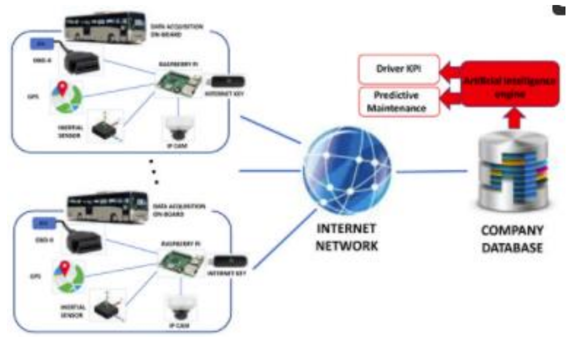

Fig.3. Platform architecture KPI and AI for predictive maintenance

The PPM is composed of architecture with Azure IoT Hub, Stream Analytics, and Power BI to collect data from UAV in real-time, process and analyze data, and visualize data for monitoring and checking the status of UAV for predictive maintenance. The architecture is used Platforms-as-a-Service (PaaS) and Software-as-a-Service (SaaS) cloud.

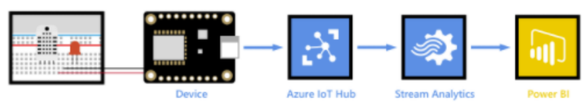

Fig. 4. the suggested approach architecture

Cost

Microsoft Azure, which is one of the cloud providers, offers various and flexible price models for cloud services, such as pay as you go, one or three-year reservation upfront payment, monthly payment. On the other hand, an architecture that uses on-premise infrastructure needs a large initial investment to purchase equipment for building and upgrading systems.

Data Visualization and Monitoring

Power BI combines data from various data sources into a single dataset and provides enriched templates and features to visualize data for user's taste. Also, it supports DAX data analysis functions to generate new valuable information from existing data. Furthermore, it offers to easily share and access a dashboard and report with others.

The Smartmontools program that controls and monitors computer storage with the Self-Monitoring, Analysis, and Reporting Technology provides third-party graphical user interfaces such as HDD Guardian for Windows users. The HDD Guardian displays device information, self-test results, device capability, error log, and hard drive life percentage using icons and graphs. Users can not customize templates and features to visualize data.

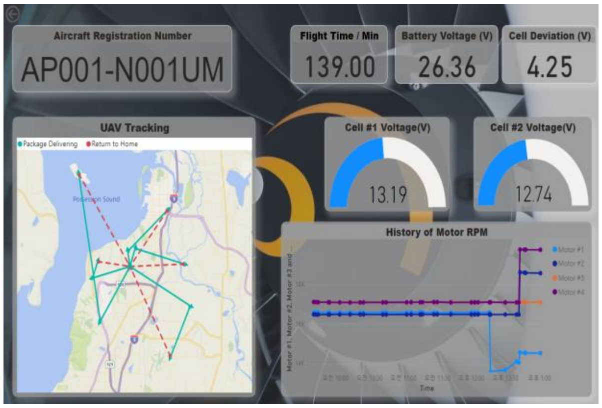

Fig. 5. Data Visualization with Power BI

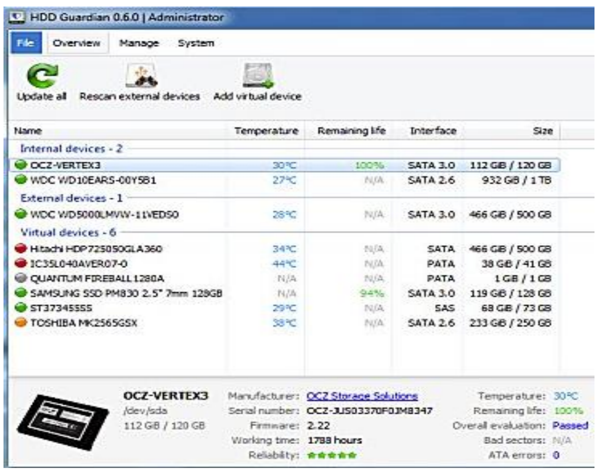

Fig. 6. Data Visualization with HDD Guardian

Data Collection from Drone

Telemetry data received from Tello drone in real-time through Azure IoT using python source codes that are from Tello SDK 2.0 manual and tutorials that have been published by Capuano (Ryze, 2018; Capuano, 2020)

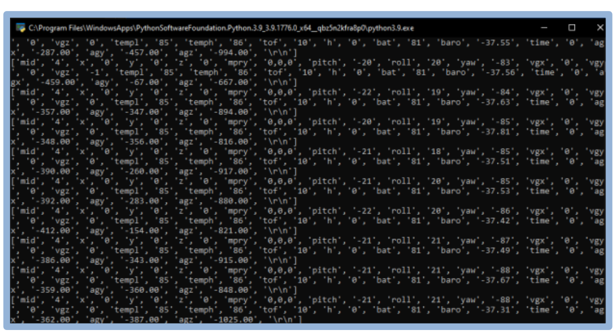

Fig. 7. Telemetry data streaming from Tello Drone

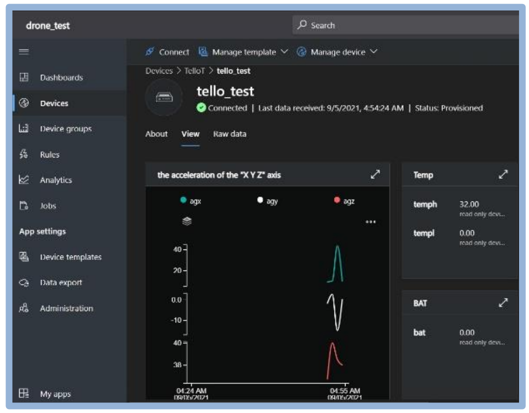

Fig. 8. Receive telemetry data through Azure IoT

6. DATA ANALYSIS

From architecture and technology, cost, and data visualization and monitoring perspective, the features of each architecture and the PPM will be analyzed and compared.

Study #1 suggests an on-premise architecture that stores data in Operational Database Management systems and processes and visualizes data using Power BI.

Architecture

- Limited scalability
- No uptime guarantee
- High risk of data loss due to back-up and disaster recovery failures

Cost

- Large initial investment including software license and equipment
- IT infrastructure maintenance costs
- Utility costs and labor costs for maintenance

Data Visualization and Monitoring

- Easy to share and access reports and dashboard with others
- Enriched features and templates
- Intuitive dashboard and high accessibility

Study #2 recommends a hybrid cloud architecture. Data is transferred and analyzed through cloud computing, and processed data are monitoring by the Smartmontools. The HDD Guardian is one of the third-part graphical user interfaces that is visualized and displayed data on an on-premise computer.

Architecture

- No uptime guarantee
- High availability and scalability
- Easy to backup data
- Disaster recovery available

Cost

- Need large initial investment to purchase equipment
- IT infrastructure maintenance costs
- Utility costs and labor costs for maintenance

Data Visualization and Monitoring

- Limited accessibility
- Unavailable to customize a dashboard
- No features and templates available to visualize data
- Hard to read

Study #3 proposes a hybrid cloud architecture. Data that is collected from sensors is interconnected in cloud trough IoT system, and the data is analyzed using AI to extract valuable information for predictive maintenance. The data is stored in on-premise database.

Architecture

- Limited scalability
- High risk of data loss due to back-up and disaster recovery failures
- No uptime guarantee

Cost

- Need large initial investment to purchase equipment and software license
- IT infrastructure maintenance costs
- Utility costs and labor costs for maintenance

Data Visualization and Monitoring

- Limited features and templates
- Limited accessibility

PPM uses a PaaS and SaaS cloud architecture. Telemetry Data is received from drones through Azure IoT, and Azure Stream Analytics processes and routes data to a dataset in Power BI. The Power BI performs to visualize data using templates and tools.

Architecture

- Low downtime
- High availability and scalability
- Easy to backup data
- Disaster recovery available

Cost

- No initial large investment
- Various pricing models available, such as Pay as you go, Monthly, and 1- 3 year reserved upfront plan

Data Visualization and Monitoring

- Easy to share and access reports and dashboard with others
- Enriched features and templates
- Intuitive dashboard and high accessibility

7. FINDING

To choose a suitable architecture for the improvement of predictive UAV maintenance, the following requirements must be considered.

- Allow mechanics to access the report and dashboard at any time for increasing collaboration and maintenance efficiency.
- Enable to flexibly expand IT resources depending on the workload in a short time to respond to massive data from UAVs.
- Need to consider operating costs.
- Require enriched features and templates to visualize data for providing insights to UAV mechanics

- Provide strong security and recovery system to satisfy FAA maintenance records regulations.

Architecture
Architectures can be divided into three groups that are on-premise, hybrid cloud, and PaaS and SaaS cloud architecture. The architecture of study #2 and 3 is designed as a hybrid cloud architecture that combines public cloud and on-premise IT infrastructure. The architecture of study #3 has the limitation of expanding resources depending on the amount of workload, and the chance of losing data may increase due to a malfunction of on-premise storage. The architectures that are proposed by study #2 and #3 have no uptime guarantee, and using on-premise IT infrastructure that is suggested from study #1 is also not free from those limitations.

Cost
All architectures are required a large investment for purchasing equipment and software licenses, infrastructure maintenance costs, utility costs, and labor costs for maintenance except the architecture of the PPM.

Data Visualization and Monitoring
Study #1 and PPM architectures that are using Power BI provide enriched features and templates, high accessibility to share reports and latest updated dashboards with others, and DAX data analysis functions to discover valuable data from the existing dataset. The architecture of study #2 utilizes Smartmontools and HDD Guardian to visualize and monitor data, but it is limited accessibility, has no features and templates to visualize data, and is unintuitive.

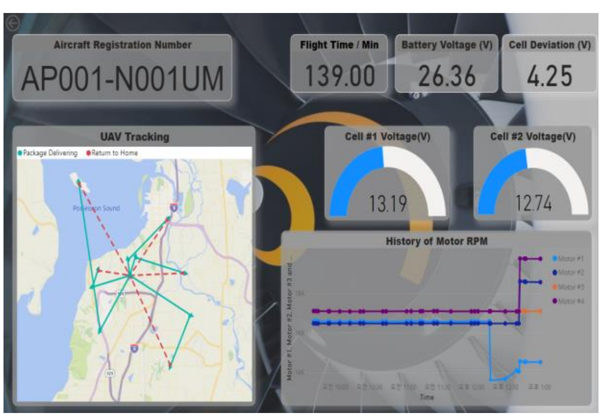

Fig. 5. Monitoring UAV components with Power BI

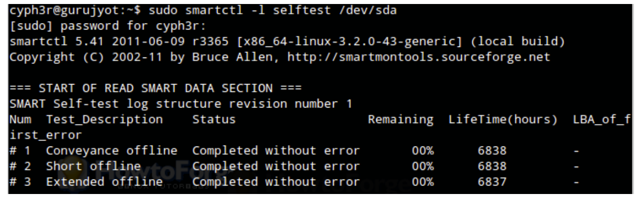

Fig.6. Monitoring HDDs with Smartmontools

Overall, architectures that are used on-premise and hybrid cloud have strengths. However, in the light of the above requirements for improvement of predictive UAV maintenance, the PPM has more benefits and satisfy requirements than other architectures so as to improve predictive UAV maintenance and reliability.

8. CONCLUSION

The PPM that uses cloud services is designed to receive data from UAV in real-time and process and visualize the data for providing valuable information for predictive UAV maintenance. Azure IoT Hub performs receiving data in real-time from UAV, and the Azure Steam Analytics processes and routes the data to a dataset in Power BI. The Power BI visualizes data on a dashboard using its enriched features and templates to provide insights to UAV mechanics. This architecture has the ability to handle resources depending on demands without impacting performance and availability, so it can flexibly respond to growing UAV data during flight. Furthermore, a large initial investment doesn't need to purchase IT equipment because a cloud provider serves software, operating system, and other resources. Moreover, the cloud provider offers various types of pricing models, so it expects to save operating costs. Additionally, it provides strong security and disaster recovery that might allay the concern of data loss. The Power BI in the PPM architecture furnishes an intuitive visualization dashboard that is consisted of significant data to UAV technicians using Power BI enriched features and templates, and the UAV mechanics are able to access the latest updated dashboard at any time for monitoring the status of UAV components so as to perform predictive maintenance. These features show that the PPM is improved than other architectures, and it is suitable for improving predictive UAV maintenance and reliability.

9. FUTURE WORK

The main required future work will be researching IoT technologies because the PPM is utilized the IoT technology to receive telemetry data from a drone. In other words, the data connectivity between UAV and IoT is essential to stably get the data. Therefore, it is necessary to research types of IoT networking technologies to find what technology is suitable. Furthermore, the data is from sensors of UAV components, so it is unable to detect UAV structure problems using this PPM. For that reason, it needs to investigate a method to get structure data from drone in real-time.

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