Enhancing Condition Monitoring with Virtual Reality Visualization for Industrial Application

ALI MOHAMMED RIDHA[1], WESSAM SHEHIEB[2]
[1]Beckhoff Automation FZE,
Dubai,
UAE

[2]Research and Development Department,
Analytica FZE,
Dubai,
UAE

Abstract: - Monitoring the machines' health in an industrial setting is crucial to maintaining the workflow without disturbance. There are multiple methods commonly used for this purpose that go under conditional monitoring. Conventional conditional monitoring can be time-consuming and difficult to interpret by a non-experienced operator, which increases the risks in such critical applications. Virtual Reality (VR) has been in use for multiple applications to ease the usage of complex tasks via proper visualization. In this paper, a visualization approach of industrial application that monitors the motor's health connected with a vibration sensor via a programmable logic controller (PLC) is presented. The Beckhoff PLC was programmed using TwinCAT 3 software and linked with Unity VR headsets via MQTT protocol. The user is given the ability to select the number of connected sensors and place them to mimic the actual environment, import their own 3D machine design, test for MQTT broker connectivity, and visualize the machine's health as per the ISO 10826-3 standard. The proposed system has been tested successfully and it is expected to ease visualization in an industrial setup.

Key-Words: - Condition Monitoring; IoT; MQTT; Programmable Logic Controller; TwinCAT 3; Virtual Reality.

Received: February 19, 2023. Revised: December 4, 2023. Accepted: December 17, 2023. Published: March 6, 2024.

1 Introduction

Continuous production output in industrial settings is a requirement, where any failure of the equipment can result in high losses. This is why monitoring the machine operation parameters has always been important to assess the maintenance requirement of a machine before a failure can occur. This will allow the user to optimize the equipment performance, reduce cost, and ensure the continuous operation of the machine, [1].

Condition monitoring, unlike traditional time-based maintenance, can estimate the health of a machine, and provide information on the performance and maintenance required based on real-time data. There are many condition monitoring methods, such as thermal monitoring, current analysis, signal processing, vibration analysis, or artificial intelligence (AI), [2], [3], [4], [5].

Recent research [4], has proposed a technique that employs motor current signature analysis and fuzzy logic to detect various types of faults in the stator winding of the motor. The system can also classify the driving system fault into two categories (inverter and motor faults), with the motor fault having 2 subcategories (Mechanical and electrical faults).

Another research [5], outlines predictive maintenance tools that support fault detection, it explores different tools such as time series, decision trees, and artificial intelligence. Additionally, it identifies AI tools that can be used to assist in decision-making for management, to increase the availability of the asset, and decrease the maintenance cost.

These techniques can then be used to obtain results that can be presented in a graphical view.

By utilizing technologies like virtual reality (VR) and augmented reality (AR) in condition monitoring, can create an immersive experience in monitoring equipment in real time. This could enable the maintenance personnel to identify the problems and resolve them. VR and AR can also be used in remote monitoring of equipment, this can be extremely useful in situations where it is not safe for people to be physically present.

Haptic technologies, which create the experience of 3D touch by applying vibrations and motion, [6], are one of the key advantages of VR. This can enhance the effectiveness of training for the maintenance personnel, by familiarizing them with the equipment without the equipment being physically present.

VR and AR technologies have been widely researched and used in several different fields, such as education [7] and landscape design [8], but the usage of VR in industrial settings is still limited.

In this paper, a novel system is proposed that utilizes a Beckhoff programmable logic controller (PLC) and Meta Quest 2 VR headset to enable the user to visualize, interact, and monitor their equipment in real time. The structure of this paper is as follows: The design and implementation of the hardware and software are described first. Then, the test results are presented, and followed by a discussion of the results. Finally, the conclusion and future work are discussed.

2 Design and Implementation

The conceptual diagram of the proposed system can be seen in Figure 1. The system consists of three main parts: data acquisition, visualization, and an MQTT broker. Both data acquisition PLC and VR headset are connected to the MQTT broker through the internet.

The first step is to read the data, a Beckhoff PLC, which is an industrial control system that can be programmed to perform automation tasks is utilized to acquire data from one vibration sensor, then perform analysis on the data and publish it to the MQTT broker.

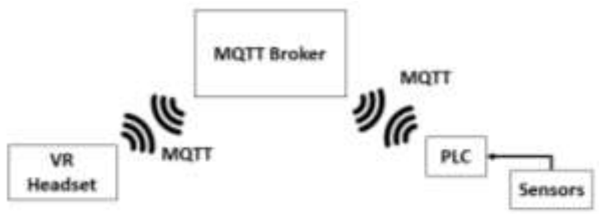

Fig. 1: Conceptual Diagram

After the results of the analysis are published to the MQTT broker, the VR headset that has a unity-developed application will visualize the users' equipment health in real-time using the analysis results.

2.1 Hardware Setup

The hardware part of the system consists of the PLC, MQTT broker (computer), and VR headset.

2.1.1 Data Acquisition Setup

The system consists of two main components: the PLC and the sensors, as depicted in Figure 2. The PLC utilized is a Beckhoff CX5130 Embedded PC. That uses an Intel Atom E3827 processor (1.75 GHz), with 4 GB DDR3 RAM, and is running Windows 10. The PLC is powered by a Beckhoff PS1111 24v power supply.

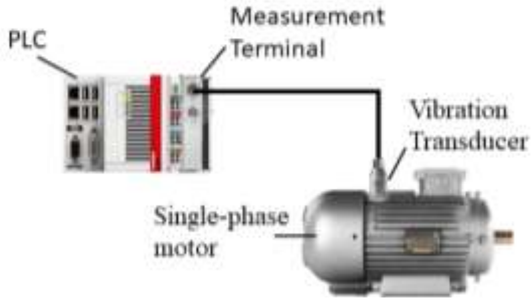

Fig. 2: System hardware design

An ELM3602 IEPE measurement terminal with a max sampling rate of 50,000 samples per second is also used. The system additionally includes one SPM IEPE SLD144TB vibration transducer, which is mounted on a single-phase motor (0.37kW, 2.7 A). To test the concept of the proposed system, an eccentric load was mounted on the shaft of the motor, to simulate vibrations that can be picked up by the vibration transducer.

2.1.2 MQTT Broker

A computer connected to the network will have Eclipse Mosquitto [9], an open-source MQTT broker running. It will allow both the PLC and VR to communicate with it, to transfer data.

2.1.3 VR Headset

Meta Quest 2, [10], VR headset was used to visualize the equipment in an immersive 3D environment, to provide an interactive experience for the users to analyze and interpret the data in real-time.

2.2 Software Design

The software part of the system consists of the PLC program, and the VR application developed for visualization.

2.2.1 PLC Software

The PLC will utilize TwinCAT 3, a real-time control software developed by Beckhoff that is based on Visual Studio. The data acquisition and analysis program was developed on TwinCAT 3 using Structured Text programming language, and then it was deployed to the CX5120 PLC. TwinCAT 3 Analytics Workbench, a user interface that was developed by Beckhoff for the design and deployment of analytics programs, along with TwinCAT 3 Condition Monitoring library, were utilized for the vibration assessment program. Some parameters such as machine group, and machine substructure, which are crucial for accurate vibration assessment are read through MQTT from the VR application. Additionally, after receiving the start signal for the real-time analysis from the VR application, the PLC will start the acquisition and publish the results to the MQTT broker.

2.2.2 VR Visualization

Unity 3D, which is a game engine that is widely used for creating interactive applications, was utilized to create the VR application. M2MQTT library, [11], was used in Unity to enable communication between the VR application and the MQTT broker. The 3D model of the motor was designed using Sketchup, [12] and then added to the VR application to provide a realistic representation of the motor's health.

The VR application will require the user to configure the MQTT communication settings, and the equipment configuration according to ISO 10826-3 standard. The VR application also allows the user to import their custom-designed equipment and set up the location of the vibration sensors, and the 3D model will have a Unity Shader that creates a heatmap to visually represent motor health. The Shader will use the sensor locations and vibration velocity values to dynamically generate the heatmap, providing an overview of the equipment's condition, which would enhance the accessibility and provide real-time assessment of the equipment for effective condition monitoring.

3 Results

The results of this study are presented in three sections: the hardware implementation, the developed PLC analytics program, and the VR application implementation.

3.1 Hardware Implementation

The data acquisition setup is shown in Figure 3 and the single-phase motor with the vibration transducer can be seen in Figure 4.

Fig. 3: Data acquisition setup

After reading the accelerometer data, the PLC program will perform analysis according to the ISO 10816-3 standard, and classify the equipment's health, then publish the results of the vibration assessment to the MQTT broker.

Fig. 4: Hardware setup consisting of a single-phase motor and a vibration sensor

3.2 PLC Software

To perform the vibration assessment according to the ISO 10816-3 standard, which involves measuring and evaluating vibrations in machinery, the assessment criteria is based on the root mean squared (RMS) value of the vibration velocity or displacement. At the same time, it is sufficient only to measure the velocity of vibrations. According to the ISO 10816-3 standard, the minimum output range for the motor must be between 15 kW to 300 kW. Considering that the motor used in this experiment is 0.37kW it cannot be categorized using the standard, Therefore, it will be considered that it's in Group 2 for simulation.

The PLC will first buffer the input data from the sensor. Since the test motor has a speed above 600 rpm, complying with the ISO 10816-3 standard, the frequencies in the range of 10 Hz to 1000 Hz will be evaluated. Fast Fourier Transform (FFT) is used to analyze only the specified frequency range, then the RMS values for the acceleration data input are calculated, additionally, the RMS value of vibration velocity and displacement is calculated from the acceleration data. The RMS values of both the vibration velocity and displacement are then checked against the ISO standard limits for machine group 2 tabulated in Table 1 to determine the classification.

Table 1. Evaluation Zones Limit Values for Machine Group 2 From ISO Standard 10816-3

Installation		**Rigid**	**Elastic**
RMS value of the vibration velocity in mm/s.	11.00 - inf	D	D
	07.10 - 11.00	D	D
	04.50 - 07.10	D	C
	03.50 - 04.50	C	B
	02.80 - 03.50	C	B
	02.30 - 02.80	B	B
	01.40 - 02.30	B	A
	00.00 - 01.40	A	A

There are in total 4 zones described in ISO 10816-3, zone A describes a recently commissioned machine, and Zone B is for a machine suitable for continuous operations without any restrictions. Finally, unsuitable machines for continuous operation and machines regarded as dangerous that may damage machines are described as zones C and D respectively. The limits described by the standard are only intended as a general guideline, and in some cases cannot apply to certain machinery or operating conditions.

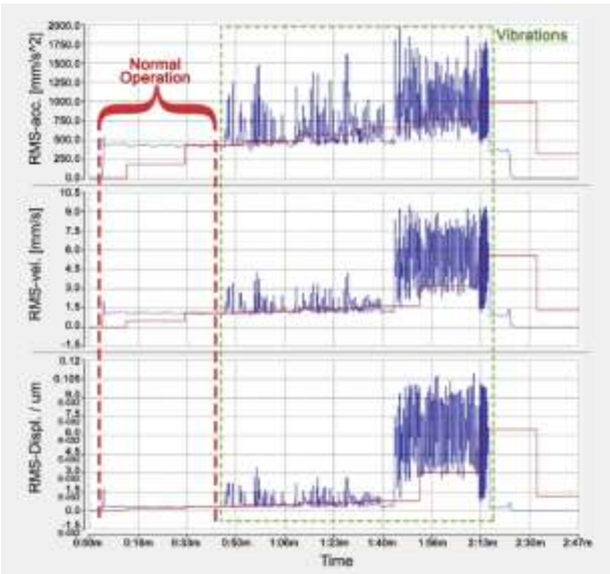

Fig. 5: Acceleration, Vibration, and displacement data from PLC

This is due to the variety of machinery in an industrial setting, where the machine groups described in the standard try to categorize the machine while accounting for the variations in design. However, due to differences in environmental factors, machinery types, or the application of the machine, the users are advised to interpret the limits only as a foundational framework when assessing the vibrations of a machine.

The worst-case classification is then determined by comparing the two possible classifications (velocity and displacement), adhering to ISO 10816-3 guidelines. Finally, the classification results are then published to the MQTT broker for the VR application.

Figure 5 showcases a sample of the acceleration data acquired from the PLC. The part in red showcases the normal operations of the motor, while the green was produced by simulating vibrations on the motor to visualize in VR.

3.3 VR Application

The Unity application was developed and installed on the Quest 2 Headset, enabling the user to move around in a virtual world and interact with a 3D representation of the motor. After starting the VR application, the user will be presented with the main menu as shown in Figure 6. The first step is to set up the MQTT broker configuration i.e., broker address, port, subscription topic, and Username/password if applicable. After that, the user can test the communication connection to check if the VR application can communicate with the broker.

Fig. 6: Main menu of VR application

The user then must set the number of sensors, and the MQTT topic of each sensor. They are also able to test the MQTT communication for the sensors to see if data is being received. The user will also be able to set the motor configuration as per the ISO 10826-3 standard and publish it to the broker, where the PLC will be subscribed to read and set the values for analytics.

Optionally, the user can import their own motor/machine 3D model if required, instead of the default 3D motor model, and then set the sensor points as shown in Figure 7.

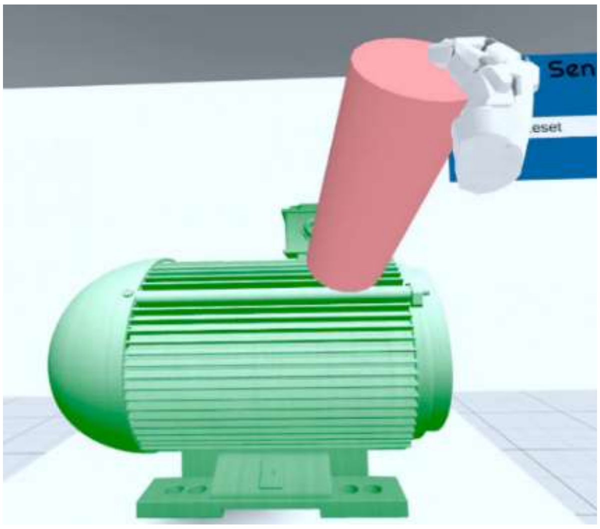

Fig. 7: Sensor placement in the VR application

Finally, after starting the measurements, the user will be able to see the motor overview with the details of the sensor and evaluation zones as shown in Figure 8.

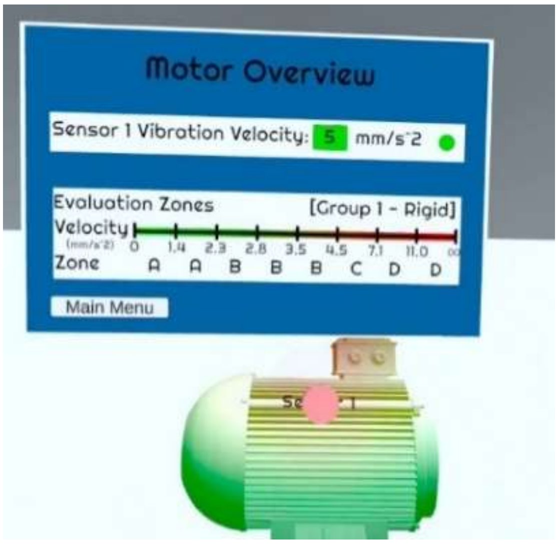

Fig. 8: Motor overview in the VR application

As per the vibration velocity and evaluation zone received from the PLC, the shaders of the 3D motor will start to display a heatmap based on the previously placed sensor point. Alternatively, if there is more than one sensor, touching the sensor placeholder or selecting it will show an overview of the sensor with its values as shown in Figure 9.

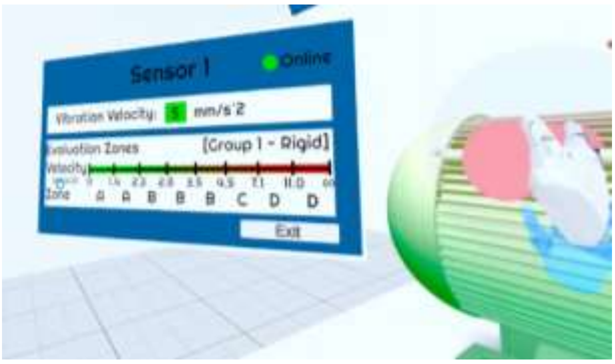

Fig. 9: Sensor evaluation in the VR application

4 Discussion

While the developed system was only tested on a small motor, the same concept can be scaled to existing machines. By integrating a data acquisition system, and the developed VR application, users will have an immersive platform on their VR device to interact with the machine in real-time, and utilizing the analyzed vibration data from the Beckhoff TwinCAT system will enhance the diagnostics of machines. Additionally, the developed VR application allows custom configurations of sensors and user-designed 3D machine models to be used, which makes it flexible to be used with a diverse range of machines. Further research can be focused on extending real-time data acquisition to create a fully functioning digital twin of the machine in VR.

5 Conclusion

The proposed system integrated a Beckhoff PLC for data acquisition and a Meta Quest 2 VR Headset for visualization was successfully implemented. The system allowed the user to view and interact with the device in real-time to evaluate the equipment's health. The use of VR for condition monitoring has the potential to significantly improve the efficiency and effectiveness of maintenance operations in industrial settings. It can help to reduce costs, improve productivity, and ensure the continuous operation of equipment. As VR technologies continue to advance and become more widely adopted, an increasing number of applications in the industrial sector will likely start employing VR. Further work can include mapping the results with multiple sensors and applying artificial intelligence predictions on the equipment to assist the operators and engineers in the field.

References:

[1] P. Kumar, A. Namdeo, and A. Dixit, "Condition Monitoring of 3-Φ A.C Induction Motor Using PLC," Semantic *Scholar Engineering,* 2015, [Online]. https://api.semanticscholar.org/CorpusID:32153976 (Accessed Date: November 27, 2023).

[2] S. H. Chetwani, M. K. Shah, and M. Ramamoorty, "Online condition monitoring of induction motors through Signal Processing," *2005 International Conference on Electrical Machines and Systems*, 2005. doi: 10.1109/icems.2005.202952.

[3] R. C. Bhavsar and R. A. Patel, "Various Techniques for Condition Monitoring of Three Phase Induction Motor-A Review," *International Journal of Engineering Inventions*, vol. 3, no. 4, pp. 22-26, Nov. 2013.

[4] Joao Rodrigues, Jose Torres Farinha, Antonio Marques Cardoso, "Predictive Maintenance Tools - A Global Survey," *WSEAS Transactions on Systems and Control*, vol. 16, pp. 96-109, 2021, https://doi.org/10.37394/23203.2021.16.7.

[5] Mohamed I. Abu El-Sebah, Faeka M.H. Khater, "A Proposed Fault Diagnostics Technique for Induction Motor Stator Winding," *International Journal of Electrical Engineering and Computer Science*, vol. 5, pp. 33-40, 2023, doi: 10.37394/232027.2023.5.5.

[6] S. Biswas and Y. Visell, "Emerging material technologies for haptics," *Advanced Materials Technologies*, vol. 4, no. 4, 2019. doi: 10.1002/admt.201900042.

[7] A. M. Ridha and W. Shehieb, "Assistive technology for hearing-impaired and deaf students utilizing augmented reality," *2021 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2021. doi: 10.1109/ccece53047.2021.9569193.

[8] S. Sun, Q. Meng, Y. Ma, and Z. Ren, "Application of virtual reality technology in Landscape Design," *2021 International Symposium on Artificial Intelligence and its Application on Media (ISAIAM)*, 2021. doi: 10.1109/isaiam53259.2021.00026.

[9] "Eclipse mosquitto," Eclipse Mosquitto, [Online]. https://mosquitto.org/ (Accessed Date: November 27, 2023).

[10] "Meta Quest 2," Meta, [Online]. https://www.meta.com/quest/products/quest-2/ (Accessed Date: November 27, 2023).

[11] "M2mqtt & GnatMQ," M2Mqtt & GnatMQ, [Online]. https://m2mqtt.wordpress.com/ (Accessed Date: November 27, 2023).

[12] SketchUp, Trimple, [Online]. https://www.sketchup.com/ (Accessed Date: November 27, 2023).

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This research was funded by Beckhoff Automation FZE, Dubai, UAE and Analytica FZE, Dubai, UAE.

Conflict of Interest

The authors have no conflicts of interest to declare.