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AUGMENTED REALITY BASED DIAGNOSTIC TOOL FOR A ROTATING MACHINE: TURBO – AR

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ABSTRACT

Excessive vibrations in rotating machines can result from rotordynamic faults, leading to wear and tear, human injuries, or complete breakdown of equipment. Monitoring machine health in real-time and making maintenance decisions using a software application with human in the loop provides a promising approach for industries to avoid such failures. However, the nonlinearity associated with rotating machine dynamics makes system representation and computational cost crucial considerations for developing such an application.Currently, digital twins play a pivotal role in replicating systems digitally and producing high-fidelity models. Predicting machine behavior through reduced-order models ensures less dependence on high-fidelity models and has a significant impact on computational cost. In this application, we developed a simple digital twin to produce physics-based models for generating a synthetic dataset used to extract reduced-order models. Synthetic datasets were developed considering unbalance and bent shaft faulty conditions in the machine, and machine learning algorithms were trained for anomaly prediction.Using this approach, we created an augmented reality (AR)-based diagnostic mobile tool that maps predicted anomalies from reduced-order models onto the actual machine for better interpretation of machine behavior and decision-making. The tool addresses the problem of interpreting complex vibration data for quick anomaly detection and diagnostics. With available measurements in the physical space, such as amplitudes and machine dimensions, the machine's health is predicted using trained machine learning models and displayed to the user operating the tool.To allow for easy user interaction, buttons are displayed corresponding to each detected fiducial marker placed at different locations on the machine. These buttons help users visualize relevant diagnostic data for different parts of the machine. The tool uses real time data from the physical machine sensors through data transmission for predicting anomaly behavior.

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NOMENCLATURE

d_r	Rotor diameter
d_s	Shaft diameter
l	Shaft length
t	Rotor thickness
m	Unbalance mass
e	Eccentricity
B_d	Bent displacements
Φ	Phase angle
$l_r p$	Rotor position

1. INTRODUCTION

In recent years, advanced technologies such as data acquisition, data communication, simulation, machine learning, deep learning, and cloud computing have greatly contributed to the development of interactive tools for industrial applications. Digital twins are among the advanced technologies in Industry 4.0 that use simulations and data acquisition to create high-fidelity models. The integration of digital twins with data analytics strengthens the relationships between the physical and virtual space of the system.

The generation of data by digital twins, followed by advanced analysis and accurate data visualization, can greatly improve the system's performance and help users make quick decisions on diagnostics. The AR reality tool we created combines almost all of these technologies to perform diagnostics on a rotating machine with given dimensions and amplitude measurements. Additionally, we used fiducial marker-based tracking in the AR environment, ensuring a simplified and promising approach for system detection.

The interpretations from the analysis results shown through visualizations in a virtual space help determine anomalies in the physical space. The illustration of the tool is given in Fig.1, which depicts the virtual scene created to show the physical environment. In the actual scenario, the tool detects a physical working rotating machine and displays visualizations accordingly.

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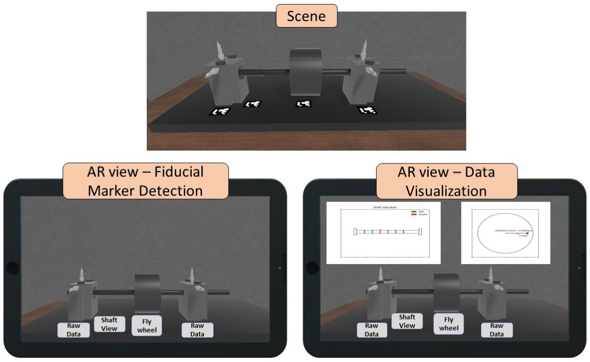

FIGURE 1: ILLUSTRATION OF THE AR TOOL

2. METHODOLOGY

The methodology for developing the tool consists of the following components: 1) Digital twin development, 2) Data representation, 3) Algorithm selection, 4) Machine part tracking, 5) Data visualization, and 6) User interface.

2.1 Digital twin development

The initial step in creating the tool was the development of a digital twin. The digital twin enabled simulations to be conducted with a wide variety of conditions and machine dimensions, generating a dataset for training the AR-tool. The digital twin was designed to enable the AR-tool to predict anomalies for machines with any dimensional configuration.

2.2 Data Representation

The representation of data is a crucial component in the backend development of the tool, as it reflects the level of complexity and nonlinearity of a rotordynamic system. In order to enable fault prediction in the tool with measurements available only in the physical space, three different design vectors were defined for the development of reduced order models. These were the machine configuration vector (d_r, d_s, t, l, $l_r p$), the fault configuration vector (m, $m * e$, B_d), and the amplitude vector (Ax_1, Ay_1, Ax_2, Ay_2). The machine configuration vector and amplitude vector represent the data available in physical space, through which the fault vector will be predicted in virtual space and displayed in the tool.

To develop such an input-output pair, the machine configuration vector and fault vector were initially used to perform simulations within the digital twin and generate amplitude vectors. The amplitude vector obtained from the digital twin, along with the machine configuration vector from physical space, were taken as inputs and the fault vector as output for training the machine learning algorithms.

2.3 Algorithm Selection

To evaluate the performance of various algorithms on the generated datasets, both classical and deep learning methods were tested. The synthetic dataset generated by the digital twin was used to train the algorithms. The amplitude responses at the ends of the shaft, machine configuration, and rotor position were given as inputs to the model, with the output being the fault vector. The accuracy of different models was compared based on their generalization performance after training, and the algorithm with the highest accuracy was incorporated into the AR-tool for prediction.

2.4 Machine Part Tracking

To track different parts of the machine such as the flywheel, shaft, sensors, etc., fiducial markers are utilized and placed at specific locations corresponding to each machine part. Fiducial marker tracking is considered a promising approach and facilitates smooth user interaction with the tool. Due to the system's dynamic nature and high speed, placing the markers on the base plate has been deemed more reasonable in terms of consistency and accuracy of detection.

2.5 Data Visualization

Data Visualization is a crucial element in the frontend development of the tool, as it plays a pivotal role in helping users interpret the machine behavior. As users operate the tool and interact with the machine, diagnostic data and machine amplitude data are displayed using various visualizations. For diagnostic data related to the flywheel, a 2D circle is displayed on the UI panel, with marker indication of predicted unbalance force at a certain distance from the center. Similarly, for the bent shaft, a 2D rectangle is displayed, resembling the shape of the shaft with appropriate dimensions, and with red and green indications at the bent locations on the shaft. The amplitude data, in the form of frequency data, is displayed as a 2D line plot, with the x-axis representing frequency and the y-axis representing displacement magnitude.

2.6 User Interface

The final component of the AR tool is the user interface design, which enables seamless human-computer interaction. The AR-tool's user interface is designed to allow users to interact with different parts of the machine using buttons. These buttons are displayed once the camera detects fiducial markers placed at specific locations on the actual machine. Users can click on buttons to visualize relevant information, such as diagnostic data and amplitude data. After clicking on a button, a UI panel will be displayed, showing the defined data visualizations for each part.

3. FUNCTIONALITY AND RESOURCES

The AR tool that has been developed requires the presence of a physical rotor kit, which is equipped with fiducial markers placed at specific locations. However, since it will not be possible to use the actual rotor kit at the upcoming IDETC demo showcase, a mock-up version of the machine will be utilized instead. This mock-up machine is designed to resemble the actual configuration of the machine, and has fiducial markers placed at appropriate locations.To demonstrate the functionality of the AR tool, amplitude data obtained from the physical machine present in the university laboratory will be transmitted to the tool via an online Firebase database. This same data will be utilized for predicting anomalies during the demo. For the AR tool to function properly at IDETC, it will require access to a power supply for charging the mobile device and a table to hold the mock-up machine.

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