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Low-Cost Portable Device Design for Preventive Maintenance of Rotating Systems

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***Abstract*— In the present work, the technological development of a low-cost acquisition device is proposed that allows the simultaneous measurement of vibration amplitude in acceleration and the temperature variable, and that through Bluetooth communication, the parameters are acquired by a cellphone. The data stored in the mobile device will be used for the development and/or improvement of predictive maintenance plans in medium and small companies, whose internal budget does not allow the acquisition of specialized vibration equipment. Finally, the developed App makes it easier for maintenance personnel with minimal knowledge of vibration analysis and thermography to acquire and analyze data insitu and/or offline, using 2D graphing**.

***Keywords*—Vibration amplitude in acceleration, mobile application, diagnosis, predictive maintenance, temperature.**

I. Introduction

The maintenance application represents one of the most important elements that maintain a production chain, directly affecting the economy of the industry. This can be seen in the research presented in [1] where it evaluates the investment of transnational companies that allocate in this area. There are different types of maintenance that can be applied, such as: corrective, preventive, predictive, proactive, as stated in [2]. Within predictive maintenance techniques, the use of vibration amplitude measurement, thermography, ultrasound or oil analysis is common, as presented in [3]. However, the high cost of the initial investment in the equipment used, as well as the hiring of specialized stuff in the different techniques, reduces the possibility of using this type of maintenance techniques in small and medium-sized enterprises. This project focuses on meeting an industrial need in the south of the state of Sonora, Mexico, where the use of predictive maintenance techniques in medium and small companies is null, commonly using in corrective and preventive maintenance, the latter being updated, based on the experience of the person in charge of the area.

And in some very specific cases, pen-type vibration meters are used, without the information provided being used. Therefore, the lack of application of new engineering techniques in the maintenance area generates unscheduled stoppages in its production line and in particular cases, these are up to 8 hours.

In the first part of the research work, the development of an electronic device that can be installed temporarily or permanently (depending on the needs of the company) in the rotating equipment is exposed, and that allows simultaneously acquiring the vibration amplitude data in acceleration and temperature: fundamental data for the development of predictive maintenance plans. Allowing with it, the periodic update of the preventive maintenance plans for the analyzed equipment. Likewise, the information acquired will be periodically transmitted to a mobile device through Bluetooth communication.

While in the second part, the development of the App is shown, which installed on a mobile device with Android system, allows to acquire, save and display vibration and temperature data to be used by a maintenance technician in decision making. on the scheduling of scheduled shutdowns for maintenance. In addition, being an App developed in Xamarin, it presents the possibility of continuing to add modules or modifying those currently developed.

II. Proposed Work

Currently, with the reduction in costs of acquisition and processing devices, as well as low-cost sensors, work has been done on devices that can be purchased at reduced prices, for example, the study presented in [4] exposes the development of a low-cost seismic meter using a self-designed magnetic switch coupled to an "Arduino Uno card", to process the information using the "Simulink de Matlab[R]" tool through serial communication.

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A monitoring study simulating a machine tool is shown in [5], measuring the vibrations in displacement amplitude through a photodiode array whose data is acquired through the "Arduino Uno" tool and sent to a PC to be analyzed through "Labview". Similarly, in [6] the analysis of a structure is performed to identify its first natural frequencies, applying the "Fast Fourier Transform (FFT)" using the Mathcad software. Data acquisition was performed using an accelerometer and "Arduino Nano technology". In 2018, in [7] the industrial alignment analysis is presented, developing a system through the use of inductive sensors connected to an Arduino Nano, sending the information through Bluetooth to a computer, which through the use of the graphical interface of Matlab^{R} (GUI) processes and analyzes the information collected. In the work presented in [8], the design of an acceleration measurement device is proposed using the Arduino system and an ADXL-345 accelerometer sending the information through the WIFI connection to be displayed online by using the ThingsPeak software. While in [9], 3 MEM's accelerometers are used with their corresponding "Arduino Nano" to receive and send the information to an "Arduino Uno" which, in turn, sends it via WIFI to a PC, where it is acquired and processed through Lab- View. Likewise, Soto et al in [10] carry out the diagnosis of failures in bearings, using an industrial accelerometer, using the Raspberry-Pi module using 3 acquisition channels and storing the data for later treatment, it compares the results using the ISO 10816-7 standard. On the other hand, Gautam et al in [11] uses Arduino Uno, to measure acceleration and temperature as a monitoring element of the state of a didactic gear train to identify the variation of the measured parameters, seeking to identify problems, and that through WIFI and LabView send an alert message to the user when any of the parameters exceeds a reference value. While in [12], the comparative study between an industrial accelerometer and an accelerometer with MEMS model ADXL002-50 is presented, comparing the numerical values obtained from two field equipment, evaluated for 220 days. Likewise, in [13] a coupled load cell of an Arduino device is used to monitor the state of a rotary system, from the Fast Fourier Transform, developing the interface in the QT Creator software.

III. THE DESIGN OF PROPOSE

At an industrial level, for the diagnosis of faults in machines, it is common to use the measurement of vibration and temperature in parallel, recording this information in the corresponding log for a later analysis, being used to improve predictive maintenance. Among these measurement parameters, there is a direct relationship, because a failure in a rotating equipment is reflected in a greater mechanical vibration, and this in turn increases the temperature at specific points of it. For this reason, it is proposed to design a portable meter to simultaneously measure vibration and temperature, which through, Bluetooth communication, sends the information obtained to an application of a mobile device. The diagram for this is shown in the figure below.

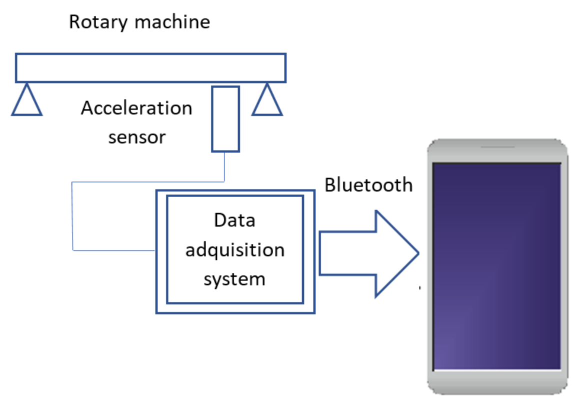

Figure 1. Simplified diagram of the measurement system.

The figure above can be represented in a block diagram as follows.

Figure 2. Block diagram for the portable system

In this diagram, the portable system will permanently install a measurement point of interest in the equipment, to send the acquired information in real time when the user connects the portable device (cell phone) with the acquisition system, displaying and saving the measured data.

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For the acquisition system, the Arduino Uno platform is used, using acceleration and temperature sensors to know the operating parameters of the rotary system. The design proposal used is presented in the following image.

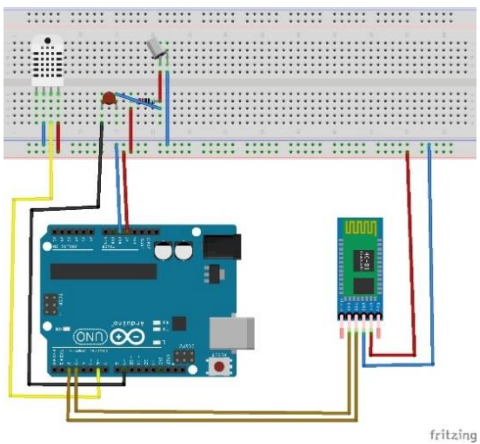

Figure 3. Connection diagram

The diagram above shows the connection diagram where the elements used are shown in the following table:

Table 1.
Materials used in the data delivery prototype

Device	Model	Quantity
Temperature sensor	DHT11	1
Acceleration sensor	SW200d	1
Acquisition system	Arduino Uno	1
Bluetooth	HC-05	1

The SW200d acceleration sensor to be used is presented in the following graph.

Figure 4. Vibration sensor of sw200d

The sensor presented in figure 4 is used for the experimentation of the mobile application, being a simple sensor that is compatible with the Arduino IDE which, due to its low cost and ease of use, is an adequate element to carry out the performance tests. of the application. This element has two metallic spheres inside its capsule that bounce when there is some movement and when they collide with each other it generates pulses at a certain frequency, due to the anatomy of the sensor it would obviously not work to evaluate a rotating system, however, Partogi at al (2021) presents the comparison between MEMS accelerometers with one for industrial application, showing good results for durations of 220 days of work in an extreme environment. This opens the possibility of using a MEMS accelerometer in a future improvement of the current prototype.

Likewise, another measuring instrument is the temperature sensor, as illustrated in the following image.

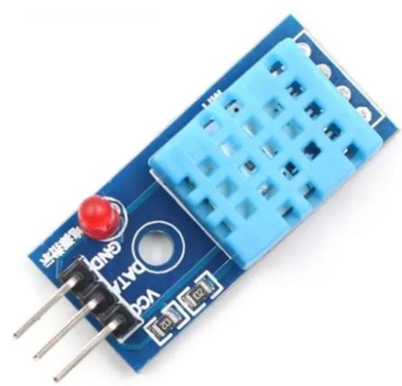

Figure 5. Temperature sensor

The DHT11 sensor shown in the previous figure can take readings of temperature and humidity units, with the temperature measurement being the reading of interest, to be registered in the mobile application. This type of sensor works with an integrated thermistor which allows it to measure the temperature and delivers a digital value at the output, being its use for academic purposes and its advantages include its low cost and easy acquisition.

The information obtained from the sensors will be collected by an Arduino Uno module, as shown below.

EXPLORING RESEARCH AND INNOVATIONS

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Figure 6. Data acquisition system, Arduino Uno

The Arduino UNO system is an open-source creation tool that allows different functionalities to be implemented through its hardware board, acting as a microcontroller intended for specific tasks and processes. This board has peripherals for analog and digital inputs and outputs, offering a wide range of development options and work tools in order to facilitate the user's work with low economic cost.

The board is made up of a microcontroller based on ATMEL technology that allows the functionality of recording instructions and establishing complex programs to execute specific tasks, while the programming allows interaction with the input and output peripherals, achieving correct administration with the handling of the data. To develop the code, the Arduino IDE environment tool is used. Specifically, about peripherals, Arduino recognizes peripherals intended to receive data as input interface and peripherals that have connections intended to supply data from the board are known as output interfaces, where the input interface is different tools can be connected with which parameter readings and measurements can be performed.

As shown in figures 2 and 3, the information will be sent to a mobile device through a Bluetooth connection, whose module is shown below.

Figure 7. HC-05 Bluetooth Module

The information measured by the sensors will be sent through the HC-05 Bluetooth module through serial communication, as it has the capacity to function as a transmitter, at a speed of 4,800 to 1,382,400 bauds. For the current prototype, testing was done at 9,600 bauds. Its range is limited to approximately 10 meters.

This proposed device can be used by medium and small industries, where commonly, the review of the equipment is carried out by visual and auditory inspection, for which wireless communication via Bluetooth is used, allowing maintenance personnel to collect vibration data and temperature to be analyzed immediately or later.

For this, the selected device is a mobile communication device, for the development of an application in the Android system. The block diagram is presented below.

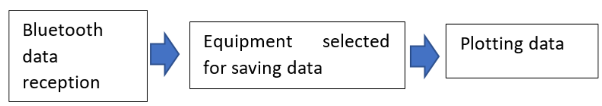

Figure 8. APP block diagram

These blocks fulfill the following function:

- Reception of data via Bluetooth: it allows to connect only to the identifier module of the HC-05 to receive information on vibration amplitude and temperature.
- Selected equipment to save data: The Bluetooth data received from the electronic device in the cell phone can be saved in the database created for the selected equipment. This decision is made by the person performing the visual inspection of the equipment. The information stored in the database can be analyzed by the technician or maintenance manager on site or later.
- Data graphing: the information stored in the database for the created equipment can be displayed in 2D in vibration amplitude and temperature.

IV. RESULTS

The electronic device, whose schematic diagram is shown in Figure 3, was experimentally developed as shown below

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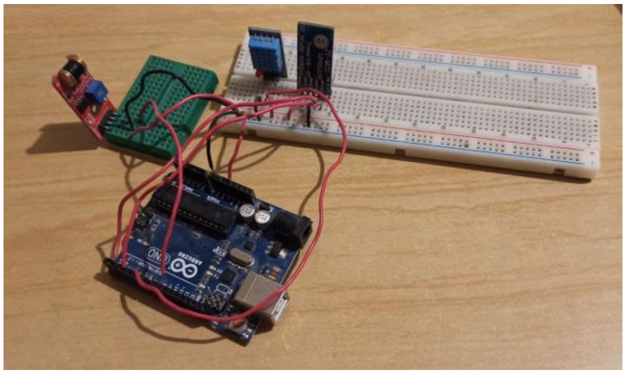

Figure 9. Experimental electronic circuit

This device allows taking measurements of acceleration and temperature, which acquires these values in a specific time and is sent via Bluetooth. This device is linked to a cell phone, which connects with the ID of the HC-05 used. Where in this first stage of the project, it is considered that the power is provided to the Arduino system, being connected through a charger to the 120V alternating current system. Likewise, the circuitry shown in figure 9 will be mounted in a housing that will contain the different elements and will be cooled by natural convection, being the prototype to be printed in 3D, as shown in the following image.

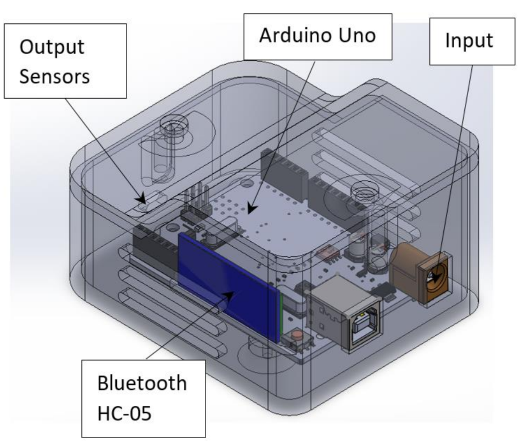

Figure 10. Housing geometric design.

The integration of the previous hardware allowed the development of the application for a mobile device that uses an Android operating system.

The graphic tool developed for the cellular application is shown in the following figure.

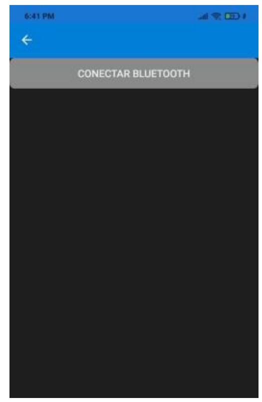

Figure 11. Bluetooth cellular connection window

The previous figure shows the connection window of the mobile device with the electronic device. Once the equipment is connected, and the device to be measured is selected, data is acquired and saved in a database, as shown below.

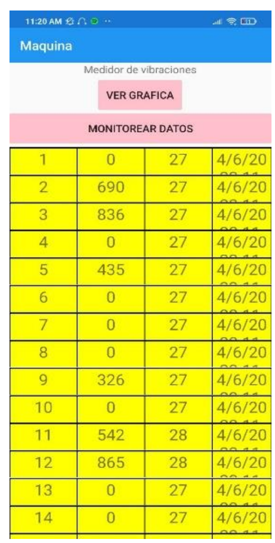

Figure 12. Database for equipment "MACHINE1"

Where from the acquired data, the user of the APP can consult them in table format as shown in the previous figure or see them displayed in a 2D graph of vibration amplitude in acceleration or temperature in linear form, whose example of a window is shown in the figure below.

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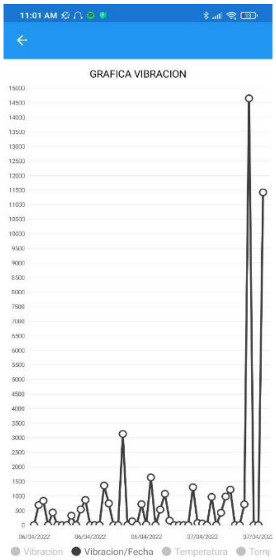

Figure 13. Linear graph of vibration

The linear graph presented in the previous figure shows the vibration amplitude data in acceleration on the vertical axis, while, on the horizontal, can be presented as the measurement number or its date. Likewise, the display of the temperature parameters can be selected.

V. Conclusions

Unscheduled stoppages in a production line in a company can cause significant losses and legal claims. Therefore, the application of corrective, preventive, predictive and proactive maintenance are actions to consider and implement. However, due to the high costs that the implementation and management of predictive and proactive maintenance plans can have, their use is mainly limited to large international companies. Being little used for medium and small companies.

Vibration and temperature analysis are two of the techniques mainly used in predictive maintenance, with the aim of identifying incipient problems and in a machine or an electrical system by identifying hot spots. In the present work, a low-cost electronic system was developed, which allows to measure the vibration-temperature parameters simultaneously that are saved and analyzed by a cellular device through the design of its application. This allows the possibility of using an analyst who does not have a specialization around vibration analysis or thermography and using his empirical knowledge of the equipment with the data acquired, schedule the corresponding maintenance application time.

The cell phone application was developed for the Android system and allows you to create and save different devices to store the measured data of the electronic device, through serial communication via Bluetooth. These data can be displayed graphically in 2D to observe the evolution over time of the measured parameters, allowing medium and small companies to use predictive maintenance techniques to reduce unscheduled downtime.

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