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DEVELOPMENT OF A MODULAR ANALYZER UTILIZING RASPBERRY PI AND LOW-COST SENSORS FOR TEMPERATURE AND SPEED ANALYSIS

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Abstract. *In the industrial sector, monitoring and evaluating machines in continuous operation is of vital importance. The lack of adequate maintenance increases the possibility of equipment suffering from failures or unexpected stops, which can result in increased costs. Predictive maintenance is applied to anticipate and identify problems before they cause major damage to the equipment. Some analyzers are used to keep track of the machinery's condition. However, the high cost of analyzers can make them an unfeasible investment for some industries, especially those experiencing periods of economic instability. The objective of this work is to develop a modular device for temperature and rotational speed data acquisition using low-cost microcontrollers. The Raspberry Pi 3B+ was used to collect and process data captured by compatible sensors, with a rotating system as the object of study. The obtained results were compared with those acquired using a benchtop acquisition system.*

Keywords: *Microcontrollers; Modularity; Low cost; Temperature and Speed analysis.*

1. INTRODUCTION

The practice of monitoring machines and critical structures plays a crucial role in optimizing equipment availability, maintaining reduced costs, ensuring facility safety, and preventing production delays caused by unexpected shutdowns. The implementation of predictive maintenance aims to extend the equipment's lifespan and prevent downtime, thereby contributing to strengthening production quality and generating long-term cost savings (Achouch et al., 2022). Frequently, data collection regarding the machine's condition is carried out through analyzers capable of recording information such as vibration signals, temperature, rotation, and other pertinent data, without the need to interrupt equipment operation. However, to carry out predictive maintenance properly, significant initial investments in analysis equipment are required. Large-scale industries typically make substantial investments in suitable technologies for this type of monitoring, whereas small and medium-sized industries perceive this investment as a significant risk.

Considering the rapid advancement of microcontrollers and their diverse applications, researchers like Travaglione, Munyard, and Matthews (2014) put some microcontrollers to the test, demonstrating how these devices can be used to create low-cost measurement systems. Results showed that the Raspberry Pi is efficient in providing stable communications, being crucial for high acquisition rates. Other applications using a Raspberry Pi 3B+, were made by Pessoa and Senko (2021) and Lira and Senko (2022), which were employed to assess vibrations in rotating systems. This approach enabled the performance of vibration analyses at acquisition rates of up to 1300Hz, facilitating the examination of motor dynamic behavior during acceleration. Furthermore, Tuemo and Lozano (2022) developed a low-cost analyzer with IoT capabilities, remote control, and monitoring, employing Raspberry Pi and Arduino for structural analyses, boasting a 100Hz acquisition rate.

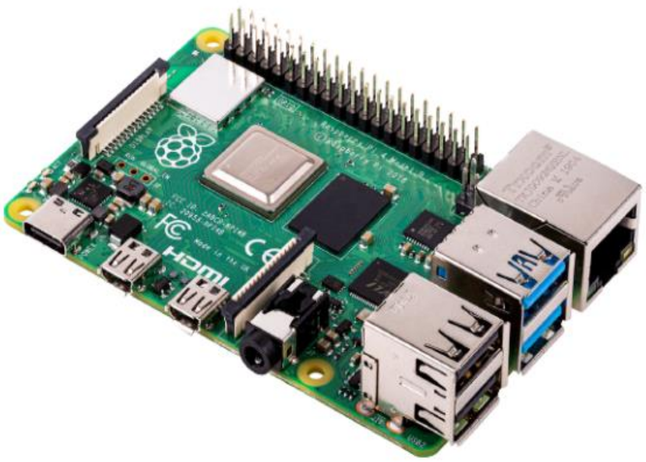
The objective of this article is to develop a low-cost analyzer utilizing the Raspberry Pi 3B+ (Rpi3B+). The purpose of this device is to conduct continuous and modular analyses of speed and temperature variables in rotating systems. The focus lies in creating a versatile and affordable apparatus capable of uninterrupted monitoring of these variables in rotating systems, enabling a detailed assessment of their behavior over time. The utilization of the Raspberry Pi 3B+ as the technological foundation highlights the feasibility of a cost-effective and efficient solution for data acquisition and processing in industrial monitoring contexts.

2. MATERIALS AND METHODS

2.1 Microprocessor – Raspberry Pi 3B+

The microprocessor RPi3B+, Figure 1, was previously chosen as the foundation for the development of the modular analyzer in studies conducted by Pessoa and Senko (2021) and Lira and Senko (2022), wherein it was compared against Arduino Mega and NodeMCU. These experiments sought to analyze parameters such as sampling rate, with and without data storage, and signal-to-noise ratio (SNR). As demonstrated in these researches, the RPi3B+ exhibited superior performance, with a 2.5% higher sampling rate when data storage was omitted, and an SNR six times higher than its other microcontrollers.

According Jucá and Pereira (2018), the RPi3B+ possesses the capability to interact with the external environment through various sensors. Another factor influencing the choice of RPi3B+ was its open-source platform, which facilitates robust user engagement. The specifications of the RPi3B+ are presented in Figure 1.



Cpu	Broadcom Cortex-A53
Clock	1.4 Ghz
Memory	1 GB LPDDR2
Ports USB 2.0	4
Connectivity	Wifi dual band e Bluetooth 4.2/BLE
GPIO	40 pins
Slot Sd Card	Micro USB
Number's GPIOS	25
Input charger	5V

Figure 1. Raspberry pi 3B+.

2.2 E18-D80NK IR sensor

The IR sensor E18-D80NK, as shown in Figure 2, has already demonstrated good results in applications such as people counting for flow measurement (Salgado, 2019), making it a suitable alternative for rotational analysis in rotating systems. This analog sensor operates through interruption, where a reflective surface passing through its capture area emits a low-level logic signal to the GPIO (General Purpose Input/Output) and measures the period between pulses. Table 1 presents its main characteristics.

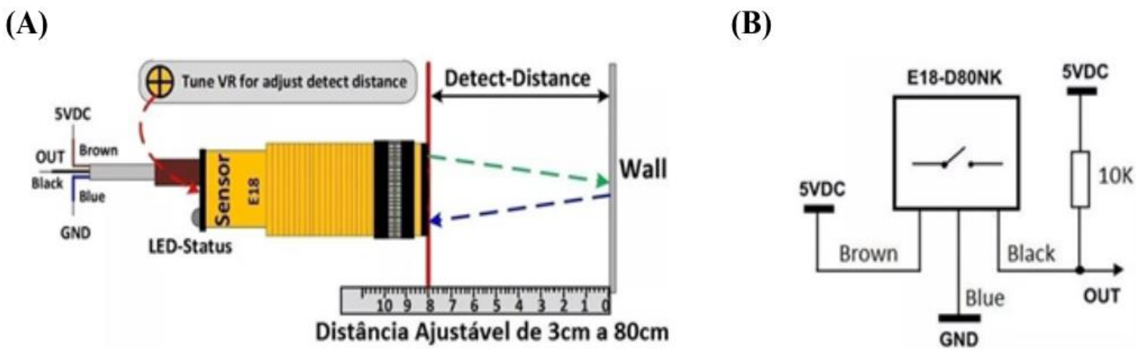


Figure 2. Infrared Sensor E18-D80NK, (A) Application Range; (B) Electrical Schematic. Source: E18-D80NK Datasheet.

Table 1. Specifications of the E18-D80NK.

Input voltage	3,3 - 5V
Current consumption	10 - 20mA
Dimensions	37x14mm
Type of detection	Diffuse reflective
Range distance of detection	3 to 50cm
Output	NPN(1)
Cost	6,35U$$

(1) *Sensors with NPN output have a negative-positive negative junction, so when the sensor is activated it emits a low logic signal.*

2.3 MLX90614 Temperature sensor

The MLX90614, as shown in Figure 3 and Table 2, is an infrared temperature sensor used for non-contact measurements. It operates using the I2C bus, which is an asynchronous communication protocol type that uses two channels : one for transmission and reception, and another for data synchronization. It has been utilized by Silva, Duarte, and Borloti Silva et al. (2021) for non-contact body temperature evaluation, by Hoffmann and Henrique (2021) for automatic access control through body measurement, and also by Pessoa and Senko (2022) in the development of a modular analyzer for vibrations and temperature. In comparison to a commercial infrared thermometer, it achieved an average error of 5.9%.

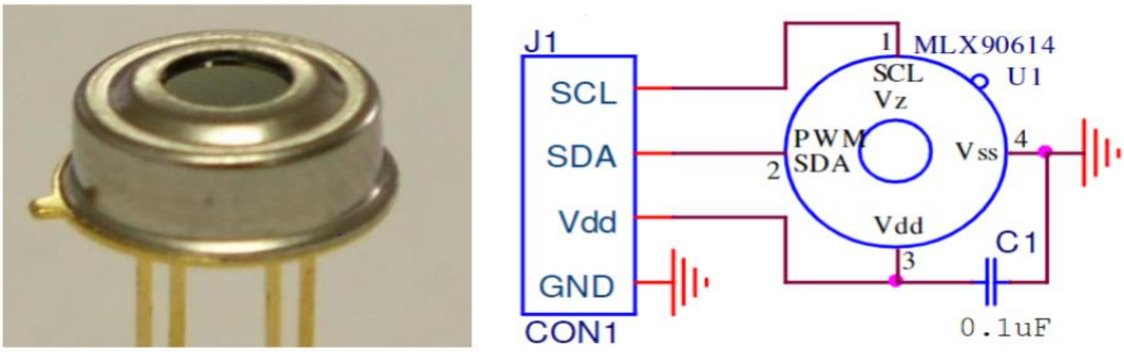


Figure 3. MLX90614 Temperature Sensor, (A) MLX90614; (B) SMBus Connection. Source: MLX90614 Datasheet.

Table 2. Specifications of the MLX90614.

Input voltage	3,3 - 5V
Current consumption	10 - 20mA
Range of temperature	-20 to 120°C
OUTPUT	I2C
Cost	33.66R$

2.4 Experiment setup

The experiment was set up shown in Figure 4:

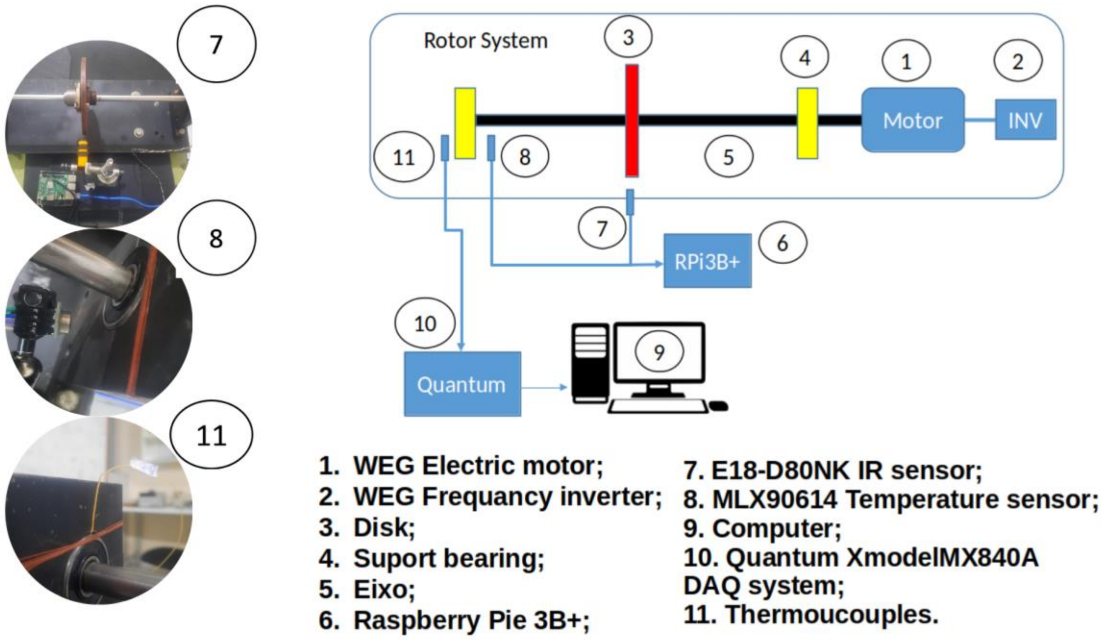


Figure 4. Experiment setup.

Reflective tapes were added to the disk (3) to activate the infrared sensor and calculate the rotational speed of the system. The MLX90614 temperature sensor and thermocouples (11) were attached to the bearings to capture the temperature of the bearings.

2.5 Data acquisition and processing

The module operates according to the following steps: collecting, saving, processing, and presenting the results, as shown in Figure 5. Python was chosen as the programming language because it is native to the Rpi3B+'s operating system. For speed collection using the E18-D80NK, the rotating system was excited at 25 and 50 Hz using the frequency inverter (2), as shown in Figure 4, set to gradually accelerate the system. The data collection for these tests lasted 100 seconds. For comparison with the Minipa Tachometer, the system was excited at 20, 40, and 60 Hz with a constant speed.

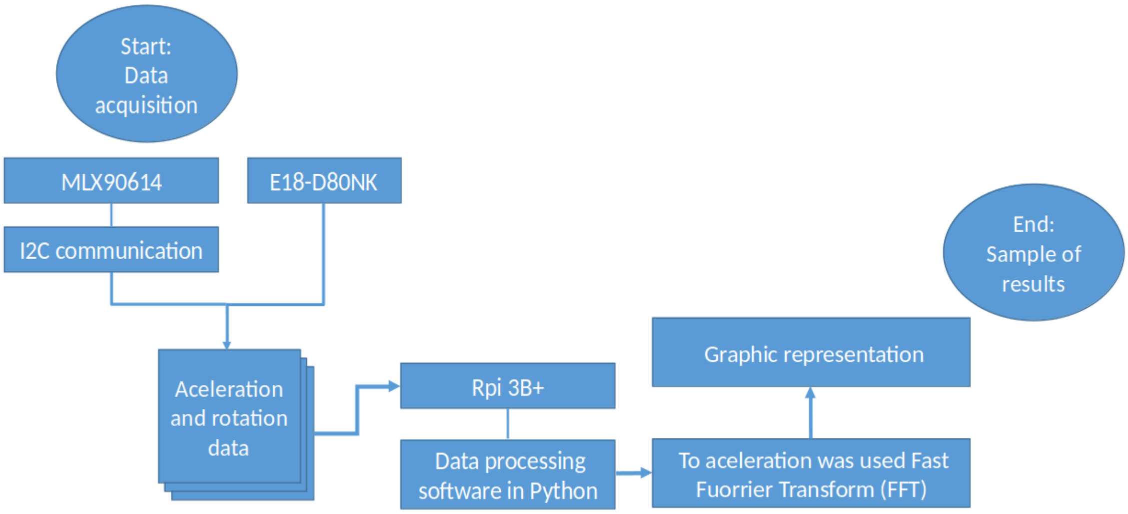


Figure 5. Methodology of operation of the developed system.

A temperature data acquisition system test was conducted using the MLX90614 sensor to monitor the heating behavior in the bearings of a rotating system during its operation. For all tests, the bearings were coupled to the support bearings and fixed with the same torque on the screws. The obtained results were compared with the data collected by the Quantum (10) in conjunction with the thermocouples (11). The data collection duration was one hour (3600 seconds), and both systems were configured to operate at a sampling frequency of 1 Hz. In both experiments, the data obtained was analyzed in the time domain.

3. RESULTS AND DISCUSSIONS

3.1 Speed analysis

In the application of the E18-D80NK for speed analysis, two acceleration ramps were obtained as shown in Figure 6. Table 3 presents the comparison between the Rpi3B+ and a commercial Minipa tachometer when exciting the rotating system at 20, 40, and 60 Hz.

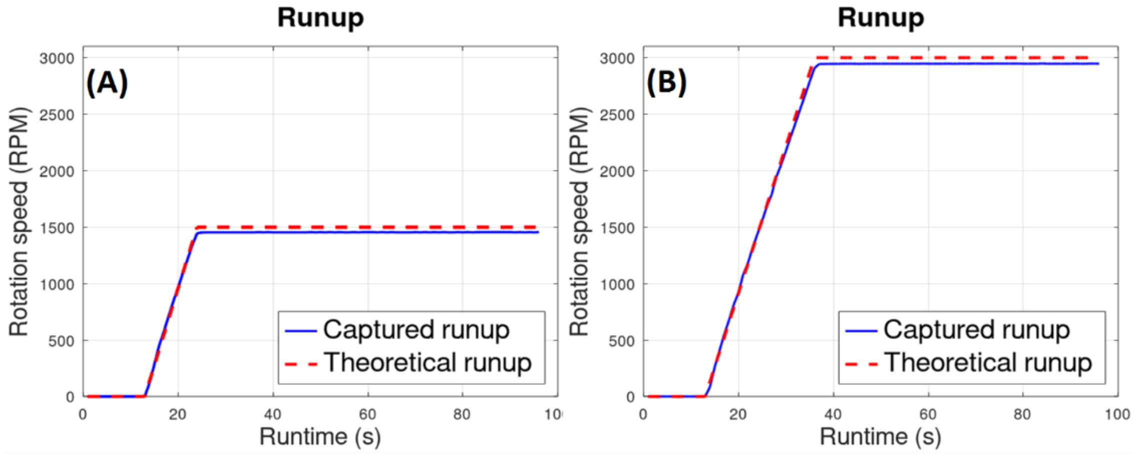


Figure 6. Acceleration ramps.

The discrepancy between the experimental results and the theoretical values is associated with energy losses in the bearings and the flexible coupling used to absorb misalignments between the motor shaft and the rotor system.

Table 3. Comparison with Minipa MDT-2238A tachometer.

MDT-2238A	Rpi3B+/E18-D80NK	Error (%)
1200 RPM	1194 RPM	0,5
2388 RPM	2380 RPM	0,3
3588 RPM	3588 RPM	0

3.1 Temperature analysis

To evaluate the performance of the developed system, the collected data from both the Rpi3B+ and the Quantum were compared. In this temperature analysis, the rotating system was excited at 20 and 40 Hz, and the results are presented in Figures 7 and 8.

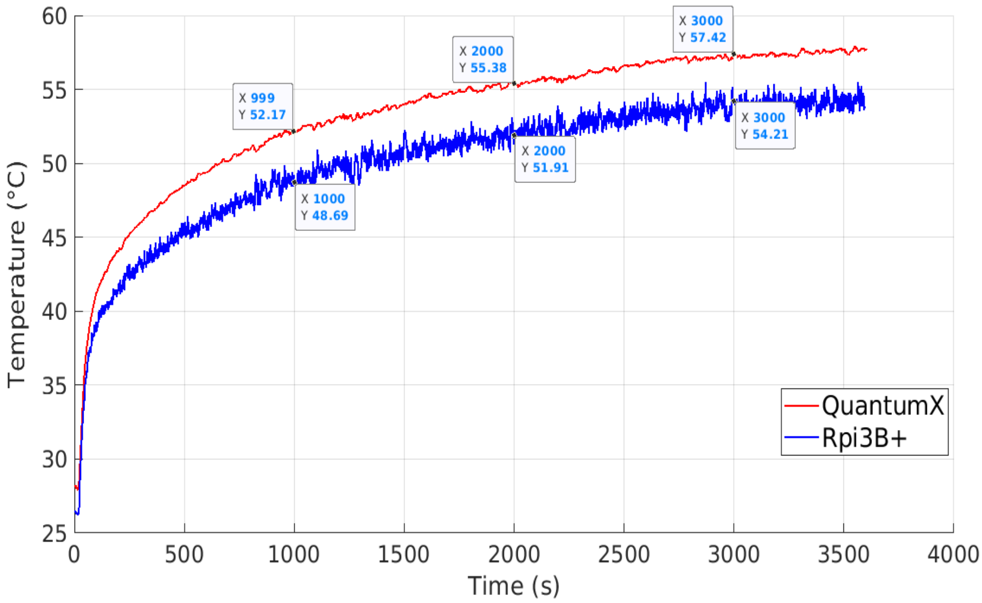


Figure 7. Temperature analysis of the rotating system at 20 Hz.

It is observed that in the 20Hz test, the temperatures in the bearings ranged from 25 to 55°C. When comparing the data with that obtained from the Quantum, the Rpi3B+ exhibited an average relative error of 6.5%.

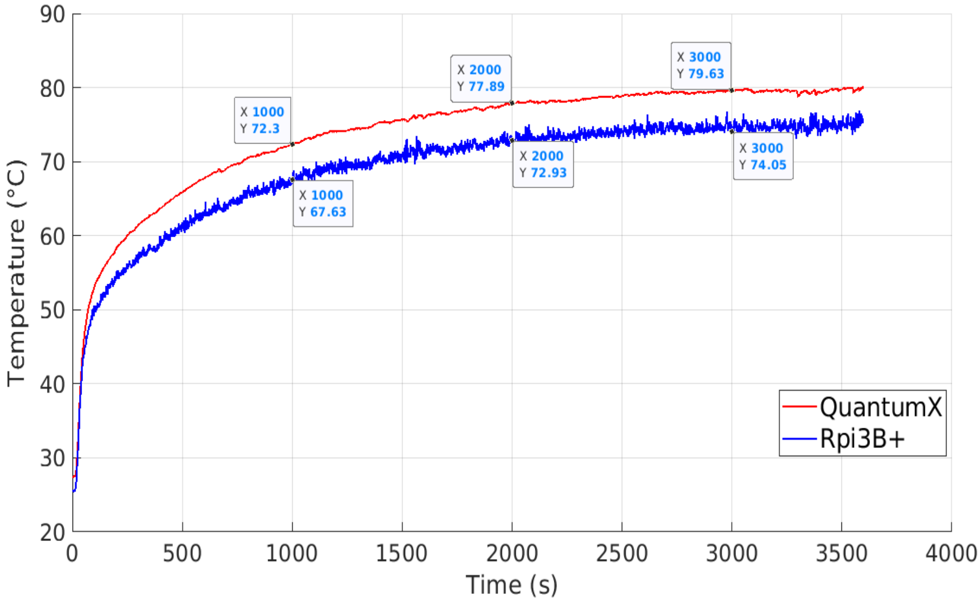


Figure 8. Temperature analysis of the rotating system at 40 Hz.

In the system excited with 40Hz, the collected temperatures ranged from 25 to 75 °C, with an average relative error of 6.8% compared to the data obtained from the Quantum.

4. CONCLUSIONS

Based on data acquisition of rotational speed, acceleration ramps, and temperature analysis, the results demonstrate that the Rpi3B+ and the sensors used have proven to be sufficient, showcasing the capability of the Rpi3B+.

For speed analysis, errors of less than 1% were obtained and for temperature analysis, average relative errors of up to 7% were observed. These errors arise due to sensor limitations and can be corrected by updating the logic of the developed algorithm, validating the developed algorithm, which, being written in Python, can be easily updated to work with remote monitoring platforms such as Microsoft Azure.

Considering the ease of application and versatility of the developed system, as well as the fact that the sensors operate without direct contact with the surfaces being analyzed, the use of this equipment becomes feasible.

Despite presenting small percentage errors compared to commercial systems, considering the low cost of the equipment at the price of R$ 966.33 and the current ease of access to these materials, this margin of error is deemed tolerable.

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6. RESPONSIBILITY NOTICE

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