Development of a modular analyzer using low-cost microcontrollers

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Abstract. In the industrial sector, the monitoring and evaluation of machinery in continuous operation has vital importance, principally considering the high competition and the pursuit of high-quality products without increasing the cost of manufacture. Although, the lack of appropriate maintenance increases the possibility of problems such as undesirable vibrations, which cause a lack of performance, several flaws in primary and secondary systems, and unexpected downtime on their applications, increasing the manufacturing cost.

Predictive maintenance is applied to anticipate and identify these issues before that lead to the unplanned downtime of the equipment. To apply this kind of maintenance, some analyzers are used to keep updated the condition of the machinery, with information such as vibrations amplitudes, temperatures, and rotation velocities. However, analyzers have a high initial cost, this does not mean a huge problem for large industries, but for small and medium-sized ones, especially for those that go through periods of economic instability, it can be an investment out of reality.

Taking advantage of the current expansion of low-cost microcontrollers and sensors, the objective of this paper is to apply these programmable open-source to develop a modular data acquisition device, initially focusing to acquire vibration and rotation speed signals with low-cost sensors. The raspberry pi 3b+ was used for that application, and an algorithm was developed to collect and process data captured by compatible sensors, and then applied to an experimental test bench.

Keywords: microcontrollers, modularity, vibration analyses, predictive maintenance.

1 Introduction

The monitoring and evaluation of equipment in continuous operation has vital importance in the industrial sector, which has cost reduction as one of its main pillars for development. Predictive maintenance is used to extend the life of the equipment and, to apply this type of maintenance the signal analysis of the industrial machines during its use is necessary, as it does not require equipment downtime. However, this type of maintenance becomes a high investment, often infeasible due to the cost of these signal analyzers.

For this study, the Raspberry Pi 3B+ (Rpi3B+), Figure 1, was chosen as the base platform for the development of the low-cost analyzer, due to its variety of applications, including automation of smart classroom environment Silva [1], web servers low-end energy consumption Aroca[2], home cloud storage systems Silva and Distadio [3], and home monitoring systems, Coutinho [4]. For applications in rotating systems Pessoa and Senko [5] applied the triaxial accelerometer MPU6050, Figure 2, with the Rpi 3B+ to develop a modular vibration and temperature analyzer.

Among the wide applications that are being made with microcontrollers and low-cost sensors, the principle of modularity is not being explored, with applications usually focused on specific use. When analyzed, modularity comes with the function of simplifying product design by dividing complex problems into more straightforward issues that can be worked on individually, as can see in Arnheiter and Harren [6]. Through modularity, Viero and Nunes [7] showed parallelism can be applied in the development of projects, allowing that the module change time does not significantly affect the product development time.

The present work aims to develop a modular analyzer for vibration and speed analysis with microcontrollers and low-cost sensors, testing and verifying the sensitivity of vibration capture in unbalanced rotating systems.

2 Material and methods/Methodology

2.1 Microprocessor – Raspberry Pi 3 B+

The microprocessor RPi3B+, Figure 1, was chosen previously as the basis for developing the modular analyzer, which started with the development of a vibration and temperature analysis module by Pessoa and Senko [5]. According to Jucá and Pereira [8], the RPi3B+ can interact with the outside world through sensors. Going further, working with microcontrollers, it can be used in a wide range of digital projects. Compatibility with low-cost sensors and an open-source platform that generates good user interaction was also taken into account when choosing the raspberry pi. Table 1 shows the specifications of the RPi3B+.

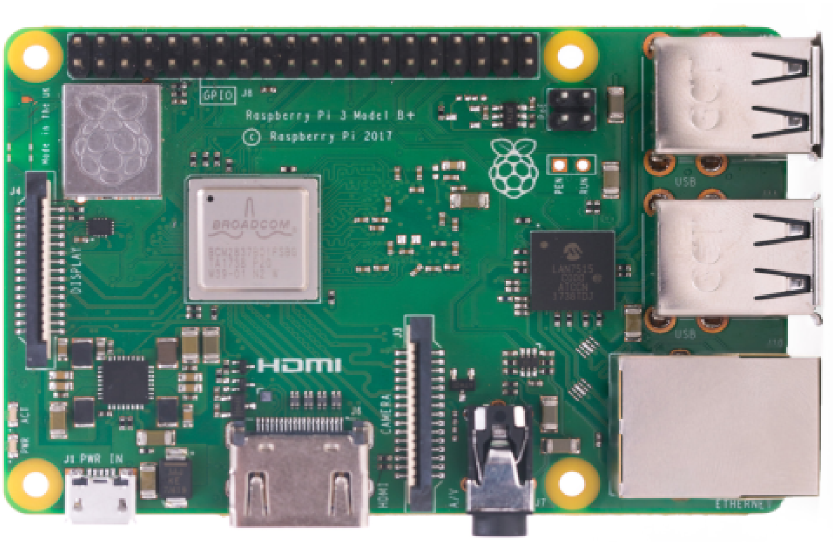

Figure 1. Raspberry pi 3B+.

Table 1 – Raspberry pi 3B+ specifications.

Cpu	**Broadcom BCM2837B0 Cortex-A53 64 bits Quad-core**
Clock	**1.4 Ghz**
Memory	**1 GB LPDDR2**
Ports USB 2.0	**4**
Connectivity	**Gigabit Ethernet over USB 2.0, Wifi dual band e Bluetooth 4.2/BLE**
GPIO	**40 pins**
Slot Sd Card	**Micro USB**
Number's GPIOS	**25**
Input charger	**5V**

2.2 Accelerometer sensor - MPU-6050

The MPU6050, Figure 2, works as a piezoelectric with the I2C bus, a type of asynchronous communication that uses two channels; one for transmission and reception and another for data synchronization, this particularity was explored to find the best logic to acquire data from acceleration. This sensor is connected to the Rpi3B+ through the I2C bus.

Used by Mascoloti [9] in the development of low-cost sensing for monitoring the structural health of a rotating machine that obtained a 70% correlation between the MPU6050 and a Tractian accelerometer, this sensor was chosen for the application in this work. The specifications of the MPU6050 were shown in Table 2.

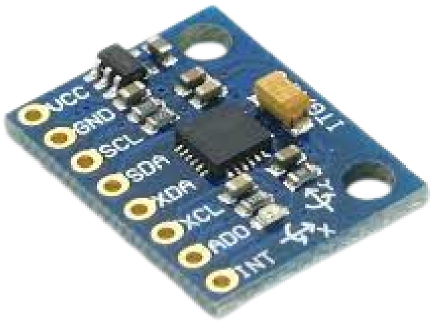

Figure 2. Accelerometer MPU-6050.

Table 2 – MPU-6050 specifications.

Input voltage	Dimensions	Range of acceleration	Output	Cost (R$)
3,3 – 5V	20x16mm	±2, ±4, ±8, ±16g	I2C	21,90

2.3 Infrared sensor – E18-D80NK

The E18-D80NK IR sensor, Figure 3, as it has already shown good results in applications such as counting people for flow recording as presented by Salgado [10], presents itself as a good alternative for this application.

Is an analog sensor that works by means of interruption, when some reflective surface passes through its capture area it emits a low-level logic signal to GPIO (General Purpose Input/Output) and starts measuring the period between pulses. Table 3 presents its main characteristics.

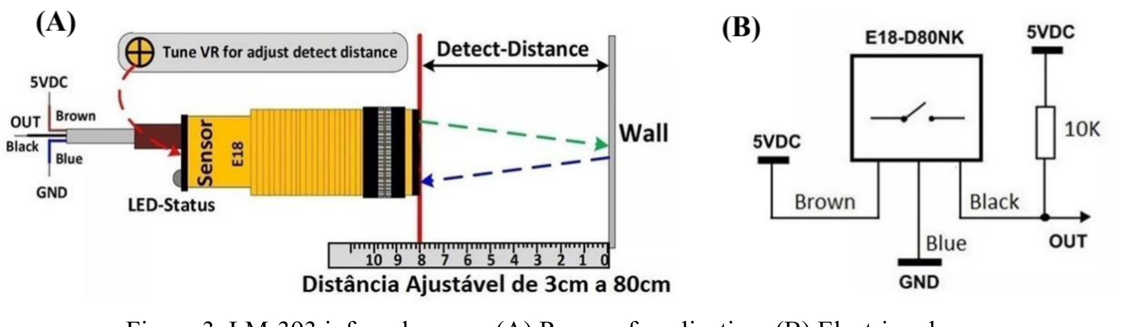

Figure 3. LM-393 infrared sensor, (A) Range of application; (B) Electric scheme.

Table 3 – E18-D80NK specifications.

Input voltage	Current consumption	Dimensions	Type of detection	Range distance of detection	Output	Cost(R$)
3,3 - 5V	10 – 20mA	37x14mm	Diffuse reflective	3 to 50cm	NPN*	34,00

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

2.4 Experiment setup

The experiment was set up according to the Figure 4:

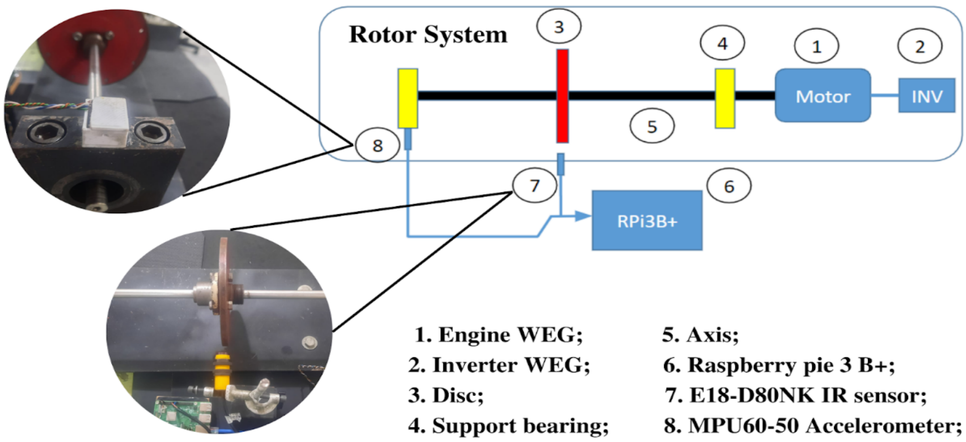

Figure 4. Experiment setup.

Reflective tapes were added to the disk (3) to activate the infrared sensor and calculate the speed of the rotating system. The accelerometer (8) was mounted on the support bearing (4) to collect the reactions simultaneously, allowing the correlation with the data obtained by the IR sensor.

The assembly presented makes it possible to apply the sensors used, put them to the test, to identify unbalances and other phenomena that occur during the use of the rotating system.

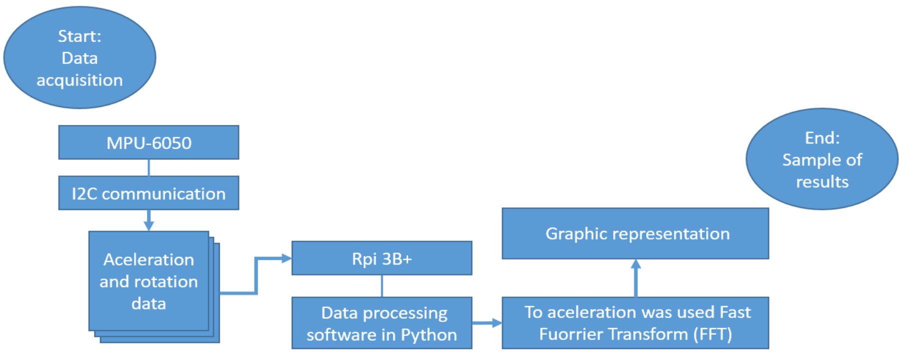

Figure 5. Methodology of module operation.

2.5 Data acquisition and processing

The module works in the following steps: Collect, save, process and present the results of the updated data, as shown in Figure 5. Python was the programming language applied. The rotating system was excited at 25 and 50 Hz through the frequency inverter (2), Figure 4, for both speeds the system was unbalanced with 2 and 4 grams.

The experiments were performed for 100 seconds, where the E18-D80NK was used to obtain the rotor acceleration ramp, and the MPU-6050 comes into action from the moment the speed becomes constant, collecting the reactions in the bearing supports.

The bearing support reaction data is analyzed in the frequency domain using the Fast Fourier Transform (FFT), with the acceleration ramp data, the real rotation frequency is obtained in the time frame in which the MPU-6050 is inactive. From the FFT, it is expected to obtain spectra of the vibration data with different amplitudes in the rotation frequencies captured by the E18-D80NK, for each unbalanced mass coupled to the system.

3 Results and discussions

3.1 Speed analysis

The velocity module developed with the E18-D80NK was also used as a reference for the analysis of the vibration results for two acceleration ramps, Figure 6.

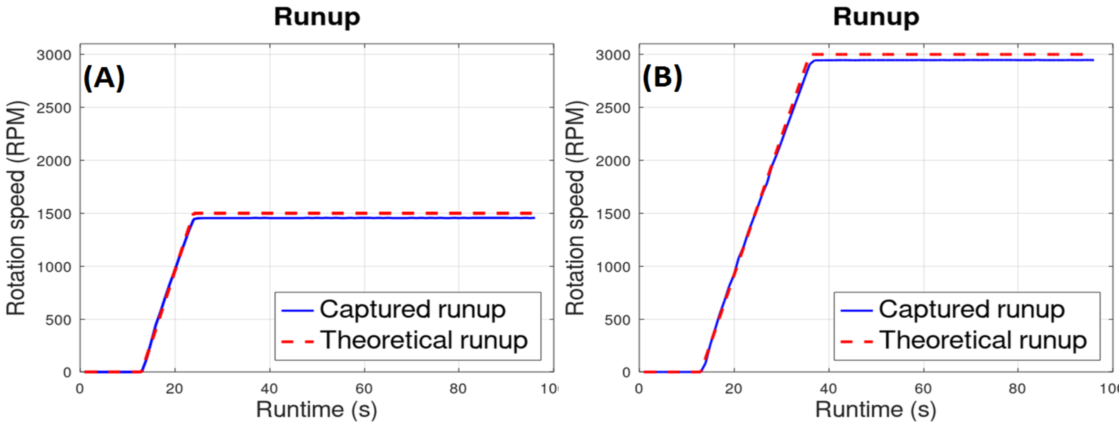

Figure 6. Acceleration ramps, (A) 25Hz; (B) 50Hz.

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

3.2 Vibration analysis

To qualify the developed data acquisition module, the assembly described in Figure 4 was used, where the data from each sensor were obtained and treated following the flowchart shown in Figure 5. In Figure 7, 8 and table 4 the results obtained will be presented.

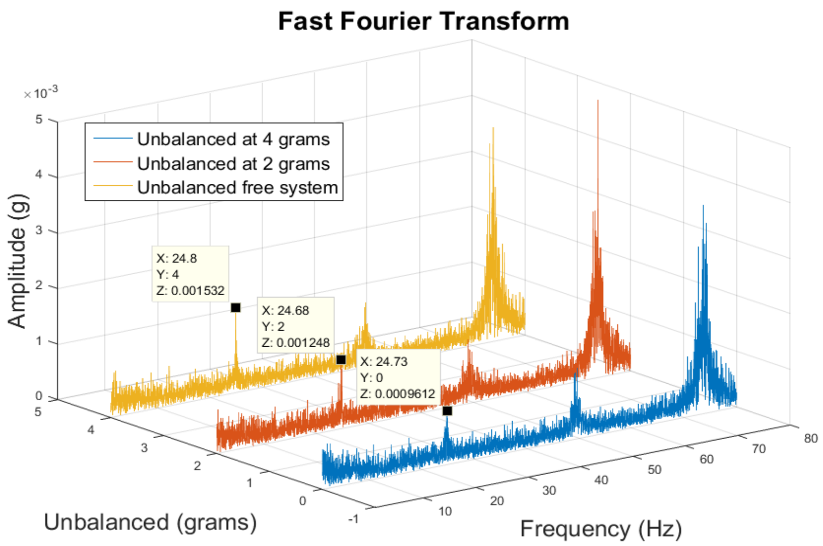

Figure 7. Test results at 1452 RPM, (A) Unbalanced free system; (B) Unbalanced at 2 grams; (C) Unbalanced 4 grams.

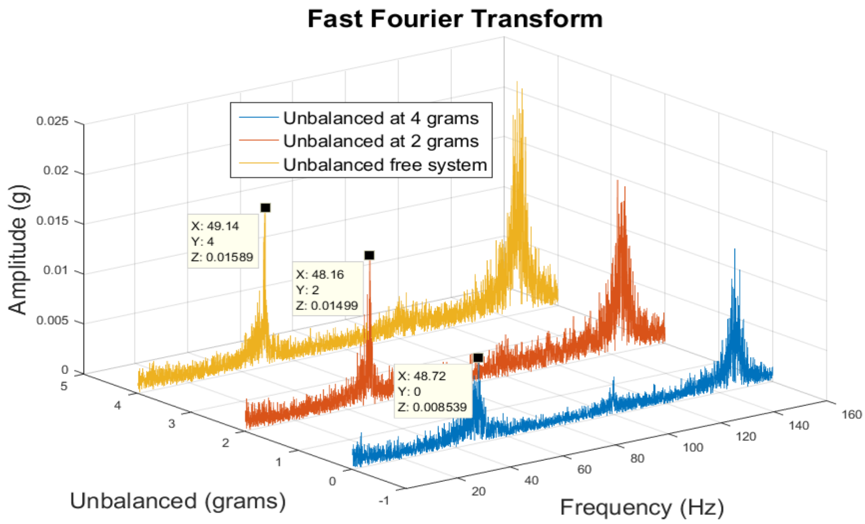

Figure 8. Test results at 2948 RPM, (A) Unbalanced free system; (B) Unbalanced at 2 grams; (C) Unbalanced 4 grams.

The difference between the data of the unbalanced system with the free system was calculated so that it is possible to verify if the module is detecting any difference between the free rotating balanced system and the unbalanced system, these data are presented in Table 4. Other peaks are well apparent located at 2x and 3x the rotation frequency, according to Scheffer [11] this characterizes a misaligned assembly of the rotor system.

Table 4 – Test results.

Velocity of rotation (RPM)	Unbalance mass (grams)	Support bearing reactions (m/s²)	Acceleration difference with balanced system data (%)
1452	0	0.00883	-
1452	2	0.01079	22.20
1452	4	0.0157	77.80
2948	0	0.07852	-
2948	2	0.13742	75.01
2948	4	0.16422	109.14

4 Conclusions

From the acquisition of rotational speed data, acceleration ramps, and rotational frequencies of the system with the proposed module, it was possible to perform the following analyses.

The vibration module identified the defects of the unbalances inserted in the system, being able to recognize a difference between the balanced system and the unbalanced system with 2 and 4 grams, exposing the increase of the unbalanced masses, and also the misalignment of the system.

By associating the velocity and vibration data, the proposed module can show a vibration spectrum in the frequency domain using the Fast Fourier Transform (FFT). With this information, it is possible to make a better analysis of the phenomenon of vibrations and other issues of the rotor systems and propose adequate adjustments without the unexpected stop of the operation. Considering that the average cost of this proposed module is US$187.10, it becomes a powerful tool for maintenance applications.

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