SENSING: An Approach to Establish the First Step to Prepare a CNC Machine for IoT Implementation

Cleginaldo Pereira de Carvalho[1], Bruno dos Reis Simões[2], Érica Alves de Carvalho[3], Rogério Rodrigues Diniz[4]

[1] University of the State of São Paulo, Faculty of Engineering of Guaratinguetá, Industrial Engineering Department
Corresponding Author: University of the State of the State of São Paulo, Avenida Dr. Ariberto Pereira da Cunha 333, Pedregulho, Guaratinguetá, São Paulo, Brazil, Zip Code: 12516-410.
[2] Faculty of Human Science of the State of São Paulo

Received: 21 Oct 2020; Received in revised form: 9 Nov 2020; Accepted: 12 Nov 2020; Available online: 15 Nov 2020

***Abstract* — *Automation as the procedure is achieved without human assistance has already applied for many enterprises to improve productivity and cost reduction. The computer numerical control machines (CNC) have been implemented in many industrial segments and the monitoring of future fails can avoid delivery time delay, improve flexibility and cost-saving. As a tool of Industry 4.0, the internet of things (IoT) has been applied to introduce predictive maintenance programs. This work aims to investigate the feasibility of an easy monitoring system, using Arduino, and sensors for ultrasonic proximity, and color recognition, as well as an accelerometer as a low-cost alternative to data acquired in a CNC lathe machine facilitating the IoT implementation, and consequently a predictive maintenance program.*

Keywords* — Arduíno, CNC lathe machine, industry 4.0, IoT, predictive maintenance, sensors.

I. INTRODUCTION

The search for competitive advantages gave rise to automated machines, called machines with computerized numerical control or, simply computer numerical control machines (CNC). According to [1], CNC machines are capable of performing operations, previously developed with the direct intervention of the operator, obtaining greater precision and less susceptibility to the occurrence of problems of non-conformity of the manufactured components.

According to [2], the use of free hardware platforms, such as Arduino, Raspberry, and others, are easy to use and simplify the task of automating processes.

According to [3], Arduino is a free hardware electronic prototyping platform that allows interaction with the external environment through the use of sensors and actuators. Basically, the Arduino works like a computer that allows the programming and processing of inputs and outputs between the device and the external components connected to it.

The author also reports that Arduino can be used in the development of independent interactive objects or connected to a computer, constantly sending and receiving data according to the schedule. It allows for a multitude of applications, is possible to use it to control light-emitting diode (leds), displays, buttons, switches, motor drives, sensors, or any other device that emits data and allows its control.

When a machine develops a defect or failure, it presents indications of defects in several ways: changes in vibration signals, temperature variation, noise, etc. The monitoring of the condition of industrial machines provides information on the equipment's operating status, which allows planning a maintenance intervention before a failure occurs. As stated by [4], the early detection of failures helps prevent unscheduled breaks and interruptions in the production line.

Thus, the work aims to present an easy monitoring system, using the Arduino and ultrasonic proximity sensors, color recognition sensors, and accelerometer, to ascertain the need for changing or replenishing soluble cooling oil and the vibration level of the bearings located in a gearbox, being able to identify possible failures, to prepare a CNC lathe machine for internet of things (IoT) implementation. The research work was developed in a Faculty of Industrial Engineering located in Vale do Paraiba, State of São Paulo, Brazil. The work presents itself with a bibliographic review of the important topics and results of tests carried out in the practical field at the Faculty lab.

II. THEORETICAL BACKGROUND

2.1 Automation

Automation can be defined as the technology by which a process or procedure is achieved without human assistance. It is performed using an instruction program combined with a control system that executes the instructions. To automate a process, energy is needed not only to drive the process but also to operate the program and the control system. Although automation can be applied in several areas, automation is directly associated with the production industries [5].

Historically, automation has been going on for a long time, in the mid-18th century, leveraged by the discovery of the steam engine, the industrial revolution took place, which was the biggest reason for the change from a productive system in the manufacturing process to a mechanical process by through the mechanical industry, with the insertion of machines, which increased the yield of labor and production. A qualitative and technological leap that has occurred worldwide in an irreversible and growing way. The various discoveries in conjunction with mechanization have also strengthened change [6].

The first phase of the industrial revolution occurred approximately from 1760 to 1860, with England as the highlight. The second industrial revolution, from 1860 to 1900, was characterized by the assimilation of industrialization in other countries in Europe, the United States, and Japan and the use of new sources of energy such as electricity and the use of oil [6].

From 1900, the third industrial phase began, characterized by the emergence of large industries, multinational and transnational companies, leveraged by the automation of production. The greatest advances in automation came after the second world war, starting in the 1950s. Since then, the chemical and electronics industries have been showing great development.

Automatic systems appeared at the beginning of the 20th century, but semi-automatic systems already existed. Automatic devices were invented due to the environmental need to increase production. The automation must be self-controlled using necessary tools and specific instructions for the execution of a described work [6].

The first computer is a collection of several inventions that allowed the tasks to be carried out as we know them.

Another major evolution of computers was the creation of the electrical numerical integrator and calculator (Eniac), in 1946, by John Mauchly and Presper Eckert, sponsored by the American government, after working for the government, developed Univac.

Some devices that allowed this evolution was used in the first generation of computers, such as vacuum tubes (valves); the second generation of computers was equipped with a transistor; the third was marked by integrated circuits. The evolution of computers continued until the present fourth generation of well-known desktop and personal computers, which use microprocessors.

Servomechanisms, which have also evolved, are devices that convert electrical signals into mechanical movements. This simplified definition allows us to conclude that the servomechanisms have existed for a long time and could operate independently of the computer or the instructions coming from the computerized numerical command, the CNC [6].

For [7], automation is a technology that makes use of mechanical, electrical, electronic, and computer systems to control production processes. And it brings some examples of automation processes in industries:

- automotive assembly lines,
- engine integration - transfer line,
- CNC type machine tools,
- robots.

Three different forms of industrial automation can be identified:

- fixed automation,
- flexible automation,
- programmable automation.

a) Fixed automation:

In fixed automation, the machines are specific to the product to be produced. They produce large quantities of a single product or product with small variations between them. The volume of production is high and the cost of the machine too, as it is designed for a specific product. On the other hand, as the volume of production is high, the cost of the product, in general, is low. Such machines are found in motor transfer lines, lamp production, paper, and bottle manufacturing. In this type of automation, care must be taken with the final price of the product, since, as the investment for the purchase of the machine is high, amortization only happens with high sales. Besides, if the product leaves the market due to obsolescence, the investment is lost.

b) Flexible automation:

Inflexible automation the production volume is average and the machine can generally be programmed to produce another product, albeit similar. This automation has characteristics of fixed and programmable automation. The machine must be adaptable to a large number of similar products, and, in this sense, it is more flexible than fixed automation. Flexible automation is used, for example, in an automotive assembly line.

c) Programmable automation:

In programmable automation the production volume is low, but the variety of products is different and high. It is programmatically adaptable. The main examples of programmable automation are CNC machines and industrial robots.

2.2 Industry 4.0

The industry produces goods and services through countless processes seeking to meet the needs of its final consumer with quality to retain customers. For this, it has an important ally - technology - where smart industries are investing in mechanization, automation, and robotization, as well as relying on a set of interconnected data. The purpose of such investments is to ensure that the products developed are produced in the best possible way, reducing costs and/or increasing revenues to maximize profits.

[8] report that the next generation of the industry - called Industry 4.0 - keeps the promise of greater flexibility in manufacturing, along with mass customization, better quality, and better productivity, where smart manufacturing plays a key role.

[9], the first industrial revolution was linked to the field of mechanization, the so-called second industrial revolution referred to the intensive use of electric energy and the third industrial revolution is related to the era of generalized digitalization. Future production contains efficient manufacturing systems where products control their manufacturing process, this is an example of future expectations, so the term "industry 4.0" was established for a fourth industrial revolution.

Industry 4.0 emerged as a proposal for the development of a new concept of German economic policy based on high-tech strategies [10].

[11], the fourth industrial revolution is a transition to the digital transformation of industry, a fusion of the physical and digital worlds that have countless possibilities, so Industry 4.0 is substantially a reformulated approach to manufacturing that makes use of technological inventions and innovations uniting operational, information and communication technologies.

[12], industry 4.0 is part of a relevant discovery by the German government, in which it seeks to present a new model of computerized manufacturing, bringing together the fields of physical and digital processes.

[13], industry 4.0 can be understood as a relevant process, marked by process automation digitization and use of Information Technology tools to manufacture products and services.

The fourth industrial revolution can best be described as a shift from manufacturing logic to an increasingly decentralized and self-regulating value approach, enabled by concepts and technologies like cyber physical systems (CPS), IoT, apple operating system (IOS), cloud computing or additive manufacturing and smart factories, to help companies meet future production requirements [14].

[15], industry 4.0 is associated with digital technologies that have great relevance in the manufacturing process, but that does not limit them in their respective uses. Among these technologies, it is possible to mention the smart factory, big data, the internet of things, and cyber-physical systems.

2.3 Internet of Things

The internet of things, for [16], is a type of communication interface between humans, machines, and objects that innovated in the way of producing, reproducing and using knowledge. According to [17] "is a technological innovation, based on already consolidated artifacts such as the internet and smart objects". Its objective is to create new applications and improve existing ones, according to [18], enabling the integration of information from the virtual and physical environment, thus extending the network to the real world [19, 20].

According to [21], it is a platform that is based on the interconnection of everyday objects. In this perspective, several of the objects that surround us will be on the network in one way or another, for this, radio frequency identification (RFID) - and the technologies with sensor networks will increase to account for this new challenge,

https://dx.doi.org/10.22161/ijaers.711.10 ISSN: 2349-6495(P) | 2456-1908(O)

thus, information and communication systems will be invisibly, however, incorporated in the environment that surrounds us [22].

[23] explains that the internet of things refers to a network of objects that have a built-in technology - usually sensors and microprocessors - and that can interact with each other either by sending or receiving information both internally and externally. Thus, according to [24], the internet of things will create a world where physical objects will be perfectly integrated into the information network to the point of being able to offer advanced and intelligent services to human beings.

[25] point out that the internet of things goes beyond smart homes and connected devices - it means getting to know the physics in real-time and remotely - and today, with the increasing expansion of smartphones, it is possible to use its built-in sensors to monitor the environment anytime, anywhere.

[26] and [27], the internet of things generate more opportunities for the business. With the introduction of these new technologies, such as radio frequency identification and intelligent computing, it became possible to create new applications and business systems involving the most different sectors, such as logistics, production, transportation, the environment, services, among others [28]. This evolution creates systems that go beyond the interconnection of individual things, being able to provide joint and collaborative services [29].

III. METHOD AND MATERIAL

3.1 Type and Scientific Approach

The present work used theoretical, qualitative, and applied research. For [30], in qualitative research there is a dynamic relationship between the real world and the subject not translated into numbers, the natural environment is the direct source for data collection and the researcher is the key instrument. The interpretation of the phenomena and the attribution of meanings are basic in the qualitative research process. It is descriptive and does not require statistical methods and techniques. Regarding applied research, [31] reports that such research is motivated by the need to solve concrete and existing problems in the research environment. Applied research, therefore, has practical purposes, different from pure research, which is motivated by curiosity and the desire to research.

3.2 Method and Material

Two methods were used for the elaboration of this work, being the open project tool to carry out the research schedule and elaboration of the tasks to be done and the Arduino software for programming the sensors.

The materials acquired for the preparation of the project were:

- (Arduino) Mega 2560 R3 CH340 + USB Cable for Arduino,
- Jumpers - Male / Female - 40 Units of 30 Cm,
- TC TCS230 RGB Color Sensor Module,
- Accelerometer and Gyro 3 Axis 6 DOF MPU-6050 GY-521,
- HC-SR04 Ultrasonic Distance Sensor Module,
- Diffuse Led 3mm Red - 10 units,
- Diffuse Led 3mm Green - 10 units.

The work was produced by 4 researchers of industrial engineering course, from a Faculty located in Vale do Paraíba in the state of São Paulo, Brazil, carried out thorough research in the Faculty lab. The research was conducted in a period of 4 months.

In the sequence, more data will be presented, and then results are presented and discussed.

3.2.1 Objective of the Application

Many industrial machines use refrigerant oils to cool the tools being used. The quality control and oil level are done manually by the machine operator, this monitoring process for changing or refilling the oil is extremely important because if it is not done correctly it can cause serious problems, such as tool breakage. Another factor to watch for is the breakage of the bearing unexpectedly, as so far, many machines do not have a wear indicator for this part.

To demonstrate the application and assembly of a monitoring system to control the level and tone of the soluble oil and vibration of the bearings located in the gearbox of a CNC lathe machine, an Arduino model mega 2560 board and ultrasonic proximity sensors, leveling and accelerometer were purchased.

The HC-SR04 ultrasonic proximity sensor, shown in Fig. 1, will be used to control the machine's refrigerant oil level and will emit a sound wave that, upon encountering an obstacle, such as the oil level, will bounce back towards the module and as soon as these waves are dissipated in the pointed direction of the sensor, the calculation data will be generated to measure the distance between the sensor and the detected oil.

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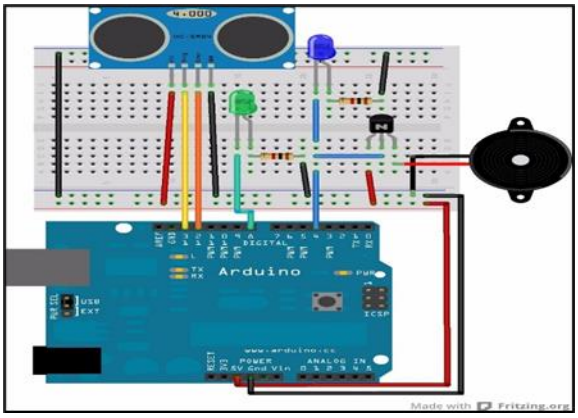

Fig. 1: Ultrasonic Distance Sensor Module HC-SR04. Source: [32].

The color sensors register the color of a surface, illustrated in Fig. 2, it can accurately detect subtle color differences. After emitting light towards the objects to be tested, these sensors calculate the chromaticity coordinates, that is, the amount of green, blue and red color that the object contains based on the reflected radiation, and compare them with chromatic reference values previously stored. If the chromatic values are within the set tolerance range, the switching output will be activated, turning on the led light according to the programmed tolerance set for each tone.

Therefore, these two sensors mentioned above aim to communicate to the operator the ideal time to change or refill the oil.

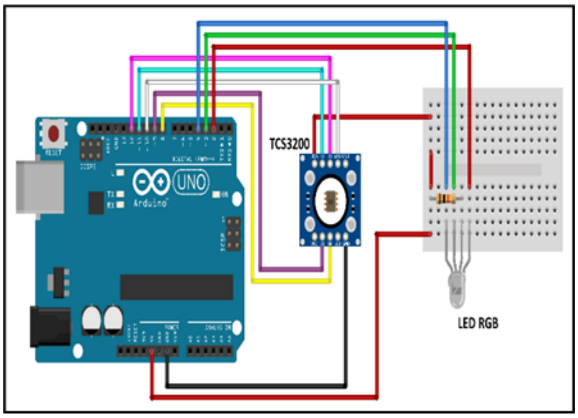

Fig. 2: Color Sensor Module RGB TCS230. Source: [32].

The accelerometer sensor, shown in Fig. 3, will be responsible for indicating the vibration index emitted by the machine's bearings, located in the gearbox, the vibration signal will be constantly captured by the sensor, the vibration being within acceptable parameters will keep the green led on, informing that the bearing It's working correctly. Otherwise, the red led will light up indicating that the vibrations are out of specifications, warning the operator that it is time to carry out predictive maintenance.

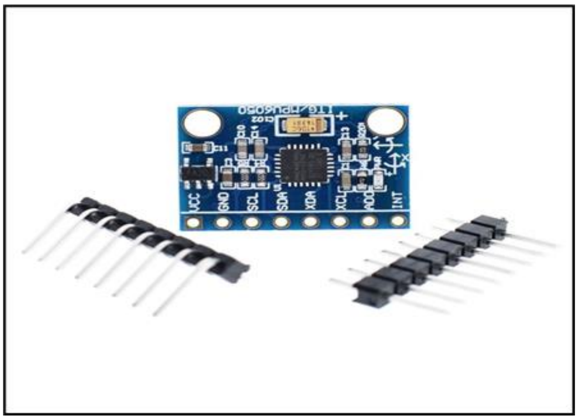

Fig. 3: Accelerometer. Source: [32].

IV. RESULTS E DISCUSSION

This sensing research was conducted to validate the application of specified sensors to support the introduction of a predictive maintenance program for a CNC lathe machine, Fig. 4. The parameters to be collected and controlled and the specified sensor was:

- Level of cooling oil: Ultrasonic distance sensor HC-SR04,
- Dusty of cooling oil: TCS230 RGB Color Sensor,
- Vibration in the transmission gearbox: Accelerometer Sensor.

Firstly, the software library was downloaded in the beginning. Compatible programming was conducted for Arduino application, and in the sequence, the three tests were conducted as the following detailed described.

Fig. 4: CNC lathe machine. Source: [33].

https://dx.doi.org/10.22161/ijaers.711.10 ISSN: 2349-6495(P) | 2456-1908(O)

4.1 Ultrasonic distance sensor HC-SR04

The first test was done with the proximity sensor, known as the US sensor. The tests were carried out with the aid of a 30 cm ruler to verify the sensor measurements. Noting that everything was in agreement, the sensor was calibrated at a distance and pointed at a container filled with liquid, thus creating three types of variables, namely: full, medium, and empty. Then 3mm Diffuse leds in green and red were used, each led was programmed to the light color, being green for the full variable, red for empty and when the sensor identified the median variable, both leds would light.

Fig. 5, 6, and 7 illustrate the results of the programming.

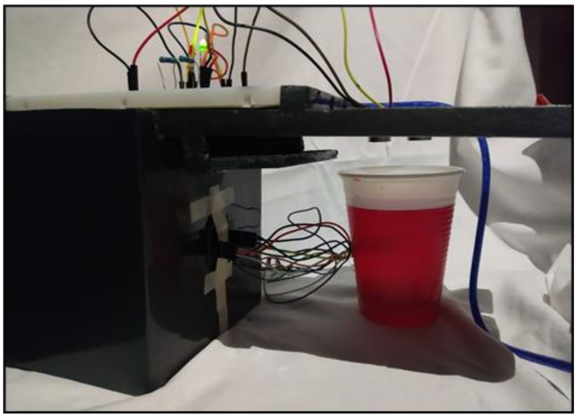

Fig. 5: Test succeded in the condition full.

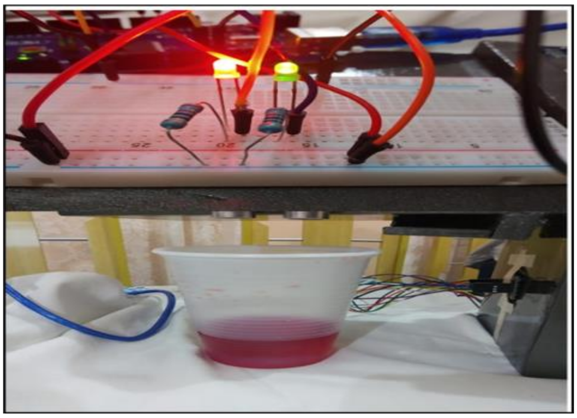

Fig. 6: Test succeded in the condition middle level.

Sources: Authors.

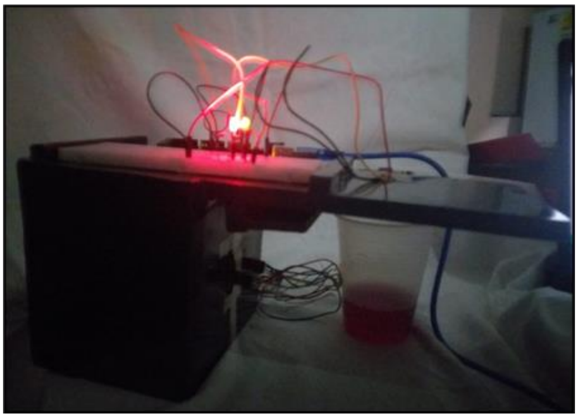

Fig.7: Test succeded in the condition empty.

4.2 TCS230 RGB Color Sensor

For the color sensor test, three containers with liquid of different shades were reserved, from the lightest to the darkest, according to Fig. 8, 9, 10, and 11 following. Initially, the color was referenced and the data was read, then we analyzed a darker color, checking the data again, thus creating the limits for reading the values obtained from the primary colors, separating into 3 variables: "good", "regular "," bad ". We use leds, where the green color means that the oil status is good, the green and red color flashing simultaneously indicate that the oil status is regular, and finally the red color indicating that the oil status is bad, according to the parameters defined in the Arduino programming. For the tests to be carried out with the containers in the same position, a wooden support was developed. This support has the function of fixing the sensor and the containers in a single position.

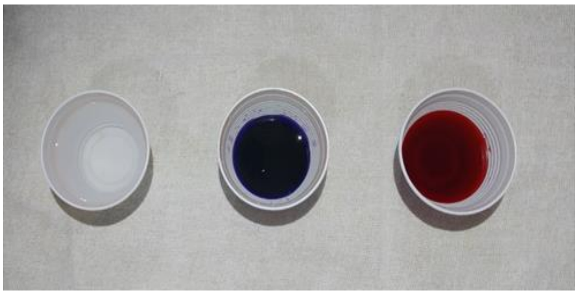

Fig.8: Test succeded for different colors sets.

Firstly, the standard colors were set, using three different patterns in a scale from lightest to darkest, this procedure was necessary to calibrate the sensors and check the response to what was programming in the Arduino.

https://dx.doi.org/10.22161/ijaers.711.10 *ISSN: 2349-6495(P) | 2456-1908(O)*

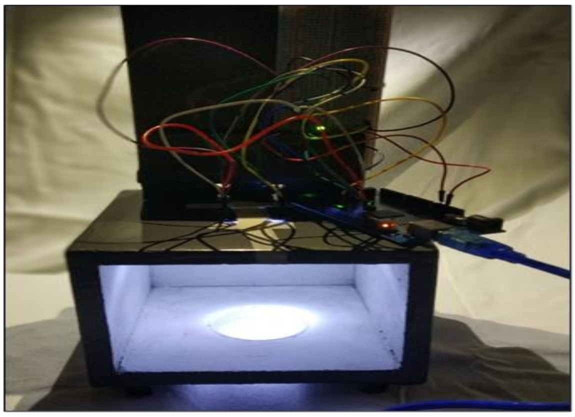

Fig.9: Test succeeded to verify the correct color set.

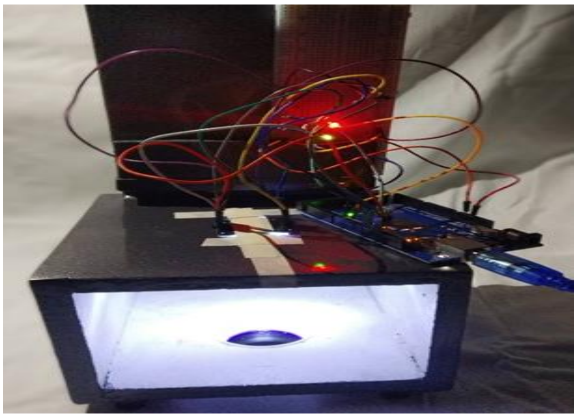

Fig.10: Test succeeded to verify the acceptable color set. Source: Authors.

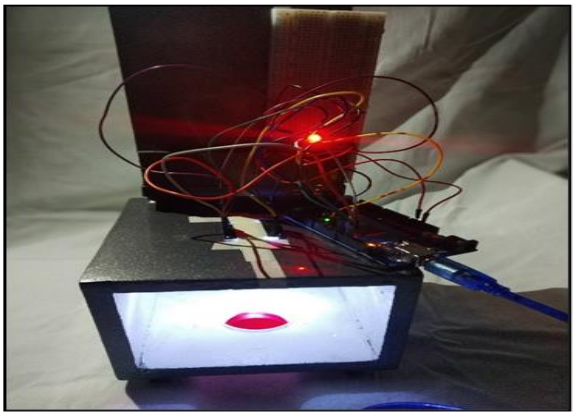

Fig.11: Test succeeded to verify the rejected color set.

4.3 Accelerometer Sensor

Two types of analysis were performed using the propellers of a fan. The first test was done with the fans on, the vibration captured by the sensor-generated data that was programmed to be considered acceptable (balanced condition) and thus, turn on the green led, indicating the balance situation, as shown in Fig. 12. For the second test, a wooden block with calibrated weight was attached to one of the fan propellers to promote a specified unbalance, to make them rotate out the balance axis. In this condition as the out-axis rotation (unbalanced condition) resulted in the vibration to be much higher than the first balanced condition, the sensor then captured these results by immediately lighting the red led, illustrated in Fig. 13.

Fig.12: Vibration signal captured in the balanced condition. Source: Authors.

Fig. 13: Vibration signal captured in the out balanced condition.

In this work, it was presented the method and the results obtained through experimental tests that sought to enable the implantation of sensors that could communicate the operator of a machine the level and quality of the emulsion cooling oil used in the process, and the vibration index of the bearings located in the gearbox, to make this operator. The experimental results demonstrated the feasibility of implanting the sensors since all tests were satisfactory. To monitor the shades in industrial oils, the programming must be done according to the manufacturer's specification, due to a possible shade variation.

https://dx.doi.org/10.22161/ijaers.711.10 *ISSN: 2349-6495(P) | 2456-1908(O)*

For the results obtained from the accelerometer, the analysis of this record allows determining changes in the operating condition of mechanical equipment, be it motors, transformers, bearings, caused by failures, or natural wear of the parts.

The use of new metrics and the collection of vibration signals on simultaneous axes will allow further investigation of the results obtained in different operating conditions with failures.

V. CONCLUSION

This work aimed to present an easy monitoring system, using the Arduino and ultrasonic proximity sensors, color recognition sensors, and accelerometer, to ascertain the need for changing or replenishing cooling oil and the vibration measurement for bearings in the gearbox, being able to identify possible failures, to prepare a CNC lathe machine for IoT implementation, as a part of a predictive maintenance program. As shown, the application of the specified sensors was successfully demonstrated.

The researchers had presented a way to introduce the data acquisition using a low-cost solution, in this case by the application of the Arduino, and specified sensors that are easily reached on the internet and that give a reasonable accuracy to prepare a CNC lathe machine to IoT application.

This research has as limitations: the number of tests conducted before sensing to be applied in the didactic CNC lathe machine, the necessity to checking the limits established for the outputs of acquired values as well as must be validated in a real application using the IoT communication interface to generate the data in the cloud, and a bigdata treatment followed by machine learning approach to the predictive maintenance implementation.

For future works, the researchers strongly recommend the implementation of this solution in different CNC machines, conduct the investigation considering the sensing full implementation, validation of the acquired data, consolidation of bigdata, and machine learning during a representative period of the machine operation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the SENAI – School of Cruzeiro for its assistance during the research period.

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