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STRUCTURAL MONITORING OF POWER TRANSMISSION TOWER BY IoT

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Abstract. *The maintenance of structures can benefit from Industry 4.0 by replacing costly preventive maintenance, in which specialists are called in based on a prior schedule, by predictive maintenance, in which a monitoring system verifies structure's condition in an automated way and specialists are called in when there are damage or potential failure signs. Connectivity problems due to limited signal coverage can be mitigated through Low Power Wide Area Network protocols. In 2008 the Electric Power Research Institute (EPRI) developed a study of promising technologies for monitoring transmission lines. Among the sensors, the use of vibration, inclination and temperature sensors were highlighted. As for data transmission, the study highlighted the use of Radio Frequency, WiFi and ZigBee. As this is an old study, it did not include more recent technologies specifically aimed at IoT technologies with low energy consumption and greater area coverage, such as LoRa and Sigfox. In this project, it is proposed to develop a monitoring system for electrical energy transmission towers based on technologies typical of Industry 4.0, namely Internet of Things (IoT).*

Keywords: *IoT, SHM, Artificial Intelligence, SmartGrid*

1. INTRODUCTION

The Brazilian Agency for Industrial Development (ABDI) estimated that the implementation of Industry 4.0 in Brazil could result in annual savings of BRL 35 billion in repairs, BRL 31 billion in production efficiency and BRL 7 billion in energy savings, totaling savings of R\$ 73 billion per year. Due to the impact that this innovation can bring, the Ministry of Industry, Commerce and Services (MDIC), together with ABDI, launched the Brazilian Agenda for Industry 4.0 in order to prepare the country to embrace this trend and not lose the potential economic benefits it brings.

The use of electrical energy is indispensable. Transmission towers account for most of the electricity distribution in the world, still operate practically the same way as when they were built, with the increase in demand for energy, the electrical grid also faces challenges such as reliability and safety (Dileep, 2020; Saleem et al., 2017).

These structures are constantly subjected to efforts and environmental factors that vary constantly, such as temperature changes, strong winds, humidity, rain and snow (Figueiredo and Brownjohn, 2022), several towers collapse due to these weather conditions, since they are sensitive structures (Cheng et al., 2018). As an alternative, the Smart Grid (SG) appears, using new communication and information technologies for monitoring, analyzing and controlling

the network of the traditional electric power system. Some of the benefits of this implementation are improvements in energy efficiency and an increase in its useful life (Dileep, 2020; Saleem et al., 2017).

Together with the Smart Grid, monitoring the structural health is necessary, as these are critical structures. Thus, Structural Health Monitoring (SHM) emerges, an extremely important tool for non-destructive measurement of various parameters in order to monitor in real time the operating condition of structures or systems, such as buildings, bridges, towers, etc. (Dileep, 2020; Goyal, 2016). This technique has been performed in two models, the model-based, which relies mainly on the use of numerical methods, usually the finite element method (FE), the most used method for creating complex computational engineering models, and the data-driven, which relies on the collection of information through sensors so that later there is processing and analysis of this data (Figueiredo et al., 2019; Giagopoulos et al., 2019). Lately, the most modern SHM systems have been adopting a mixture of the two monitoring models.

This technique is advantageous in relation to traditional inspection methods, which makes it an ideal tool for maintenance activities, since it is possible to dispense with more traditional methods and visual inspections, which are susceptible to interpretation errors by the operator (Muttillio et al., 2020; Treacy et al., 2020). Possible parameters to be used in SHM techniques are corrosion, cracking, displacement, fatigue, force, deformation, temperature, inclination, vibration, water level and wind (Sonbul, 2023).

One of the challenges for monitoring is connectivity, automation and keeping track of the large number of devices (Saleem et al., 2017). For this, the emergence of industry 4.0, which includes several easily accessible communication technologies, such as Radio Frequency Identification (RFID) and Internet of Things (IoT) (Lu, 2017), which, in addition to the use of microcontrollers and sensors, has made long range monitoring methods more accessible, which are extremely useful to guarantee the integrity of these structures.

2. TRANSMISSION TOWER

Due to its flexibility the single mast guyed towers are widely used in power grids. We propose a construction and instrumentation of a tower in a 1/10 scale, made by common materials like aluminum, easily found.

The manufacture of the tower is being carried out by scientific initiation students linked to the FAPITEC research project, using 6060 T5 aluminum materials in the form of an angle bracket L-1" E-1/8", profile T L-1" A-1 "E-1/8", bars L-1/2", E-1/8", parts in impressions in additive manufacturing, in polylactic acid material (PLA), steel cables of 1/8" in diameter and unions riveted with AD-440-S rivet, as shown in Figure 1.

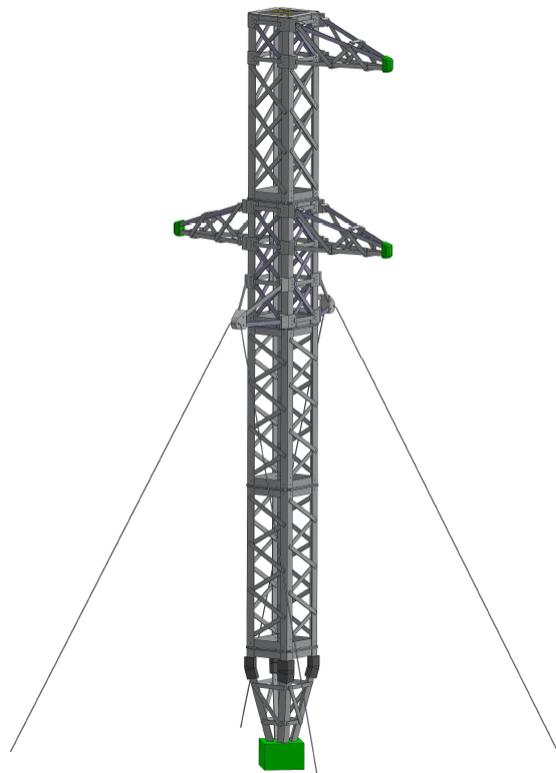


Figure 1. Single mast transmission tower in 1/10 scale. Source: Author

3. IoT PROTOCOLS

The use of IoT grows rapidly in the scenario of industry 4.0, it allows conventional sensors to perform interconnections and communicate with other devices over the internet and it is expected to cover even larger areas (Sundaram et al. 2019; Svendsen et al., 2022). One of its applications is to employ objects with the ability to detect variables such as pressure, temperature, acceleration and humidity, and communicate with other devices and guide decisions (Al-Fuqaha et al., 2015).

Due to its popularity, problems related to the possible distance at which it is possible to carry out communication between sensors and gateways, and how to transmit this data, taking into account costs and operating conditions are in evidence (Svendsen et al., 2022). Thus several communication protocols arise, which require a study about the advantages and disadvantages of each one. Kam et al (2019) divided the communication protocols into two types, the short distance ones, such as WiFi, Bluetooth, RFID, ZigBee, etc. And the long distance ones, the Low-Power Wide-Area Network (LPWAN) protocols (Kam et al., 2019), that appear as an alternative to the conventional methods, mentioned above, which cover small areas and are of low energy efficiency, among them, Sigfox, NB-IoT and LoRa, in which the last two are the most used emerging technologies (Sinha et al., 2017; Sundaram et al., 2019). The latter type of technology is capable of covering areas of dozens of kilometers, in addition to consuming little energy, which makes it an ideal technology for the use of SHM, especially when the structure to be monitored is far from urban centers.

Among the LPWAN protocols, due to its ease of use, such as easy implementation and low maintenance cost, Jouhari et al. (2022) suggests the use of LoRaWAN to ensure connectivity of massive IoT networks. The use of Sigfox is not recommended because the services are offered to few countries, only 45 when the article was published (Jouhari et al., 2022).

Sundaram et al. (2019) points out that the LoRa network has gained attention from academia and industry, since it is possible to build autonomous LPWAN networks (Sundaram et al., 2019 Verma (2019) states that LoRa is the most suitable communication protocol for smart buildings (Verma et al., 2019). In addition, other factors such as low complexity, long lifetime, concurrent connection capability with gateways, and standardization are reasons why the LoRa network is widely used in cases of monitoring and automation (Sinha et al., 2017; Sundaram et al., 2019; Verma et al., 2019) and, consequently, adopted in this work.

The author (Lee H et al., 2022) reports experiments in which LoRa devices can transmit data over a distance of 15 km in open areas. However, these devices still cannot communicate with a nearby gateway via a wireless connection, mainly due to obstacles between the sensors, which can attenuate the wireless signal strength and result in data loss and communication errors (Svendsen et al., 2022). To solve this connectivity problem, we propose a use of a SD card to register the data besides the IoT protocol.

4. MATERIALS AND METHODS

The data collected by the monitoring system is recorded in a completely automated way and sent by the monitoring system. An instrumented monitoring module will be installed in each tower with sensors, such as accelerometers, gyroscopes, temperature sensors (Model MPU 6050), extensometers (350 Ω with Hx711 amplifier) and pressure sensors (BMP280). The data acquisition system consists of an Heltec LoRa 32, which contains a ESP32 microprocessor with a LoRa node chip SX1276 and Onboard 0.96-inch 128*64 dot matrix OLED display, development board connected to a that will perform the routine reading of these sensors, acquiring vibration, temperature, deformation, pressure, etc. data, which will then be communicated from the tower via protocol LoRa to a receiving substation, the dual-channel Dragino gateway. The data collected by the Heltec LoRa 32, which acts as an end-device, sends LoRa modulated messages to the gateway. The latter one is responsible for receiving these messages and forwarding them to a network server, (The Things Network, 2023) The Things Network server is the chosen one for this project. The figure 3 and 4 shows intuitively how it works

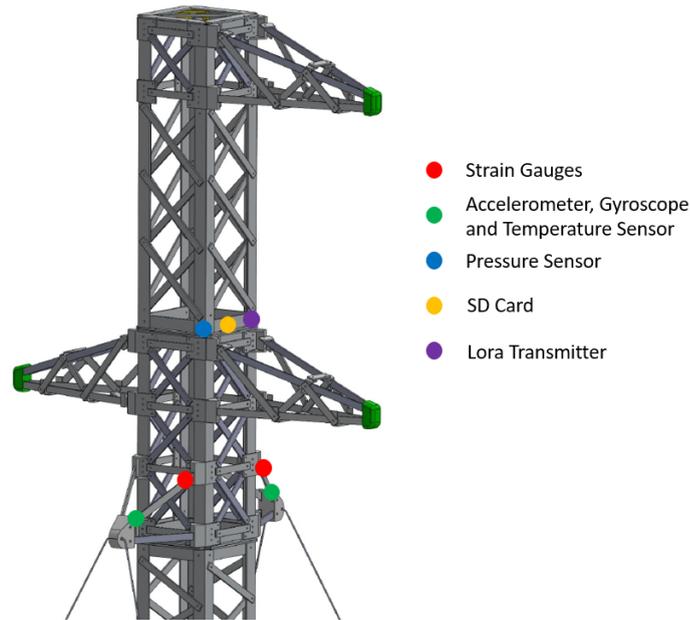


Figure 2. Tower Instrumentation. Source: Author

A photovoltaic panel will be present in each circuit, in order to allow the operation of the monitoring system even in case of a temporary power outage. In addition, the architecture of the communication network must be fault tolerant, so that the communication system continues to function even after the destruction of one of the modules due to, for example, a tower fall, with data being stored on a SD memory card.

To measure the tower's deformation and stress, we used strain gauges sensors, widely used in engineering applications. They are easy to install, have low cost and maintenance frequency. It also can be used in various environmental conditions. Also, the use of an accelerometer is critical to monitoring, since the vibration is one of the most important parameters to measure in a structure. Once damaged, the structures' physical properties will cause changes in modal properties, such as natural frequencies and mode shapes (Sung, S. et al. 2013). The MPU-6050 is an accelerometer and gyroscope used in this SHM system, the gyroscope is responsible for the measurement of inclination in all the three axes. It is very useful when combined with the accelerometer. To predict rains and storms, a barometer and temperature sensor BMP-280 was also used, since the atmospheric pressure drops just before it occurs. The sensors were placed as the schematic shows down below.

The BMP-280 and MPU-6050 sensors are connected to the Heltec LoRa 32, via I2C protocol. The strain gauges are disposed as a Wheatstone bridge, i.e, each resistor actually is the way the strain gauges are used. Due to the extensometers' weak signals output, each node is connected to an HX711 amplifier to generate more understandable data. To prevent LoRa connectivity problems, the SD is used to store information over time.

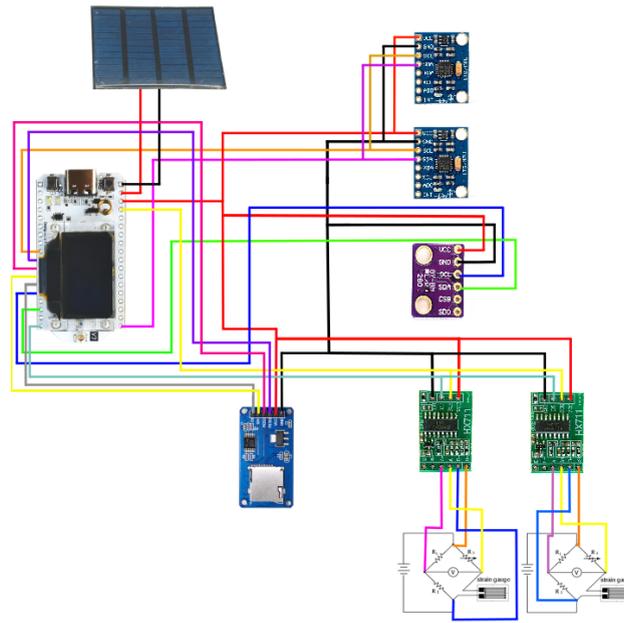


Figure 3. Heltec LoRa 32 pinout. Source: Author

Once working, the data collected by the Heltec LoRa 32, which acts as an end-device, sends LoRa modulated messages to the gateway. The latter one is responsible for receiving these messages and forwarding them to a network server, (The Things Network, 2023) The Things Network server is the chosen one for this project. The figure below shows intuitively how it works.



Figure 4. IoT communication architecture. Source: Author

5. RESULTS

The construction of the scale tower that will be instrumented is still in progress, however, a part of the proposed monitoring system was tested and validated. Some data was obtained but some sensors like the barometer needed to be configured and calibrated, as shown in figure 4 below.

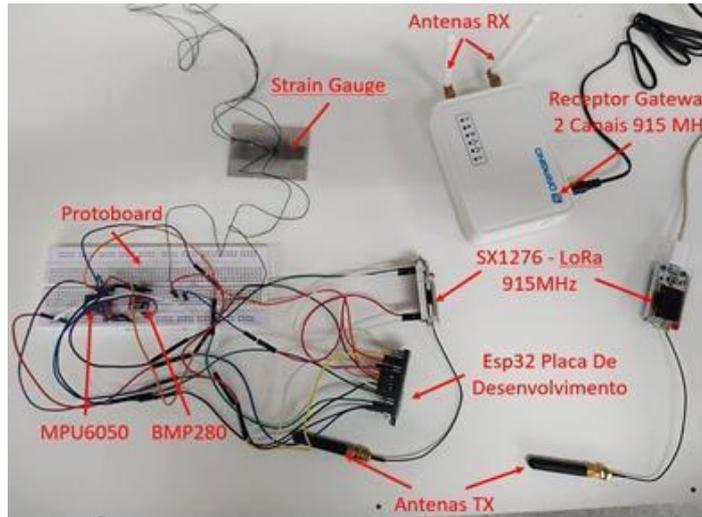


Figure 5. Laboratory Test Rig. Source: Author

Tests were performed in the laboratory with the MPU6050 for 10 seconds at a rate of one sample per second. From the sixth second, a sudden horizontal movement was performed on the sensor to verify the acceleration, thus a maximum acceleration decrease of -10 m/s^2 is observed on the Y axis. It is also observed in the curve in green, representing the Z axis, that the acceleration of gravity was successfully measured, as well as the curves in blue and red showed an acceleration when they are stopped, this can be explained because the MPU6050 sensor is not fully aligned with the direction of gravity, as can be seen in figure 5 .

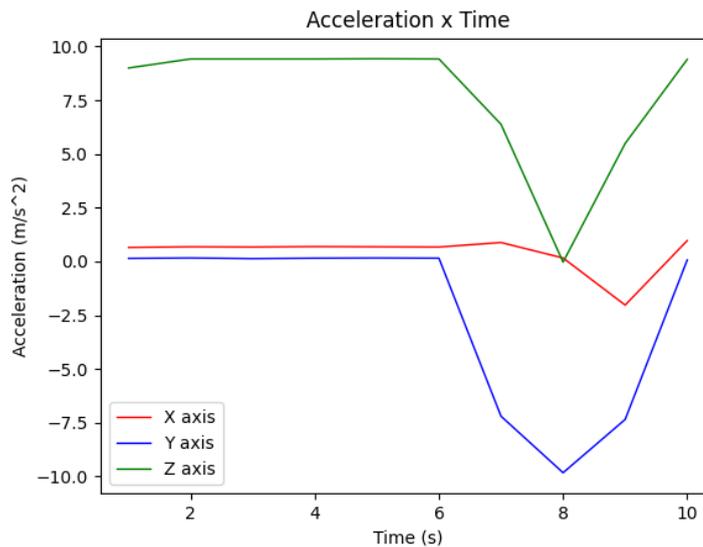


Figure 6. Accelerometer test. Source: Author

The response of the gyroscope can be seen in figure 6, where it is possible to notice that there was a rotation with greater angular velocity in the Y axis, represented by the curve in blue, followed by the X axis and with less intensity in the Z axis, given that the movement of the gyroscope breadboard was horizontal.

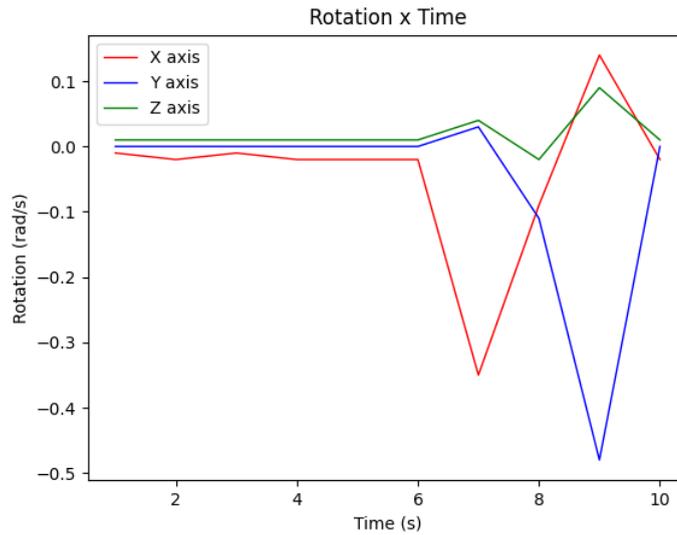


Figure 7. Gyroscope test. Source: Author

In figure 7, we can see that the BMP280 sensor presented pressure above atmospheric pressure at sea level, as the test was carried out at São Cristóvão - SE, next to the coastal city of Aracaju, it is necessary to calibrate the pressure sensor, however, a small deviation is observed between the measured results.

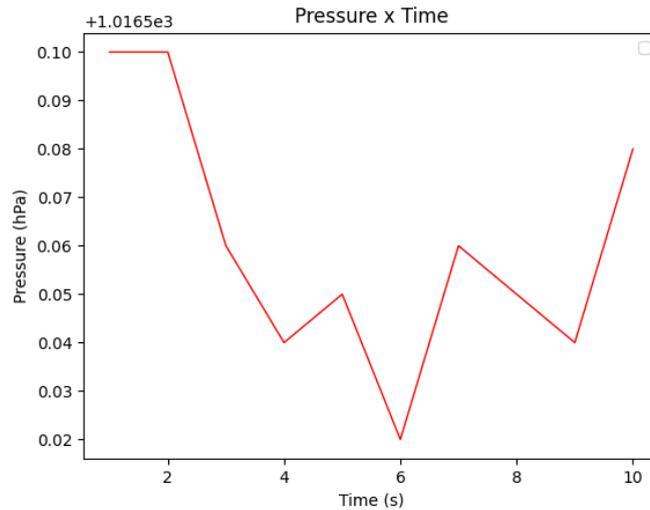


Figure 8. Barometer test. Source: Author

Figure 8 shows the results of the temperature sensor, MPU6050, it is possible to notice a variation of $24^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$, which was the ambient temperature during the laboratory tests.

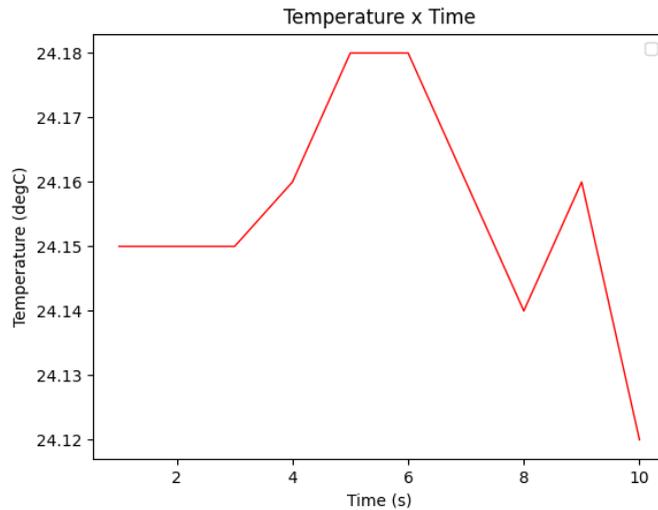


Figure 9. Temperature monitoring. Source: Author

6. CONCLUSION

Although the proposed system is still unfinished, it shows promising results, since the sensors are working. The tower is being built and IoT tests are in progress as well. We pretend to send the collected data through a LoRaWAN network. Thus, in the final version of the article the transmissions of all measured parameters instrumented in the transmission tower with strength tests will be performed to validate the measurements.

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