Sensor Network for Structural Health Monitoring: Online Monitoring of Transmission Line Towers

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***Abstract*—Structural health monitoring has become a very important technology in civil engineering and is highly dependent on advances in instrumentation, communications and microelectronics. This paper presents results of an ongoing project aiming at the development of a system for structural health monitoring. More specifically, the goal is to monitor transmission line towers, with the main objective of capturing vibrations on the tower and a secondary goal of monitoring deformation, temperature and wind speed and direction. The mentioned physical quantities are obtained by means of a sensor network, controlled by a module responsible for the synchronizing the measurements and sending to a data processing station located at a remote spot. The adopted physical layer is the Ethernet with a protocol that ensures better reliability with respect to the information flow. The measured data is sent to a remote computer through sockets and analyzed by a Java software. This work discusses the developed embedded system and the project achievements.**

1. Introduction

Structural health monitoring (SHM) [1] is a field that aims to detect damage in a given structure. The damage that these methods detect ranges from the development of fatigue cracks to the degradation of structural connections and bearing wear. This study explores a method known as deformation and vibration-based structural health monitoring [2]. This method has been shown to be able to not only detect damage presence in the structure but also to indicate the vicinity of the damage. Deformation and vibration-based SHM attempts to detect damage in its initial stage by analyzing the deformations and acceleration responses of several points in a system to a known or unknown excitation. Here, the technology is applied to the transmission lines that transport electric power.

The maintenance of transmission line towers is one of the major problems faced by the concessionaires of electric energy, especially the towers that already show signs of aging due to the long period of operation.

A purpose of the towers maintenance is to provide security, being the action caused by the wind one of the principal factors that is considered in the security analysis of transmission line towers.

In Brazil, most towers are not monitored through vibration analysis. This work aims to make possible the implementation of a program for on-line monitoring of high-rise towers with indications of excessive vibration, to predict eminent structural failures and destruction of structural elements. Besides the vibration, it is also of interest to measure the deformation, temperature, wind speed and its direction, providing a more complete analysis of the factors that affect the towers structure.

The first author has developed most of this work while he was an undergraduate student at UFPA, where he is now starting his Master's course.

This paper is organized as follows: Section 2 shows a system overview. Subsequently, the Section 3 shows the sensors used and the Section 4 commented on the conditioning and conversion of signals. Next, in the Section 5 is shown how to the flow of information on the bus is organized. Section 6 refers to the cost and transmission of data and Section 7 presents the conclusions.

2. System Overview

This work presents an on-line monitoring system for transmission line towers, in which it is installed a network of sensors [3] over the tower for acquisition of physical quantities under study. Five types of sensors are used for measuring: acceleration, deformation, temperature, and speed wind direction. The sensors are grouped into predefined locations and are connected to a module that consists of signal conditioning circuits, analog to digital (A/D) converter and a microcontroller. For a tower, three modules are used and positioned at different locations of the tower. These modules are interconnected by a two-wire bus, used by the CAN (Controller Area Network) protocol [4]. The information flow is directed to another module, called master node, responsible for managing the data and transmitting to an Ethernet network. Fig. 1 shows the diagram of the proposed system.

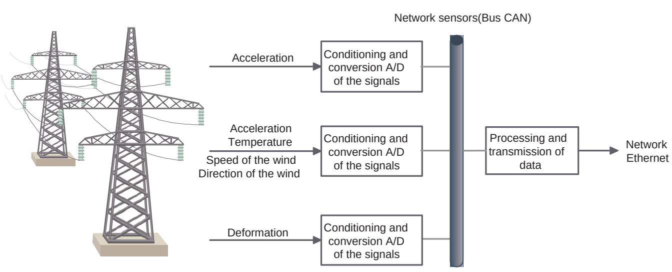

Fig. 1. Diagram of the overall system.

Sections 3-6 describe the elements that compose the monitoring system.

3. SENSORS

As mentioned, the used sensors are acceleration sensors, deformation, temperature, wind speed and direction (anemometer). The positioning of sensors on the tower and their sampling rates are:

- Two accelerometers [5] in the central tower with 20 samples per second (SPS).
- Three accelerometers in the highest part of the tower with 20 SPS.
- Four extensometers at the base of the tower with 20 SPS.
- One thermometer with a sample per minute (SPM).
- One anemometer with a SPM.

The following subsections briefly discuss each sensor.

3.1. Acceleration Sensor:

The acceleration is measured at specific points of the tower using Wilcoxon accelerometers, model 793L. Each accelerometer has output of 500 mV/g and is excited by a current source (2-10 mA) and voltage of $(18 - 30)V$.

Accelerometers to detect possible rotations of the tower, will be directed as in Fig 2:

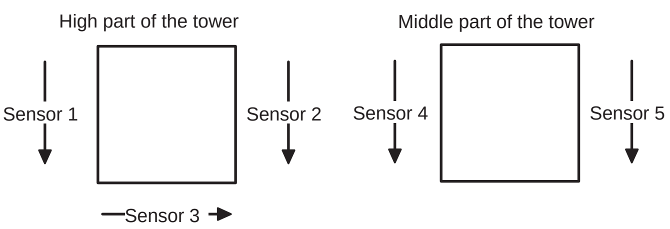

Fig. 2. Positioning of the accelerometers in the tower

3.2. Deformation Sensor:

The deformation at predefined points of the tower is measured with the extensometer. The extensometer has sensor output as a variable resistance to $120\ \Omega$, with deformation of the order of 0.0001 m/m. The compression of the tower is detected by increased resistance, while the dilatation is detected by the decrease in resistance.

3.3. Temperature Sensor:

To monitor the temperature of the tower used the temperature sensor National Semiconductor, model LM35DZ/NOPB. The LM35 sensor is highly accurate and has output 10 mV/°C, its total range of temperature range varies from -55° C to +150 °C.

3.4. Sensor speed and wind direction:

To monitor the speed and wind direction, it was used a Wind Sensor anemometer, model 034b. The speed sensor generates two pulses on its output at each cycle completed by the windmill. The speed is estimated by the software using the equation $V = 0.799f + 0.29$, where f is the frequency of the pulses. The wind direction is represented by a potentiometer to 10 kΩ and the sensor resistance varies according to the positioning of the reed. The position-angle is obtained by software using the equation: $p = V \times 0.142$, where V is the voltage provided by conditioning circuit.

4. CONDITIONING AND CONVERSION OF THE SIGNALS

Analog signals from the sensors must be conditioned and digitized [6]. The conditioning occurs in the characteristics of the output signals from sensors and voltage levels at the input of the used A/D converter. For example, the conditioning circuit of an accelerometer is designed according to the characteristics of excitation. In addition, the output signal is conditioned to allow observing acceleration in two directions, using a voltage reference in one channel of the A / D converter, whose value is half of the range from the sensor signal conditioning, which is connected to another input in the same channel converter, as shown in the circuit of Fig. 3.

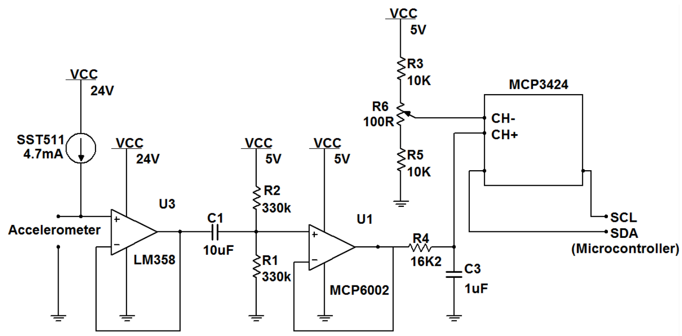

Fig. 3. Conditioning circuit for an accelerometer.

The conditioning of signals from deformation gauges [7] is done by applying a voltage gain of in the output signal, allowing monitoring in both directions (compression or dilation) [8]. For the thermometer and wind direction sensor, a circuit was made that provides a voltage gain and for the speed sensor, a circuit a pull-up resistor limits the current in the sensor.

For the accelerometers in particular, it is desired a resolution of approximately 0.0001 g, with maximum frequency of 10 Hz. Then, to properly perform the A/D conversion, 14 bits per sample are needed. Due to this necessity, it was used the A/D converter MCP3424 from Microchip, which has 14-bit conversion with a conversion rate of 60 SPS. This A/D converter is capable of meeting the requirements of resolution and sampling system, including the requirements of the sensors of deformation, temperature and wind direction. The data converted by the MCP3424 are sent to the microcontroller through an I2C interface.

The signal conditioning for deformation gauges is designed to allow for a voltage gain of [8] in the output signal and to allow monitoring in both directions (compression or dilation), by a reference voltage, similar as in the circuit for the accelerometer.

5. Networking Sensors (Protocol CAN)

The CAN protocol used by the system interconnects conditioning circuits and centralizes information from the sensors. This protocol has a bus with high speed data transmission (up to 1 Mbps), with an error control that avoids the loss of information. The nodes of the system are shown in Fig. 4.

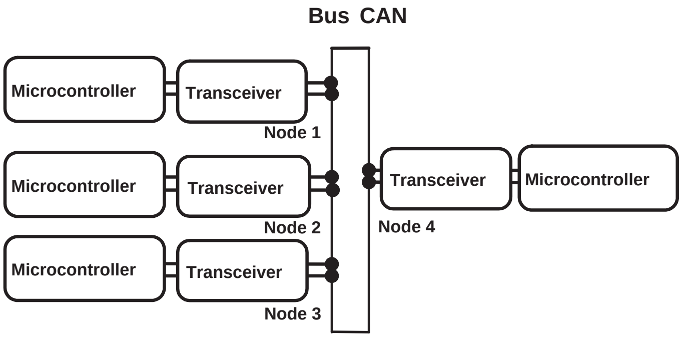

Fig. 4. Diagram of the CAN bus.

Each signal is digitized after being released on a node from the CAN bus by a microcontroller, which requests the data converted by A/D converter and feeds the CAN bus. In another bus node, called master node, there is another microcontroller, and this will get all the data converted, will manage the information and make the transfer via a RS232 serial interface for the module with interface to the internet (see Section 6). It was used a MCP2551 transceiver, which is necessary for communication on the CAN bus.

Firmwares are obviously required in each microcontroller according to the same function on the bus for the implementation of protocol CAN. Fig. 5 depicts the flowchart of the firmware of the master and slave nodes.

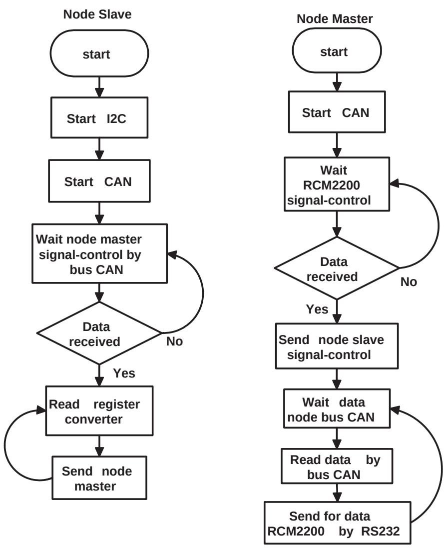

Fig. 5. Firmware of the microcontrollers nodes.

6. Transmission of data

This module sends the information from the sensors to a computer network located in a remote spot. It was necessary to mount a wireless infrastructure (wireless) ethernet network enabling the transmission module remotely access the computer network of the UFPA.

For transmission via Ethernet it was used the RCM2200. This chip is scheduled to convert the data from the RS232 interface to the communication protocol used by Ethernet. This way the system is able to send the information to any Internet-connected computer using an access point. For the access point (AP) it was chosen a wireless equipment that was available.

The information provided by this module is directed to a specific computer on a network.This computer will receive and store the information by a socket interface made in the Java language [9]. This way the information is available for the necessary analysis. Transmission occurs as shown in Fig. 6.

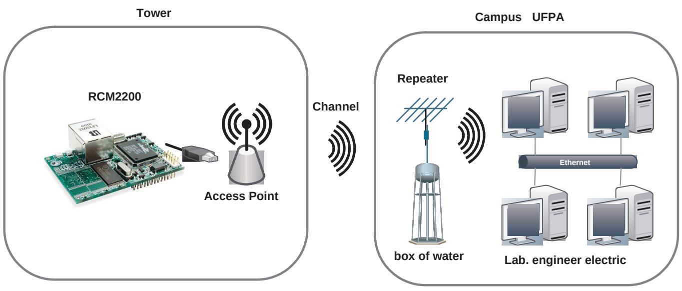

Fig. 6. Diagram of the data transmission system.

7. Conclusions

This work described an embedded system developed for SHM. The monitoring system is used in transmission line towers. It uses several conditioning circuits to provide a proper resolution of the signals at the sensors' inputs and takes into account the climatic characteristics of the region. The adoption of the CAN protocol ensures high speed data transmission with error performance guarantees, allowing management of information appropriate for the situation. In summary, the developed circuits led to a reliable system, which has been generating consistent results.

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