NEW LOW-COST SENSOR FOR TIMBER STRUCTURAL HEALTH MONITORING

Juan J. VILLACORTA[1], Gamaliel LOPEZ[2], Roberto D. MARTINEZ[2], Antolín LORENZANA[3], Alberto IZQUIERDO[1], José-Antonio BALMORI[2], Lara DEL VAL[1], Álvaro MAGDALENO[3], Luis ACUÑA[2], Milagros CASADO[2], Luis-Alfonso BASTERRA[2]

[1] Signal Theory and Communications Department, University of Valladolid Campus Miguel Delibes, 47011 Valladolid, Spain (larval, juavil, alberto.izquierdo)@tel.uva.es

[2] Research Group of Timber Structures and Wood Technology, University of Valladolid Avenida de Salamanca, 18, 47014 Valladolid, Spain (robertomartinez, balmori, basterra)@arq.uva.es

[3] ITAP. Universidad de Valladolid Paseo del Cauce, 59, 47011 Valladolid, Spain alvaro.magdaleno@uva.es, ali@eii.uva.es

ABSTRACT

This paper presents the design of a new device to be implemented in Structural Health Monitoring for timber structures. This device is of small dimensions and uses MEMS sensors, which simultaneously acquire acceleration data in three axes, temperature, environmental relative humidity and moisture content of the wood.

Moisture is an agent that in excess deteriorates structures of any material very quickly, especially timber structures. This new device makes possible not only read the moisture content in real time, but also to correct the acceleration readings as it records, a parameter influenced by moisture content, mainly in timber elements.

These devices are inexpensive, unlike analog accelerometers, and allows to increase the number of monitoring units. The presence of more reading points facilitates the early detection of pathologies, as well as obtaining more accurate FRFs.

This device can also be used for structural wood grading and is part of a mayor monitoring system developed by this research team.

The paper discusses the design of the sensor device, detailing both the electronic components that compose it and the structural design of the casing and the external connector. Various scenarios of used sensor are also shown depending on the placement on the timber structure to be measured, ensuring the correct reading of moisture content.

KEYWORDS: MEM, Structural Health Monitoring, Timber, Moisture, Acceleration

INTRODUCTION

The diagnosis, restoration and conservation of architectural heritage structures require a thorough knowledge of the characteristics of the structure and the materials they are made of, as well as their response throughout their span life. The number of old exiting buildings and civil structures (i.e., resident buildings, hospitals, bridges, . . .) that need an adequate control and maintenance to guarantee their structural operation and safety is currently huge [1].

The evolution of these properties over time can be helpful to assess the actual state of a structure and locate the potential damage it may suffer [2,3]. In addition, monitoring the ambient properties like temperature or humidity can be of great importance in order to correlate the estimated properties with them and separate the deviations due to atmospheric phenomena from true damage [1].

In the case of wooden structures, as a hygroscopic material, wood can adsorb or desorb water in response to temperature and relative humidity of the atmosphere surrounding it. This affinity of wood for water is caused by hydroxyl groups accessible in the cell walls of wood. Consequently, the moisture content of wood is one of the most important variables affecting its physical and mechanical properties [4]. As an example, below fiber saturation point (FSP) the first natural mode of vibration of wood increases and dumping decreases with the loss in moisture content of wood [5]. The speed of sound and de young´s modulus decrease with increasing temperature and moisture content [6]. For these reasons it is essential to know the moisture content of the monitored structural timber components.

However, for these techniques to be truly effective, the sensors need to be permanently installed on the structure, continuously recording the structural response, transferring the recorded data to a remote server, and providing trustfully information about its current state [7-10].

Unfortunately, currently, this is a hard challenge that commercial structural health monitoring (SHM) systems are not fully prepared to undertake. There are many monitoring systems intended to identify the structural properties, some permit to incorporate ambient properties measurement, but few are conceived to work continuously. Finally, none of the commercially available SHM systems satisfy another important restraint: its cost [1].

This contribution presents the design of a prototype measurement sensor using an array of distributed MEMS sensors for the analysis of the vibration modes of a timber structure corrected for its moisture content.

SENSOR AND ACQUISITION SYSTEM

For the analysis of vibration modes, a low-cost data acquisition system has been designed with the - Use of digital MEMS sensors, integrating the analog sensor, the digital converter and the communication interface (Figure 1).

- Use of digital MEMS sensors, integrating the analog sensor, the digital converter and the communication interface.

- Multisensor, allowing the control and reading of up to 6 accelerometers simultaneously.

- Two analog input channels, valid for simultaneous acquisition of data from analog accelerometers or load cells.

- Two analog output channels, for the generation of excitation signals with the possibility of choosing different operating modes, single frequency sine tone, band-limited white noise, pink noise, etc.

- Stand-alone control system, with wireless connection via WIFI between the acquisition system and the computer where the captured data will be stored.

- Automatic power saving mode when the system is no longer in use.

The accelerometer chosen to implement the acquisition system is the Analog Devices model ADXL355. It is a low-power triaxial accelerometer, with a 20-bit digital output and a configurable dynamic range between ±2g and ±8g, which provides a sensitivity of up to 3.9 µg/bit. It allows the use of SPI and I2C interfaces for data reading at a maximum rate of 4000 Hz. In the case of the chosen Humidity and Temperature Sensor was Sensirion model SHT35, fully calibrated, linearized, and temperature compensated 16-bit digital output, with a typical accuracy of ± 1.5 % RH and ± 0.1 °C

Both sensors are incorporated on a 12 x 17 mm circuit board with a mini HDMI connector. This board is encapsulated in a 14x22x9mm plastic housing with different configurations depending on the type and material of the element to be monitored, as well as the duration of the monitoring.

The myRIO platform has been selected to read and control the sensors. It is an embedded hardware, developed by National Instruments and based on the Zynq 7010 chip from Xilinx, which integrates an ARM Cortex A9 dual Core processor and an FPGA. It has 40 digital I/O lines, 2 input channels and 2 analog output channels. The myRIO platform runs a real-time OS (Operating System) that allows the execution of programs created with the LabVIEW graphical language. The communication between the accelerometers and the myRIO is done through digital lines. The SPI protocol has been implemented in the FPGA to access the acceleration data of each sensor and the control program. The ARM processor is in charge of reading the data from all the connected accelerometers and sending them to the central system through the WIFI connection [11].

For the physical interconnection between the sensors and myRIO's digital connectors, mini HDMI connectors have been chosen. The interference protection of this type of wiring allows a greater distance between the sensor and the control system, with cables of up to 10 m having been successfully used.

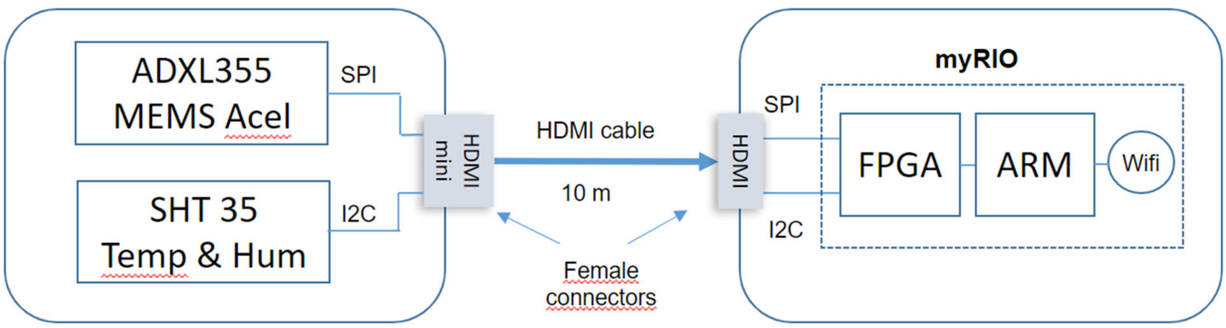

Figure 1: Proposed system architecture.

As for the way to fix the sensors to the structure to be analyzed, different external casings have been designed to adapt the circuit to different measurement scenarios (Figure 2).

A. Rectangular prismatic box to be attached to the surface to be monitored. Preferably for use in long-term monitoring where the sensor is left installed for periods longer than one year. To check the annual cyclic behavior of a structure.
B. Rectangular prismatic box with holes for screws or magnets. This design allows the installation and removal of the sensor. For wooden or masonry elements it is fixed with screws and for metallic elements neodymium magnets are placed in the holes.
C. Casing with cylindrical design, which allows it to be inserted inside the wood elements and to monitor both their dynamic behavior and their moisture content. The hole to house the sensor is drilled through a borehole. This must be at least 5 mm deeper than the length of the sensor, creating a chamber where it is possible to monitor the temperature and relative humidity of the indoor air, which is in hygroscopic equilibrium with the moisture content of the wood. This type of design is intended for constant monitoring of wooden structures.

Finally, thanks to advances in 3D printing, it is possible to design and manufacture the outer casing ad hoc for almost any monitoring scenario.

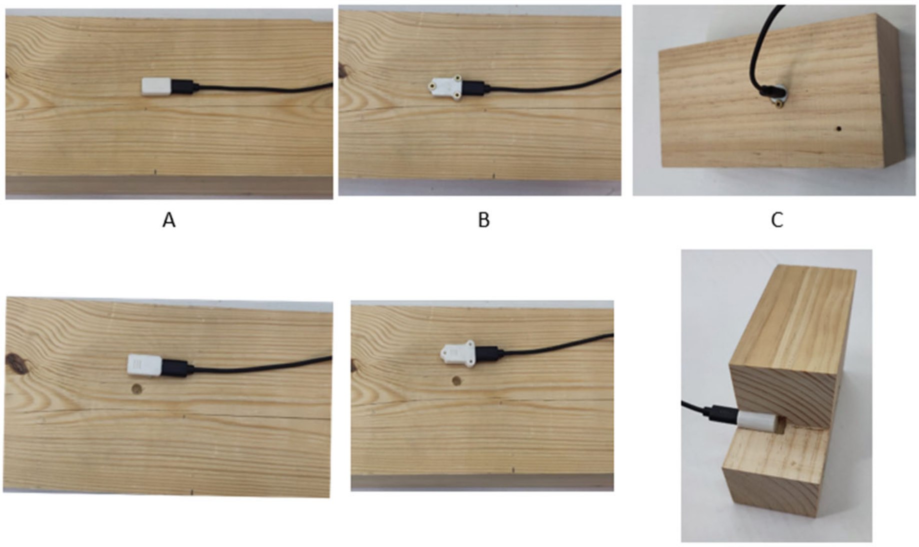

Figure 2: Different external sensor casing. A: Rectangular prismatic; B: Rectangular prismatic with holes for screws and C: Cylindrical. Top figures: installation; Bottom figures: Detail of the internal air chamber.

CONCLUSIONS

A small, versatile, and inexpensive sensor has been developed to enable Structural Health Monitoring for timber structures. This sensor can detect increases in moisture content in structural elements for any reason, as well as read the environmental data, so acceleration readings can be corrected as it records, a parameter heavily influenced by moisture content.

Funding:
This research was funded by the Junta de Castilla y León, co-financed by the European Union through the European Regional Development Fund (ref. VA228P20).

REFERENCES

[1] Magdaleno, A.; Villacorta, J.J.; del-Val, L.; Izquierdo, A.; Lorenzana, A. Measurement of Acceleration Response Functions with Scalable Low-Cost Devices. An Application to the Experimental Modal Analysis. Sensors 2021, 21, 6637. https://doi.org/10.3390/s21196637

[2] Farrar, C.R.; Doebling, S.W.; Nix, D.A. Vibration–based structural damage identification. Philos. Trans. R. Soc. A: Math. Phys. Eng. Sci. 2001, 359, 131–149.

[3] Mahammad, A.H.; Kamrul, H.; Ker, P.J. A review on sensors and systems in structural health monitoring: Current issues and challenges. Smart Struct. Syst. 2018, 2, 509–525.

[4] Hartley I., and Hamza M.F., Wood: Moisture Content, Hygroscopicity, and Sorption. In: Saleem Hashmi (editor-inchief), Reference Module in Materials Science and Materials Engineering. Oxford: Elsevier; 2016. pp. 1-7

[5] Jianget al.(2012). "Wood properties &moisture sorption,"BioResources7(3), 3585-3596.
Yang, H., Yu, L., & Wang, L. (2015). Effect of moisture content on the ultrasonic acoustic properties of wood. Journal of forestry research, 26(3), 753-757.

[6] James, W. L. (1961). Internal friction and speed of sound in Douglas-fir. For Prod J, 11, 383-390.

[7] Ye, X.W.; Jin, T.; Yun, C.B. A review on deep learning-based structural health monitoring of civil infrastructures. Smart Struct. Syst. 2019, 24, 567–585.

[8] Farrar, C.;Worden, K. An introduction to structural health monitoring. Philos. Trans. R. Soc. A: Math. Phys. Eng. Sci. 2006, 365, 303–315.

[9] Matos, J.C.E.; García, O.; Henriques, A.A.; Casas, J.R.; Vehí, J. Health Monitoring System (HMS) for structural assessment. Smart Struct. Syst. 2009, 5, 223–240.

[10] Soria, J.M.; Diaz, I.M.; Garcia-Palacios, J.H.; Iban, N. Vibration monitoring of a steel-plated stress-ribbon footbridge: Uncer-tainties in the modal estimation. J. Bridge Eng. 2016, 21, C5015002.

[11] Villacorta, J.J.; del-Val, L.; Martínez, R.D.; Balmori, J.-A.; Magdaleno, Á.; López, G.; Izquierdo, A.; Lorenzana, A.; Basterra, L.-A. Design and Validation of a Scalable, Reconfigurable and Low-Cost Structural Health Monitoring System. Sensors 2021, 21, 648. https:// doi.org/10.3390/s21020648