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Design of a Vibrations and Curvatures Sensor based on Optical Fibers Using an FPGA

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Abstract. In this work, we present the simulations results for a building monitoring system design. The goal is the flexibility to activate one or more alert modes (alarm sound, warning light, or both) to alert the population in the most effective way possible to a seismic movement. The mechanical effects we are testing are vibration, curvature, displacement, and strain. By the proposed sensing setup, using mono-mode optical fiber and an optical fiber sensor, can be analyzed remotely the data acquired and take decisions in an opportune way. The use of a Field Programmable Gate Array (FPGA) is proposed for data acquisition and processing. The simulations we realize, using six different data sets, are very promising, because of that, many other applications in corrosive or electromagnetics environments could be explored. In future investigations, industrial equipment, conveyor belt structures, or motors will be tested with this design, to detect breakage or malfunction promptly.

Keywords: FPGA; DOFS, optical fiber.

1 Introduction

Optical fiber has taken a leading role in recent decades, specifically, optical sensors are highly versatile [1]. This, coupled with the possibilities offered by distributed optical fiber sensors (DOFS Distributed Optical Fiber Sensor), has led to their being implemented for dissimilar applications; among which we highlight the evaluation of the health and integrity of the structures [2]. A DOFS has distinctive features compared to traditional electronic sensors, including the ability to provide long-distance monitoring of strain, vibration, and many other physical parameters with a single wire mode [3] [4].

For a long time, a human being has been looking for different ways to generate an alert before a seismic movement. This effort has resulted in many ways to do that from an empty bottle placed inverted on the floor, too expensive impact sensors placed in cars, showcases, and buildings, etc. However, how efficient are these systems? This

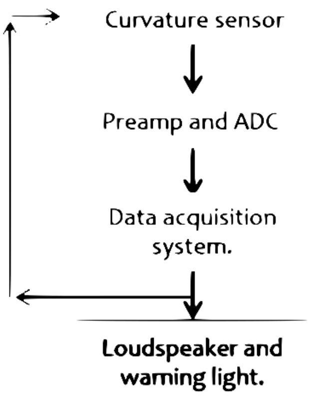

Fig. 1. Block diagram for the seismic warning system.

question is one of the reasons that can cause more problems when choosing a seismic alarm.

In countries prone to seismic activity, there are certain construction standards that respond to studies of the demand and displacement capacity of structures [5]. However, due to the high construction costs, on some occasions, structures are designed with lower resistance than elastic since these demands are not considered in the correct way [5]. Consequently, the damages or collapses in buildings due to seismic activity are generally greater than those predicted by the engineers who worked on their design [5]. Although the economic losses that the collapse of a structure implies are, at times, invaluable, if we consider that they may be the cultural heritage of a certain region, the most important damages are the human losses that they could cause [6, 7]. Therefore, it is important to design policies that minimize these effects [6, 8, 9].

For these reasons, we present the design of a system that allows us to monitor the vibrations, curvatures, displacements, and strain of any structure. The proposed setup uses optical fiber as a transmission medium and a Field Programmable Gate Array (FPGA) as a data acquisition card [10]. With this system, it will be possible to remotely monitor buildings to alert people, using one or more alert modes (alarm sound, warning light, or both), in the most effective way possible to a seismic movement. Additionally, this system takes the advantage that the fiber optics system has magnific immunity to electromagnetic field [11–13]

2 Design

A seismic warning system is composed of a typical vibration signal processing and measurement system. It is made up of a vibration transducer, a pre-amplifier, a data acquisition card, and, in most cases, a loudspeaker. These transducers transform vibrations into electrical signals [14].

The main structure of a curvature sensor is formed by an optical fiber filament through which a beam of light is sent and depending on the change in refraction that

Table 1. Experimental data for curvature.

Curvature [m-1]	Voltage [mV]	Analogic data	Binary data
50	4.66	3.817472	0100000011010000000000000000000
52	4.84	3.964928	01000000011111011011110000000000
54	5.02	4.112384	01000000100000111001100000000000
56	5.2	4.25984	01000000100010000000000000000000
58	5.38	4.407296	01000000100011010000000000000000
60	5.56	4.554752	01000000100100011100000000000000

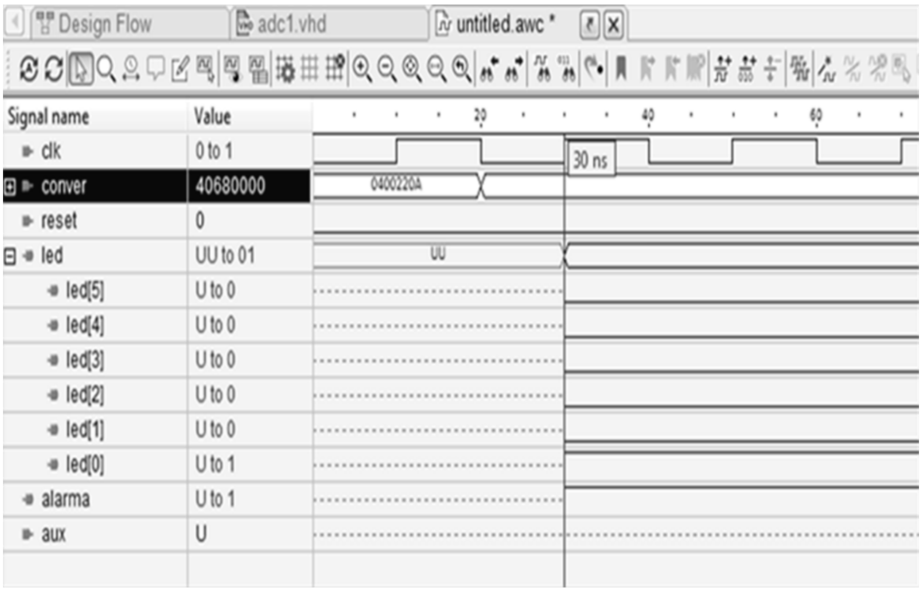

Fig. 2. Simulation's testing.

occurs, a product of the curvature existing in the optical fiber, the curvature is quantified [15]. Curvature sensors allow us to obtain a highly sensitive and compact sensing system when determining small variations in displacement [16-21]

In our project, a curvature sensor will take the place of the vibration transducer, while as a data acquisition card we will use an FPGA from the Altera brand, from the Cyclone V family, model 5CSEMA5F31C6N.

As a first step, the ADC converter equation was cleared. The original equation was obtained in the card's user manual:

$$ADC_{dato} = \frac{4096 \times V_{muestra}}{5v}. \quad (1)$$

Once the equation was obtained, the conversion of the voltage obtained in the sensor to the analog data was carried out, to place it in the code. The analog data were converted to binary; however, when we realized that the analog data obtained was with decimals, we proceeded to use the IEEE 754 protocol, obtaining the following table of results (**¡Error! No se encuentra el origen de la referencia.**).

As the last step, the code was made using the “Modelsim-Altera” software. This allowed us to select from the beginning the FPGA with which we will work and, in this way, make the code with the respective pins.

3 Simulations results

Considering the table of values shown in the development, we conclude that we have six different cases, which is why in our system we will have a series of LEDs that indicate each of the cases, in addition to activating a loudspeaker. The simulation has the reading of the ADC pin, placing a variable that has a range of 4096 bits (which is the maximum value of bits of our ADC).

4 Conclusions

The results obtained during the simulations have been satisfactory, since we have used different tools to perform an adequate calculation, such as the IEEE 754 standard (used to make our programming code).

This system is viable to monitor housing structures by recording the data of vibration, curvature, displacement, and strain to which they are subjected during an earthquake to be able to predict structural effects, even when they are not visible to the naked eye.

This system will allow to intervention in a timely manner in houses, rooms, walls, columns, or any other civil works whose structure has not been affected by the earthquake in its verticality or geometry, however, it has structural damage that could cause total or partial collapse of the work, thus avoiding the possible material losses or human lives that it could entail.

It should be noted that, although our system is oriented to structures such as buildings or homes, it can be adapted to any structure and/or industrial area, such as monitoring motors, conveyor belt structures, etc.

By using fiber optics, it allows us to monitor large spatially distributed structures with a single cable (multi-mode or mono-mode fiber optic). It must also be taken into consideration, that the system has high durability and low-cost maintenance because of the use of fiber optics as a transmission medium.

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