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Impact Detection System for Structures during their Storage and Transport

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Abstract

This paper considers the unexpected deterioration of structures due to impacts, within the scenario of Industry 4.0. More specifically, this research includes the detection of damages that cannot be seen using only a visual inspection and which might occur during the stages prior to the final assembly of the components on structures, i.e., the manufacturing, the transportation, the storage, and the delivery. The research is focused on the detection of damages inside structures due to unexpected impacts during the early manufacturing stages. In the case that any damage is detected, not only the strength of the impact is recorded, but also the date and time of the event are stored in the system memory. Hence, the continuous monitoring helps the correct identification of responsibilities for any damage incurred. Two panels, one metallic and one composite, were assessed using the developed system.

1 INTRODUCTION

Structural Health Monitoring (SHM) is a well-known research field that embraces the analysis of how the health of a structure can deteriorate. The deterioration can be progressive (such as when the structure shows signs of wear due to mechanical stress) or unexpected (such as when impacts to the structures occur). This paper considers the unexpected deterioration of structures due to impacts, within the scenario of Industry 4.0. More specifically, this research includes the detection for damages that cannot be seen using only a visual inspection [1] and which might occur during the stages prior to the final assembly of the components on structures, i.e., the manufacturing, the transportation, the storage, and the delivery.

The research is focused on the detection of damages inside structures due to impacts during the early manufacturing stages, and their storage or transport. In case any damage is detected, not only the strength of the impact is recorded, but also the date and time of the event are stored in memory. Hence, the continuous monitoring helps the correct identification of responsibilities.

The detection of impacts on a structure during the stages previously described exhibits many constraints. The monitoring capability of the system must function for several months, the monitored component may often be moved, and the gathered data should only be transferred to the authorized personnel upon request. These constraints determine many aspects of the design and performance of the monitoring electronic system. This paper proposes a methodology to address the problem and describes the developed electronic system. There are other methods of impact detection more complete, as described in [2], but the interest of this system is its simplicity.

The system proposal is based on piezoelectric transducers, as they are capable of detecting impacts over a large surface area, when working in passive mode and with no energy consumption. The proposal is a lightweight wireless electronic circuit that includes a real-time clock, a microcontroller, and a small battery.

During the transportation of the structure, whenever any impact happens, the transducers generate an impact signal and the microcontroller records the specified data, i.e., the intensity level of the impact and the time when it happened. At the end of any of the stages, it is possible to read the data recorded and stored in the system. Moreover, many systems can be connected at the same time over the same structure. This way the approximate impact area can be estimated.

The paper summarizes the results obtained with the proposed system whilst monitoring and detecting impacts on both aeronautical metallic and composite structures.

2 SYSTEM DESCRIPTION

The system consists of two parts. The sensor subsystem has the function of detecting the impact event and the reader subsystem has the function to read the data recorded by the sensor and transfer this data to the PC via USB. Each sensor subsystem is housed in a small sized card that is attached to the sheet of the material to be monitored.

2.1 Sensor subsystem

The sensor subsystem scans for the presence of an impact condition and is built around the microcontroller PIC24F08K from the manufacturer Microchip. This microcontroller belongs to the family of 16-bit processors with ultra-low power consumption. It integrates all the necessary peripherals to enable the development of the application without using external components.

The internal modules used in the detection phase include the dual analog comparator and the reference voltage generator, which fixes a preset voltage to be compared with the piezoelectric voltage. As a result of this comparison, an event occurs when the peak voltage of the piezoelectric is higher than the internal reference voltage. This reference voltage can also be modified to set the threshold intensity of the impact to be detected and registered. The piezoelectric transducer is connected to one analog comparator and to one analog channel, as shown in Figure 1.

Meanwhile, the RTCC internal module remains active and provides the time and date of the event. During this detection phase other peripherals remain in a "deep sleep" state with an ultra-low energy consumption.

Once the impact event is triggered, the microcontroller “awakens”, and the impact data is sampled at a frequency of 200Hz during 200 milliseconds. The impact data packet incorporates the time and date of the event, which are subsequently stored in the internal flash memory, before it returns to its deep sleep state. The operations sequence is better described graphically in the flow diagram shown in Figure 2.

The RF module is a high-performance, FCC & IC certified radio module that incorporates the Texas Instruments CC110L transceiver chip in a small package (9 x 16 x 2.5mm). It has a low current consumption (15 mA, 3V, in RX operation, 1.2 kBaud, 868 MHz) and accepts a broad range of supply voltages (1.8-3.6V). This module remains in an off state, except when the reader subsystem requests the stored data. For this to happen the reader subsystem uses a mounted magnet. When the reader approaches a distance of less than 15 mm, a reed switch is activated causing the on state of the RF module through a pass P-channel MOSFET transistor.

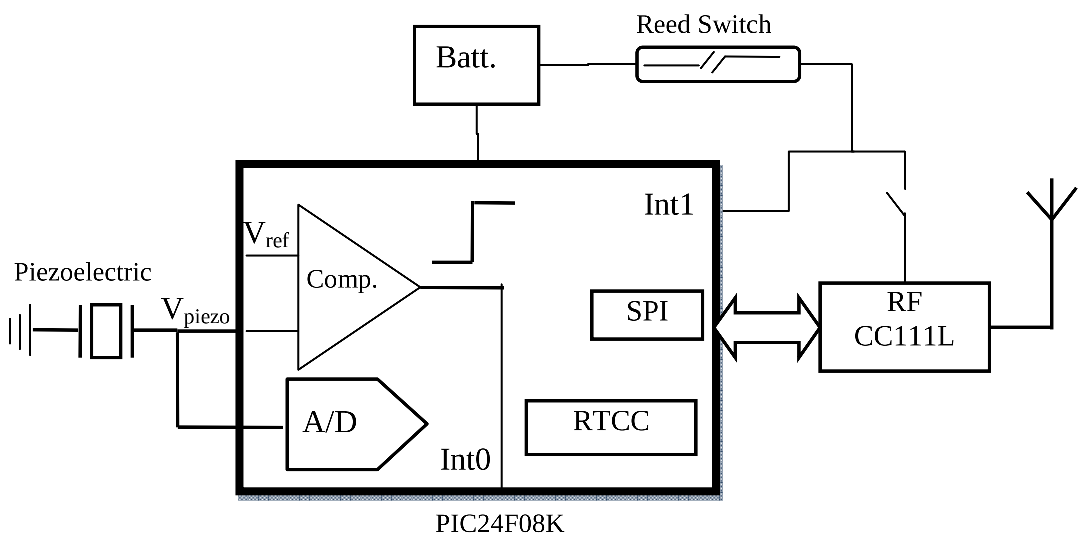

Figure 1. Impact detection, sensor subsystem block diagram.

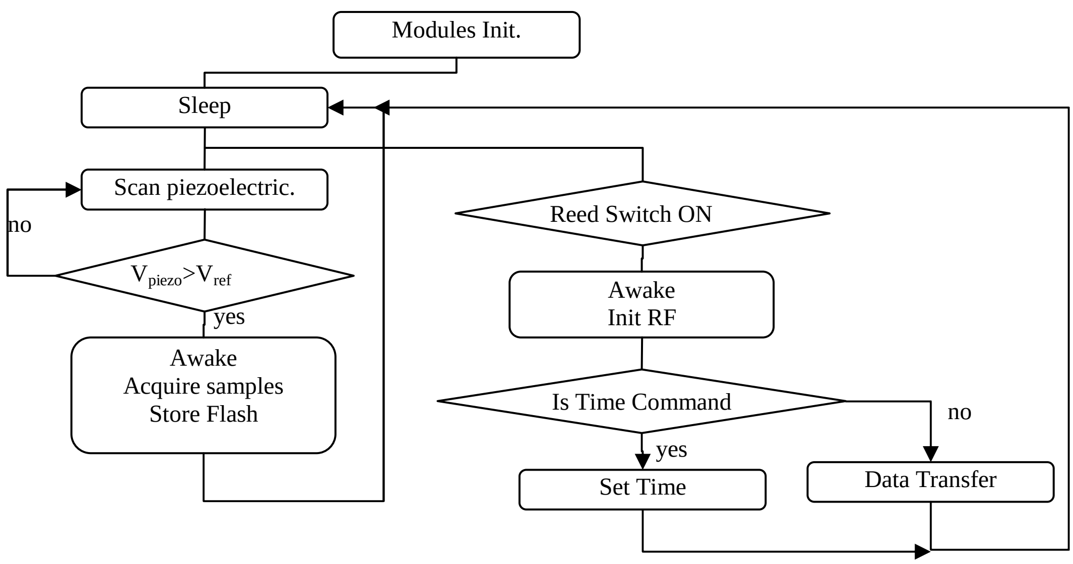

Figure 2 Operations sequence flow diagram. Sensor subsystem.

Based on this mode of operation the consumption values of the module are extremely low, which ensures a long battery life. These values are shown in Table 1. During the detection or scanning phase, the intensity measured is 800nA. Given that the circuit is powered by a 3 V battery with 250mAh capacity and considering also a feasible use until 50% discharge, the battery life would perform for a period exceeding 10 years

Operation Mode	Average Power (uW)
Scanning	0.12
Acquiring & Storing	1.2
Wireless Uploading	45000

Table 1 Power Consumption values

In short, the main features of the sensor subsystem are:

- Very low power consumption. The RF module is off. The current consumed by the microcontroller in a state of very low power consumption is in the order of several nanoamperes.
- The system is powered by a lithium ion battery of 3V and with 300mAh capacity.
- It features overvoltage protection to avoid damage in the analog front end.
- A Real Time Clock module (RTCC), optimized for long battery life determines the time and date-calendar. The clock source is selectable between external (32.768 kHz) or internal.
- Selectable impact detection threshold. This feature enables the selection of the detection threshold according to the material specifications.
- Small dimensions (34x28x6mm) and low weight (12gr).

2.2 Reader subsystem

The reader subsystem, which collects the impact data for subsequent transfer to the PC, is built around the microcontroller PIC18LF2550 from Microchip. This microcontroller belongs to the family of 8-bit processors for ultra low power consumption. It integrates a fully featured Universal Serial Bus communications module that is compliant with the USB Specification Revision 2.0. The USB module supports both low-speed and high-speed communication for all supported data transfer types. It also incorporates its own on-chip transceiver and 3.3V regulator and supports the use of external transceivers and voltage regulators. It functions over an extended VDD range of 2.0V to 5.5V.

The subsystem is powered by USB and incorporates one LDO with fixed 3.3Voutput to suit the range of voltages used in the RF module and the microcontroller. In one corner is a circular magnet with high permeability properties. Its range of action is up to 15mm. At any distance below this 15mm to the reed switch of the sensor subsystem, will cause the system to awake and transition to the state of power-on the RF module (see Figure 3).

The module has two distinct features. Firstly, it sets the date and time for the sensor subsystem, and secondly, it collects the data from possible impact events. The first function is executed at the time of initial installation of the sensor module and ends whenever the impact data collection is finished.

3 EXPERIMENTAL SETUP

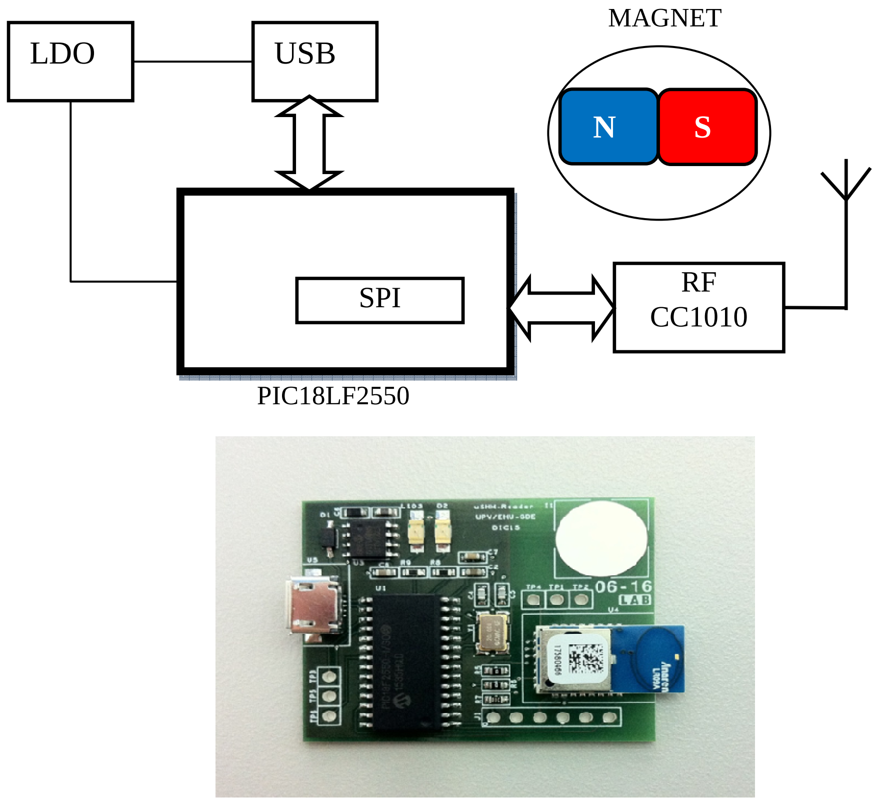

Figure 3. Top: Impact detection, reader subsystem block diagram. Bottom: reader electronic card.

Three sensor subsystems placed on a 3mm thick aluminum plate (AL7075-T6) of one square meter were tested. The plate was arranged vertically upright with the bottom edge fixed on a support. One piezoelectric transducer, type PZT from Murata ref. 7BB-15-6L0, was connected to each sensor module and then attached to the plate with an adhesive, 3M type 3731. The piezoelectric transducers were placed to form a triangular shape with the vertices at the end of the plate, as shown in Figure 4. One aspect that was analyzed was the possibility of locating the position of the impact based on triangulation techniques.

In order to verify the performance of the sensor modules, the plate was subjected to impacts of different intensities using a hammer containing a force meter in order to indicate the force of each impact. The impacts were distributed in four different zones of the plate. After each impact several signals were acquired using an oscilloscope. The obtained signals included the transducer`s rectified signal and the envelope of each rectified signal. In Figure 5, these curves show that the three enevelopes correctly track the transducer’s signal. The good quality of these envelopes helps in the detection of impact events without risk of failure. For further analysis, both the impact force in N and the peak voltage of the envelope signal were recorded.

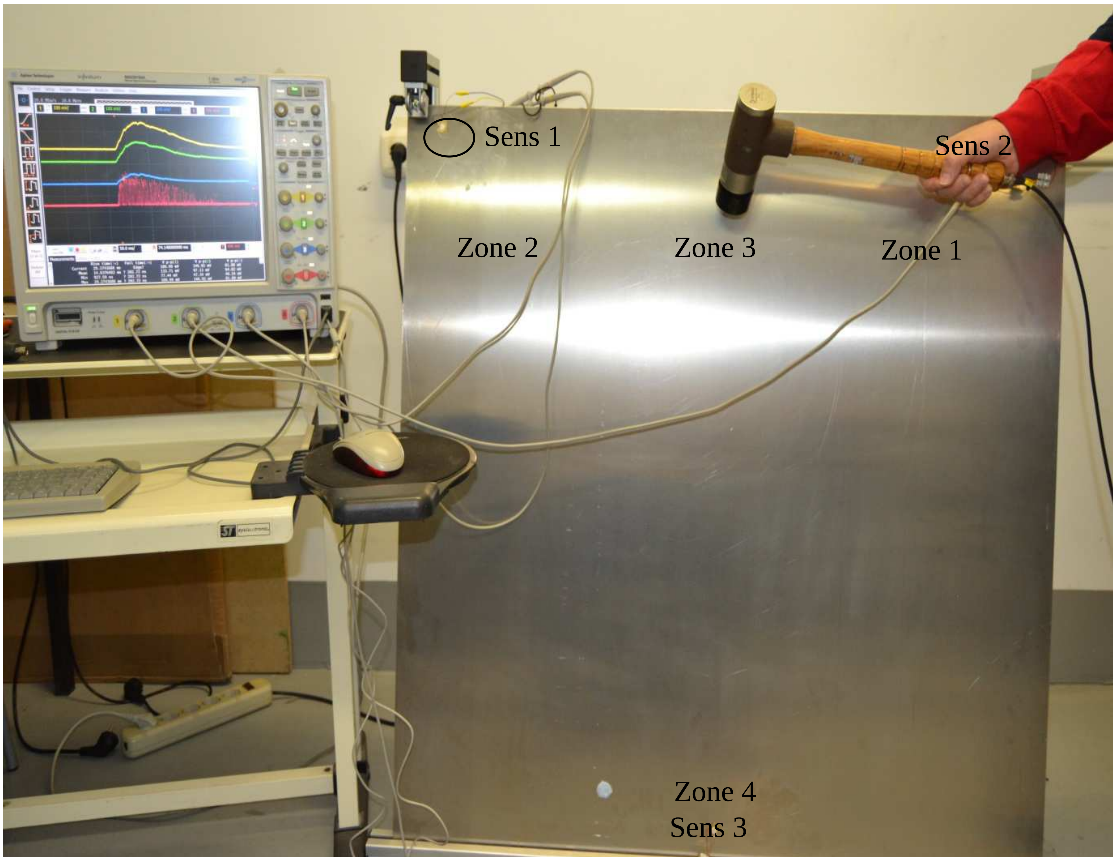

Figure 4. Picture of the experimental setup.

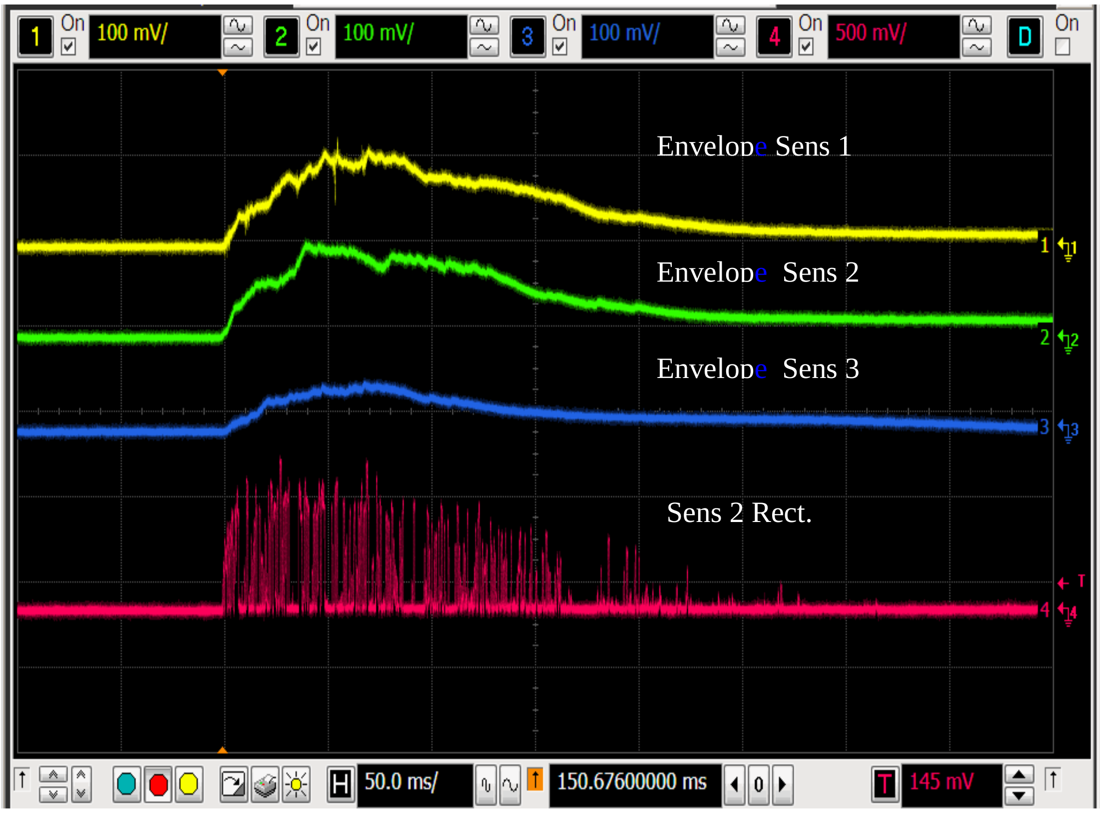

Figure 5. Oscilloscope signals showing voltages of envelope and rectified signals from the three transducers.

A repeated series of impacts was carried out, located in each of the four zones marked in Figure 4. All the recorded data was plotted in four graphics (Figure 6). For each panel the peak voltage amplitudes of the envelope signals in millivolts were measured versus the force of the impact in Newtons. In each of the four zones the response was approximately linear, as previously expected, making it possible to register the intensity of the impact.

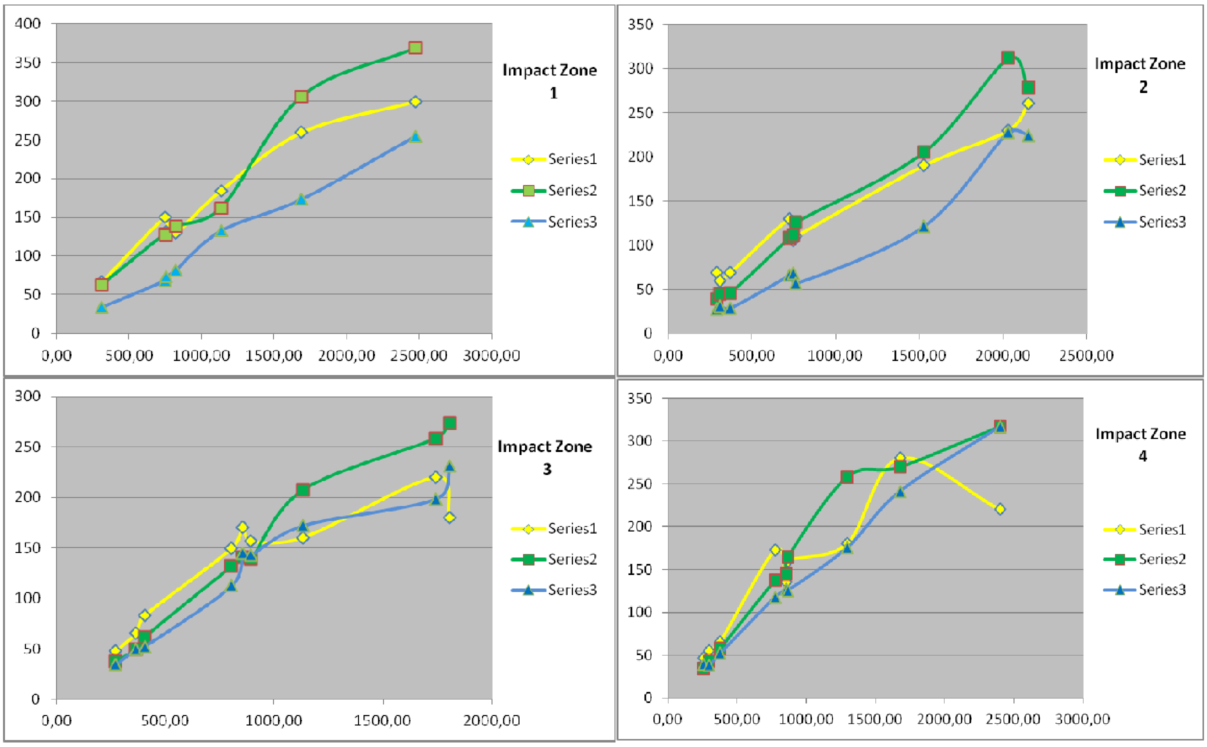

Figure 6. Peak voltage amplitudes vs impact forces for the three sensors for the four different zones of impacts made on aluminum plate material. Horizontal axe: force of the impact in Newtons. Vertical axe: peak voltage of the signal in millivolts.

However, after analyzing the response of each transducer with respect to the zone where the impact was introduced, it proved very difficult to identify the location of the impact area. For this reason, a previous calibration of the sensors and subsequent triangulation advanced procedures [3] would be required.

The tests were repeated using a plate of composite material (epoxy reinforced with fiberglass VETOXIL-T11) and the results were plotted in Figure 7.

In this second case, two different features were observed. Firstly, the peak voltage amplitudes were higher than those registered with the aluminum plate and secondly, an abrupt change was observed in the evolution of the voltage signals.

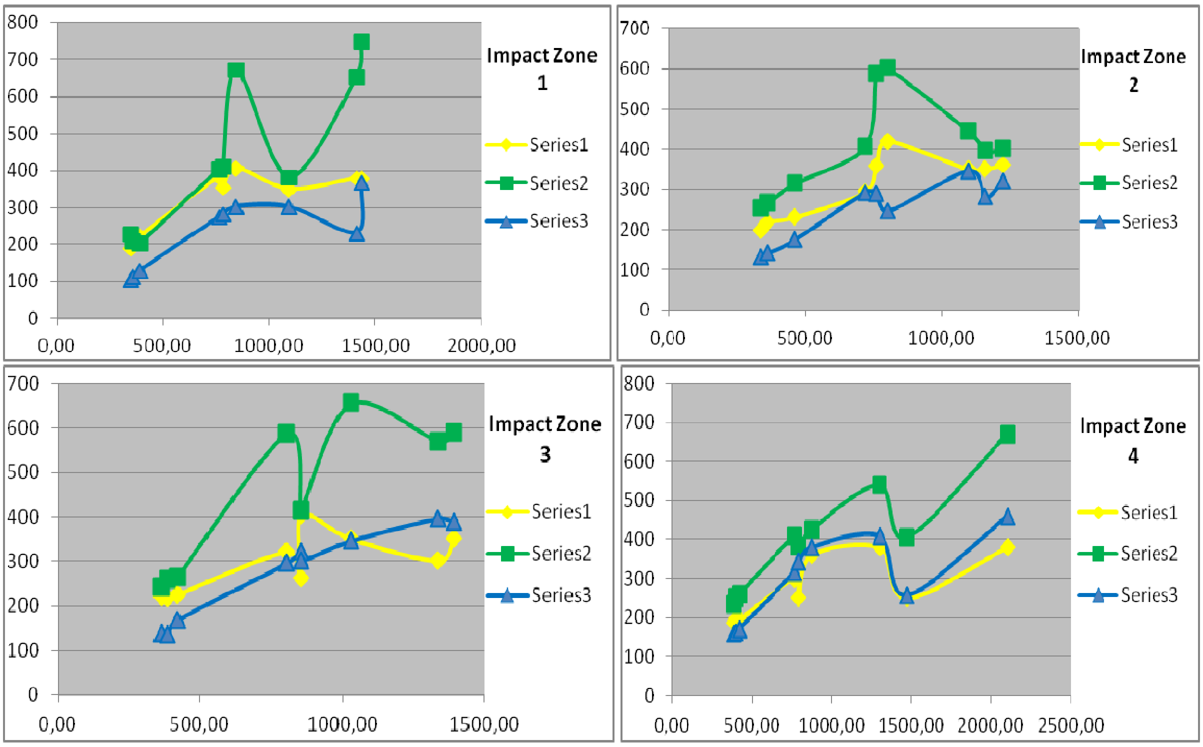

Figure 7. Peak voltage amplitudes vs impact forces for the three sensors for the four different zones of impact made on composite material. Horizontal axe: force of the impact in Newtons. Vertical axe: peak voltage of the signal in millivolts.

4 CONCLUSIONS

A system for detecting the impact damage suffered in plates of different materials during their transport, storage or subsequent assembly is presented. The proposed solution offers advantages such as very low power consumption and easy implementation through wireless data upload.

The tests revealed that the detection of an impact and the measurement of its intensity could be measured in a repeatable manner. However, based on the current format of this system, it proved difficult to locate the impact area based solely on triangulation of signals.

ACKNOWLEDGMENTS

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