Emergency-Awareness System for Vibration Sensing, Monitoring, and Safety

To-Po Wang, Zi-Ping Kuo

***Abstract**: An emergency-awareness system for vibration sensing, monitoring, and safety is proposed in this paper. The presented electronic system comprises a central monitoring unit and three vibration-sensing modules. They are connected to an Ethernet network for rapidly transmitting the monitored data and issuing command signals. Each vibration-sensing module consists of a compact 3-axis micro-electro-mechanical system (MEMS) accelerometer and three high-resolution 24-bit sigma-delta analogue-to-digital converters (ADCs). The proposed sensor modules can be attached to infrastructure and machines (e.g., toxic-gas valves, seismic monitors) in industrial factories. Upon detecting a tiny 4-gal vibration from a high-resolution sensing module, it immediately reports to the central monitoring unit via the network and issues commands to shut off the gas valves. Because the presented system leverages high internet transmission speeds (much faster than vibration waves propagating through infrastructure) and high-resolution sensor modules, safety measures (e.g., switching off toxic-gas valves) can be implemented immediately before the arrival of the vibration waves.*

***Keywords**: Emergency Awareness, Micro-Electro-Mechanical System (MEMS), Vibration Sensing.*

Nomenclature:
MEMS: Micro-Electro-Mechanical System
ADCs: Analogue-to-Digital Converters
MEMS: Micro-Electro-Mechanical System
BPDN: Basis Pursuit Denoising
FBG: Fibre Bragg Grating
CNN: Convolutional Neural Network
FPGA: Field Programmable Gate Array
SPI: Serial Peripheral Interface

I. INTRODUCTION

For monitoring and safety considerations, studies on vibration and applications are reported [1]-[4]. In [1], a continuity-modified basis pursuit denoising (BPDN) algorithm is proposed to reconstruct vibration signals and obtain the order spectra. In [2], a wireless alarm microsystem self-powered by a vibration-threshold-triggered energy harvester is presented. A wireless alarming signal induced by an abnormal vibration event can be autonomously transmitted to a point over 2 km away when the vibratory excitation lasts for 1 minute. Three types of modules with threshold accelerations of 2*g*, 2.6*g*, and 3*g* are designed and fabricated. In [3], a method for identifying different milling states in a robotic surgical system is introduced to acquire and process vibration signals. The tissue vibration signal is measured with a laser displacement sensor, and an accelerometer records the power device's acceleration signal. According to the experiment results, 20-*g* accelerations were recorded. In [4], a new current-aided vibration-order-tracking method for bearing-fault diagnosis of variable-speed direct-drive wind turbines is presented. The technique explores a simple, practical approach to vibration order tracking. An acquisition system with a 10-kHz sampling frequency was used, and a wind turbine with an inner-race fault was measured in the fundamental frequency range of 50 to 75 Hz. In the literature [2]-[4], vibrations are characterised by accelerations exceeding 2g (2000 gal) or frequencies exceeding 50 Hz. For this study, the proposed emergency-awareness system is designed to detect tiny 4-gal seismic vibrations with frequencies below 50 Hz.

The use of seismic accelerometers for vibration sensing is presented in [5]-[7]. In [5], a fibre three-component accelerometer based on an ultrashort fibre Bragg grating (FBG) array for seismic exploration in oil and gas wells is proposed and demonstrated. The accelerometer consists of three orthogonal sensing units, each based on a spring-mass structure with a cylindrical casing that is resistant to temperatures up to 155 °C and pressures up to 50 MPa. In [6], an experimental procedure for moving-person detection is developed. The sensitivity and weight of the seismic transducer with a piezoelectric membrane are 400 mV/g over 3-200 Hz and 50g, respectively. Moreover, the seismic signal processing unit performs filtering, amplification, processing, and analysis. The digitisation of the input analogue signal is performed at 600 Hz. In [7], a method for detecting elephant movement by analysing ground vibration recordings from seismic sensors is introduced. A convolutional neural network (CNN)-based model named “GajGamini” is used to track the elephant movements.

To accurately capture the vibration waves, we developed a new high-resolution emergency-awareness system. The proposed system consists of a 3-axis MEMS accelerometer with a high sensitivity of 420 mV/*g*. Due to its small bulk size and high sensitivity, the MEMS accelerometer is suitable for emergency-awareness industrial systems. To provide sufficient time for safety measures to be implemented, the proposed high-resolution 24-bit sigma-delta ADC circuits are used for vibration detection.

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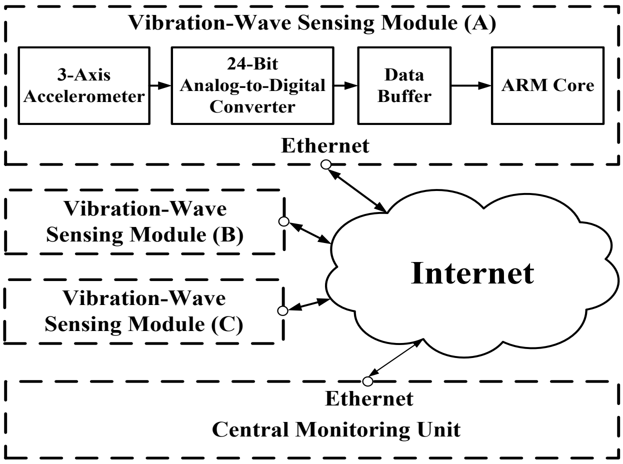
II. PROPOSED SYSTEM

The proposed system consists of a central monitoring server and three vibration-sensing modules connected via a high-speed computer network, as shown in Fig. 1. Because the Ethernet network is fast, the data transmission rate is much higher than the propagation speed of vibration waves through the infrastructure. This speed advantage can be used to lift on-wafer probes and to switch off gas valves before the incoming vibration waves arrive. The sensing module comprises a 3-axis accelerometer, three 24-bit analogue-to-digital converters. (ADCs) for high accuracy, a data buffer, an ARM core for data processing, and an Ethernet controller for data transmission.

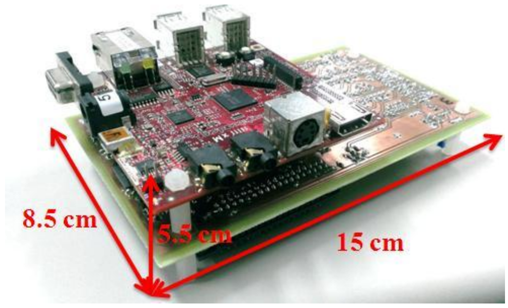


[Fig.1: Block Diagram of the Proposed Emergency-Awareness Industrial-Electronic System for Vibration Sensing, Monitoring, and Safety]

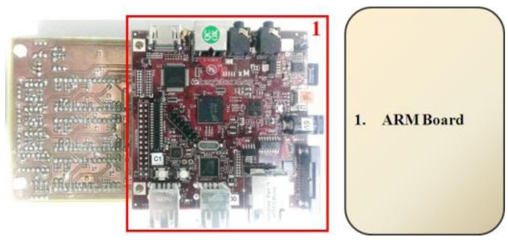
An outline of the proposed emergency-awareness sensing module is shown in Fig. 2. As shown in Fig. 2(a), the sensing module dimensions are 15 cm × 8.5 cm × 5.5 cm. Fig. 2(b) depicts a top view of a sensing module with an ARM development board. The bottom view of a sensing module is presented in Fig. 2(c). It consists of a compact 3-D MEMS accelerometer, three ADC drivers, three high-resolution 24-bit sigma-delta ADCs, and a data transmission circuit with an index generator in the FPGA.

An ARM microprocessor (MPU) is used in this work to process seismic wave data. The peripherals of the MPU can include a USB host, image-capture hardware, an LCD panel, a multimedia card, secure data I/O, etc. Therefore, the MPU must deal with many programs in sequence. To continue monitoring seismic waves, the sensed analogue data from a compact 3-D MEMS accelerometer are digitised in real time by high-resolution 24-bit sigma-delta ADCs. These digital data must be processed and transferred in real time to a central monitoring unit via a computer network.

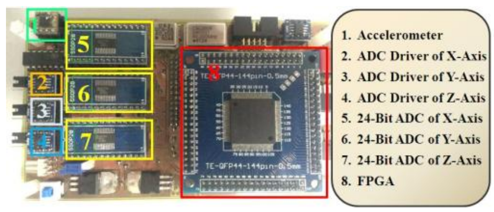
To prevent data loss caused by differences in data processing speeds between the ADCs and MPU, a high-speed, high-reliability data transmission circuit in the FPGA is proposed in Fig. 3. This circuit is implemented in a field-programmable gate array (FPGA) due to its flexible design. The FPGA has a serial peripheral interface (SPI) for receiving digitised data from the ADC. In addition, a memory size of 128 bits x 512 words is implemented as a data buffer for reliable storage of the digitized data, and the interface between the memory and ARM MPU is constructed for robust data transmission, including the sections of addressing, reading registers, memory output registers, chip selection, and clock control.



(a)

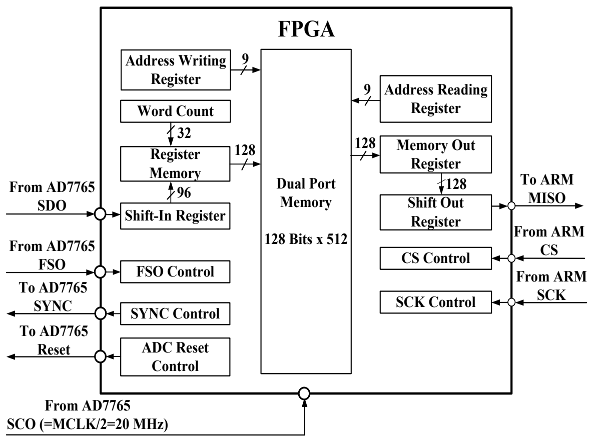


(b)



(c)

[Fig.2: Proposed Emergency-Awareness Sensing Module, (a) Dimension, (b) Top View, and (c) Bottom View]



[Fig.3: Block Diagram of the Proposed Data Transmission Circuit with Index Generator (Word Count) in FPGA]

Fig. 4 shows an earthquake wave detected by the proposed system. Upon detection of an acceleration greater than 4.0 gal around the time of 0:31:09, it immediately reports to the central monitoring unit and issues commands to switch off the solenoid gas valve shown in Fig. 5. The measured overall system response time is 75 ms, resulting in 1,525 ms (=1,600ms-75ms) for safety before the occurrence of 18-gal peak motion.

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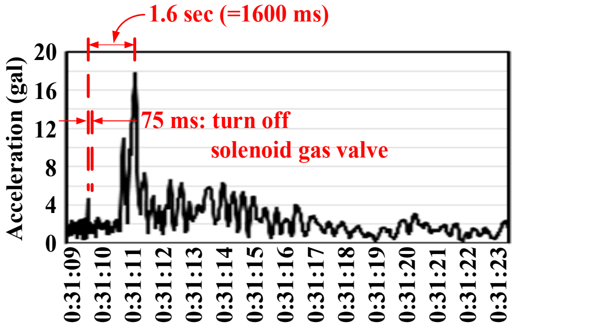
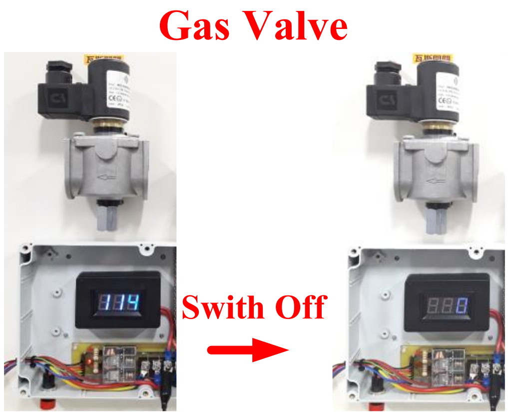


[Fig. 4: Detected Earthquake wave and Measured System Response Time to Switch off the Solenoid Gas Valve]



[Fig.5: Gas Valve is (a) on, and (b) off]

III. CONCLUSION

A high-performance, emergency-aware industrial electronic system for vibration sensing, monitoring, and safety has been developed and validated. Featuring a compact 3-D MEMS accelerometer, a high-resolution 24-bit sigma-delta ADC, and a data transmission circuit in an FPGA. It has the advantage of high internet transmission speed (much faster than vibration waves propagating through infrastructure), so safety measures (e.g., switching off gas valves) can be implemented before the arrival of the vibration waves (e.g., when the threshold voltage is exceeded). Compared to other works in the literature, this work not only achieves high performance but can also be adopted in industrial environments for safety.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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