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Alarm System for Earthquake Monitoring in Civil Constructions

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ABSTRACT

This research work aims to improve earthquake alarm systems which is focused to monitor civil construction system. The proposed system has been used to monitor in real-time the stability of the structures and to report the state of the structure. Monitoring and determining the stresses at critical points also in the event of a catastrophe where the structure loses its stability and consequently collapses. The logging system will alarm and send the information to data collecting server. Due to the usage of this monitor system we can identify the extent of structure damage in case of damage caused by the earthquake.

Keywords: Monitoring sensor, displacement sensor, earthquake alarm system, emergency server.

1. INTRODUCTION

Through this proposed system, we can monitor in real-time the civil and industrial objects to determine the degree of their damage from a seismic shock. We are clear that with current technologies it is not possible to predict the exact place and time when and where an earthquake will occur, but we can monitor structures to ensure that they are still ready to continue service or should be considered as damaged or at risk of destruction. If the stability of the civil or industrial constructions is endangered then the network of sensors installed in its columns will signal the weakening of the structure. The sensors presented in this paper were designed and manufactured in Albania and have undergone laboratory tests to guarantee measurement accuracy

This system provides information if the construction collapses by using SFG-0 sensor and sends the alarm status to the emergency center. Through this study, the aim is to create a reliable and stable monitoring system over time. The technological methods and systems proposed in this research work will serve not only for the modernization of the national emergency system but also as a valuable source of data for other subsequent studies of seismology or construction techniques

2. TYPOLOGY OF APPLIED SENSORS

To monitor the constructions, we need to use a set of sensors to guarantee accurate and reliable information. The project will use a strain gauge sensor and SFG-0 sensor to detect when the structure has moved in the incorrect position or when is destroyed. From the installation of these sensors in civilian buildings we would benefit from real-time monitoring of the displacement and strain of the structural columns. But from the monitoring of the stress of the columns can be used as data which helps us to determine the status of damage (after a seismic shock). But this is not enough data to determine the identification of the collapse of the civilian object (as a solution we use the SFG-0 sensor) [1].

2.1 Strain gauge sensor

In these constructions, the monitoring can be realized by means of a network of strain gauge sensors, which will be installed in the steel of the columns as shown in Figure 1. By recognizing the initial state of resistance of the strain gauges for the sensors installed in the columns, we can determine the deviation caused by the earthquake's force. Deformation of the structure will cause stresses in the columns and the sensor will send the new result from which will be calculated the deviation of the structure and the assessment of the alarm status. The sensors will be installed on all columns and beams of the building and the end is connected to the microcontroller box to perform the measurement. The conductor cables will be positioned in plastic pipes intended for the metering network. The electrical installations of the sensors will be similar to those of the electrical system of the apartment but distanced from them. Transmitters should be screened to minimize noise signals [2].

(a)

(b)

Figure 1. (a) Strain gauge sensor configuration 1, (b) Strain gauge sensor configuration 2

2.2 SFG-0 sensor

The SFG-0 sensor has the function of sending an electrical signal, at the moment when the structure would like to monitor the development of seismic shock. The principle of its work is based on the ability of a metal plate inside it with a mass at its edge to change the bend depending on the acceleration induced by the force of seismic impact. The curved plate inside the SFG-0 in normal operating mode stays inclined at an angle ϴ and reduces this angle if the sensor together with the structure on which it is supported moves with acceleration a (where this acceleration is the acceleration of collapse of the structure by seismic force). Figure 2 illustrates the design of the SFG-0 Sensor [3].

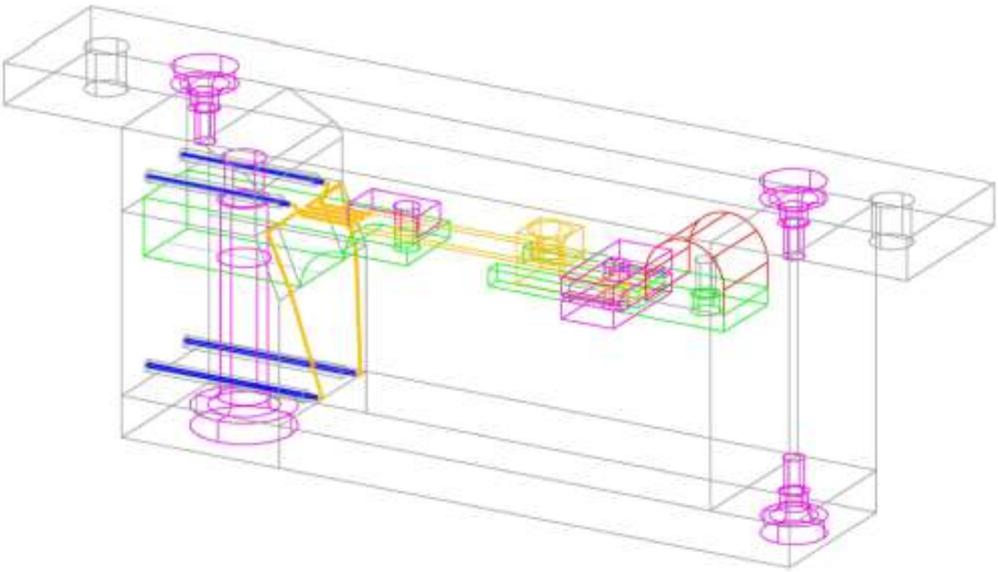

Figure 2. SFG-0 sensor 3D design

In the action of the earth gravity force G, the curved plate stays bent by equalizing the force of the mass at its edge with that of the elastic. But when the earthquake affects the supporting structure, the object will make an induced in the ceiling a thrust and which will reduce the weight of the mass at the edge of the curved sensor plate by changing the bending position [4]. The change in curvature will be accompanied by the change in the strain at the point of support and which can be identified by a strain gauge, which has not reached a curved plate. By knowing the value of the strain gauge's resistance when the ceiling was in the static position we could determine the state of the out-of-equilibrium to determine from the value of the resistance changes. We can calculate the result of the SFG-0 sensor with this matrix equation:

$$\begin{bmatrix} x \\ \theta \end{bmatrix} = \frac{1}{EI} \begin{bmatrix} \frac{1}{3} l^3 & \frac{1}{2} l^2 \\ \frac{1}{2} l^2 & l \end{bmatrix} \begin{bmatrix} \frac{F}{T} \end{bmatrix} \quad (1)$$

Where:

x – Plate extension; *Θ* - Bending angle; *E* – Elasticity modulus; *l* – Plate length

Using the matrix equation (1) from it we can determine the material strain and the angle of refraction of the slab for different values of acceleration a which can be induced in the ceiling of the building. Knowing that the force acting on the deformation of the plate is the weight of the body placed at its edge we can write the equation:

$$F = P = m(g - a) \tag{2}$$

Where:

F – Bending strength; P – Bodyweight at the edge of the plate; g – Acceleration of free fall; a – Induced acceleration

Substituting in the equation for determining the extension of plate x we have:

$$x = \frac{1}{El}\left[\frac{1}{3}l^3 m(g - a) + \frac{1}{2}l^2 T\right] \tag{3}$$

As for determining the angle of refraction of the plate Θ we have:

$$\theta = \frac{1}{El}\left[\frac{1}{2}l^2 m(g - a) + lT\right] \tag{4}$$

The curvature of the plate will decrease with increasing induced acceleration a consequently the angle of refraction of the plate will also decrease. These values are shown in Table.1

Table 1. The extension of plate *X* and the angle of refraction *Θ* depending on the induced acceleration *a*

a (m/s^2)	**X $x10^{-3}$(m)**	**Θ $x10^{-3}$ (°)**
0	0.1594	0.6676
1	0.1432	0.5996
2	0.1269	0.5315
3	0.1107	0.4635
4	0.0944	0.3954
5	0.0782	0.3273
6	0.0619	0.2593
7	0.0457	0.1912
8	0.0294	0.1232
9	0.0132	0.0511
9.81	0	0

The SFG-0 sensor performs indirect measurements to determine the free fall or acceleration of the object ceiling, must convert the above quantities into electrical signals. Strain at the support point of the bending plate would cause the strain gauges resistance to change depending on the induced acceleration a. Different values of the ohmic resistance at the output will set different values of the refractive angle.

The ohmic resistance and output voltage depends on the induced acceleration which present this dependency in the Table 2.

Table 2. The resistance of the strain gauge and output voltage depending on the induced acceleration *a*

a **(m/s^2)**	**R_{SG}** **(Ω)**	**V** **(V)**
0	120.1700	0.0032
1	120.1527	0.0028
2	120.1354	0.0023
3	120.1180	0.0019
4	120.1007	0.0015
5	120.0834	0.0010
6	120.0660	0.0006
7	120.0487	0.0002
8	120.0314	0.0001
9	120.0140	0.00001
9.81	120	0

It has been noted that the resistance values of the measurement strain gauge R_{SG} were very close to each other and the change of values as a result of the temperature efferent would bring significant measurement errors which could lead to false alarms. To eliminate the effect of temperature a compensating strain gauge has been connected according to the diagram shown in Figure 3. From the bridge balance equation, we can write:

$$R_{SG}R_4 = R_3R_2 \tag{8}$$

Where:

R_{SG} - Resistance of the strain gauge; R2 - Balancing resistance; R4 - Calibration resistance; R3 - Resistance of the temperature compensating strain gauge

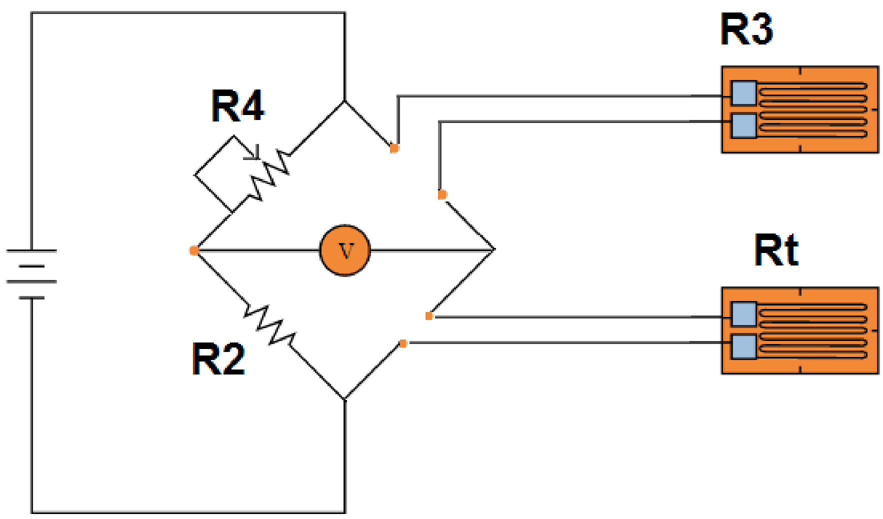

Figure 3. Electrical scheme of strain gauge connections

By feeding the bridge with voltage U = 12V at its output we will get the values of voltage V depending on the inductive acceleration a and by setting the values R_2 = 1000Ω and R_4 variable resistance which has a calibrating role we get the results of Table 2.

In a lot of cases, we don't have free fall of the ceiling during the building's collapse. This is caused as a result of the resistance that the building material and construction exhibit to the shock force of the earthquake. The building's ceiling shall fall with acceleration in the process of demolition. This critical acceleration at which the building collapses will correspond to a critical value of the V output voltage [1].

3. LABORATORY TESTS AND EXPERIMENTS

The experimental prototype of the SFG-0 sensor shown in Figure 4 has been tested through several tests by applying controlled values of induced acceleration in order to stimulate the situation during the collapse of the building. These values are compared with the situation of plastic oscillations (when the building vibrates as a result of the action of seismic force but manages to resist shock).

(a)

(b)

Figure 4. SFG-0 Sensor (a), Inside SFG-0 Sensor (b)

For the realization of the laboratory measurement process, a high-performance DAQ NI USB-6008 data receiver was used, which through analog inputs receives the signals sent by the SFG-0 sensor and sends them for processing to a computer in which it will the graphic display of the signal through a digital oscilloscope is also realized.

Numerical processing of measurement signals is performed through software where it is considered necessary to use a bandpass filter in order to eliminate noise signals and allow only the output of the signal useful for measurement.

To perform this experiment, the SFG-0 sensor will be placed under the action of an induced acceleration or according to the vertical component. During the accelerated fall, the angle of inclination φ will change and consequently, we will have a change in the output signal of the sensor thus identifying the process of falling of the object.

Figure 5 depict the output signal from the sensor as a result of the induced acceleration a where we notice that we have an increase in the signal amplitude at the output during the time the sensor is in motion along the time of fall τ. When the sensor stops moving the signal will return to its original value but this process is accompanied by oscillation due to the inertia of the oscillating element in the sensor. Furthermore, these oscillations come to be extinguished according to their constants but do not pose a concern in sensor operation as amplitudes there are small.

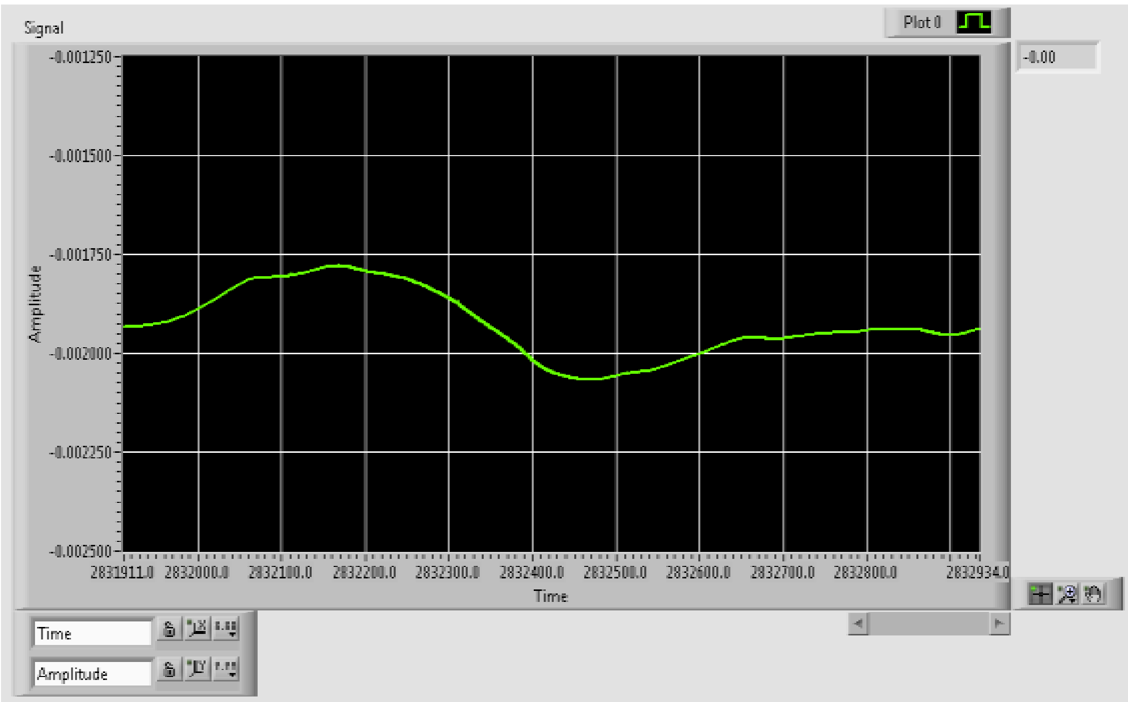

Figure 5. Analysis of the output signal caused by a vertical acceleration component *a*

Furthermore, Figure 6 shows the simulation analysis of the output signal caused by a horizontal acceleration component *a*.

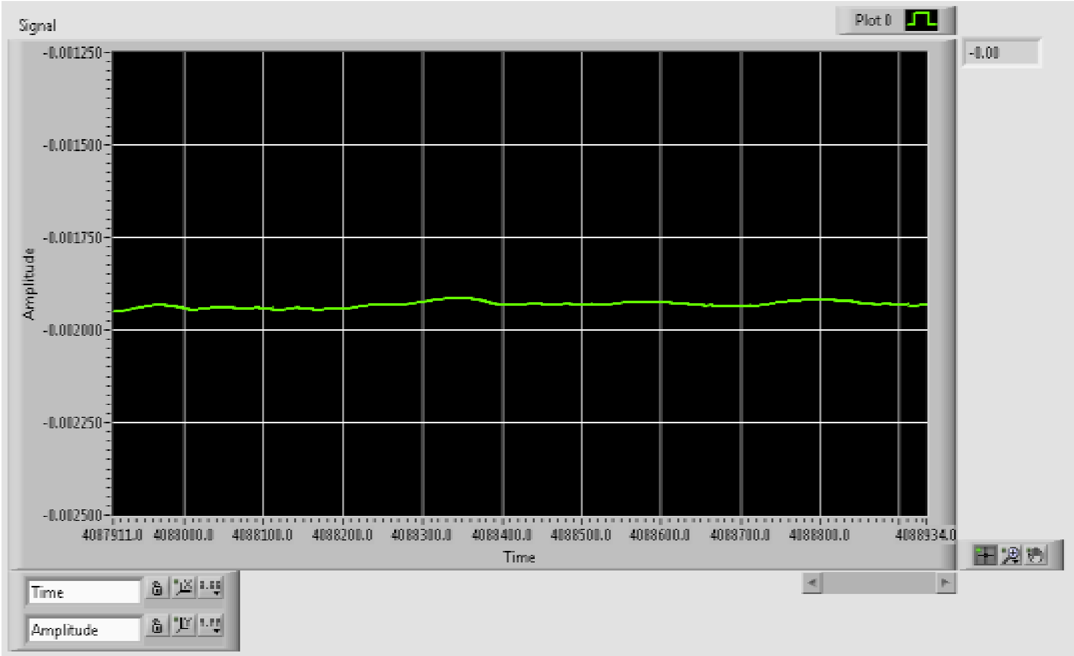

Figure 6. Analysis of the output signal caused by a horizontal acceleration component *a*

To perform this experiment, the SFG-0 sensor will be placed under the action of an induced acceleration or according to the horizontal component. During accelerated displacement the angle of inclination φ will not change as the inclination of the plate is not affected by the horizontal components and consequently, there will be no change in the output signal of the sensor. Figure 7 presents the simulation analysis of the output signal caused by a plastic oscillation.

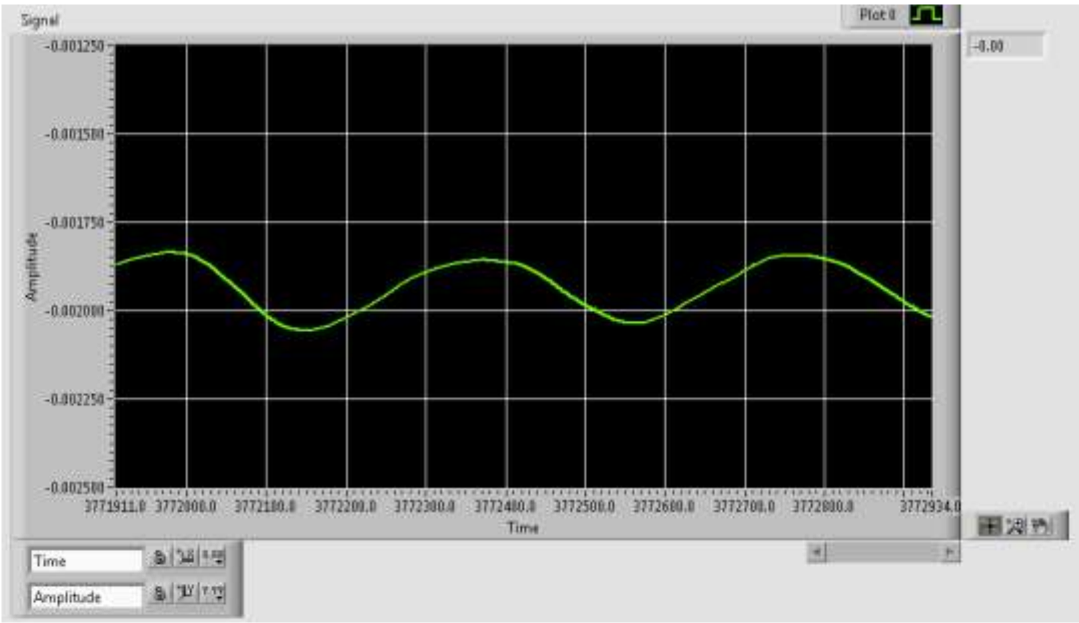

Figure 7. Analysis of the output signal caused by a plastic oscillation

To carry out this experiment, the SFG-0 sensor will be placed under the action of an oscillation with induced amplitude according to the vertical component and variable frequency from 1Hz to 10Hz to stimulate a seismic oscillation in which the building structure manages to resist striking force. During accelerated displacement, the angle of inclination φ will undergo periodic change, as the inclination of the plate will be affected by the vertical component of acceleration and consequently, we will have a periodic oscillation of the curved plate of the sensor which follows the change of the acceleration amplitude induced [5, 6].

In the sensors output signal, we will have a periodic change that resembles a sinusoid (since the overload time during the experiment is accepted equal to the landing time).

In the case in which we have a fall (collapse of the object) the signal has an overload and then goes to stabilization when the movement of the object ends.

It is considered that in the case when the structure fails to withstand seismic shock, the time Δtc at which the signal has overlap corresponds to the time it takes the object to collapse.

In the case of plastic oscillations, the time of overload Δtv is shorter than the time of overload Δtc (the case when the object collapsed), from the results of laboratory experiments this fact is easily confirmed. Identifying a critical time constant will serve as information on the presence or absence of object damage.

3. COMPUTER BASE CENTER

Figure 8 shows the LabView interface in which software built to perform measurement and alarm signalling in the SFG-0 laboratory experiment process is executed.

The interface has calibration cursors that help to determine the first position, it is also equipped with a critical value setting cursor. If the object is hit by an earthquake the system will monitor the movements of the columns, will present the displacements from their initial values and if these displacements exceed the critical values the alarm will be activated.

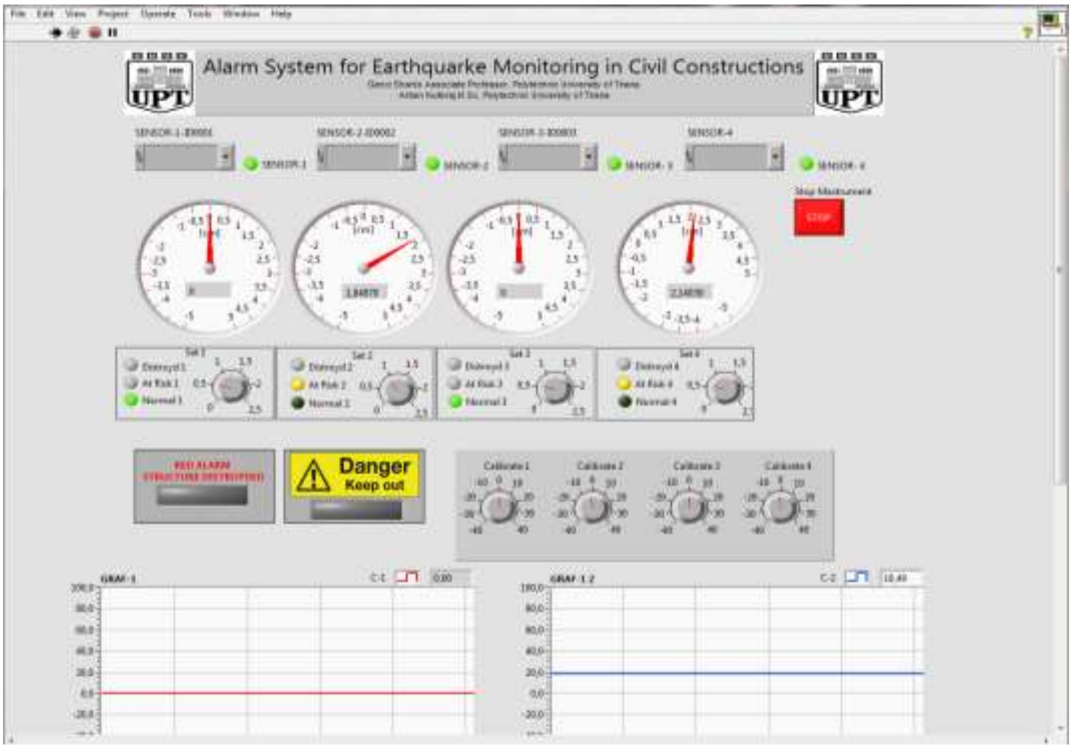

Figure 8. LabView Interface

In the event of a breakdown, the information is sent to the national emergency center together with the location of the damaged facility. Location information is based on geographical coordinates and is attached to the local address system. When the object has withstood the earthquake but its structure poses a hazard, the microcontroller will order a siren to give the hazard signal to evacuate the building as it poses a collapse.

The microcontroller algorithm is shown on the Figure 9.

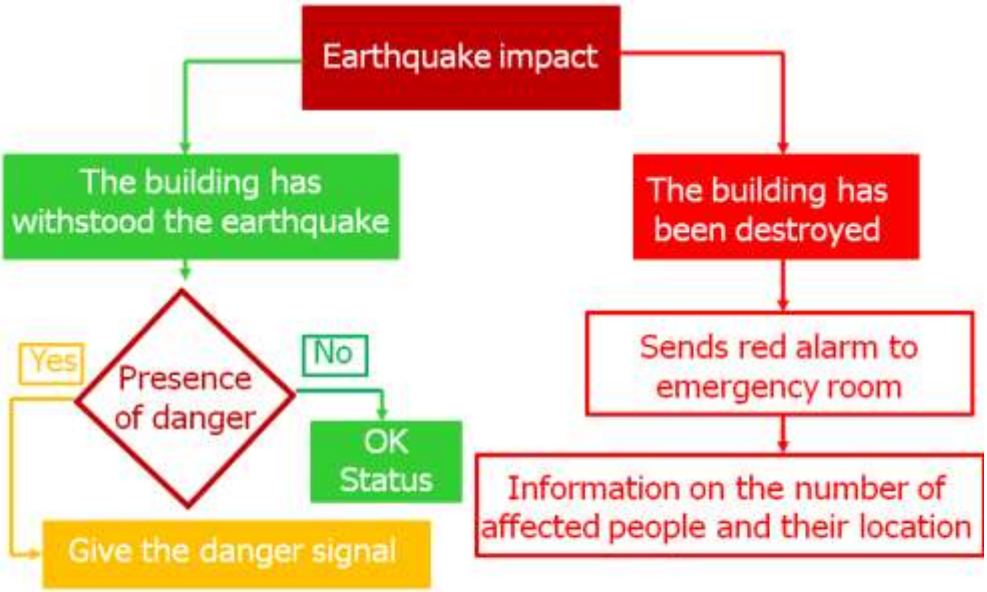

Figure 9. Microcontroller algorithm

3. CONCLUSION

Through this earthquake alarm system, we can monitor in real-time the civil and industrial constructions to get information on the safety of their operation. Obtaining information in a short time will be accompanied by immediate action measures as well as in the more efficient management of the intervention forces and missions for search and rescue of the injured.

The implementation of this technology significantly increases the safety of civil and Industrial object and help more emergency structure to operate more easily in their missions. The sensors presented in this paper were designed and manufactured in Albania and have undergone laboratory tests to guarantee measurement accuracy. The system can be easily applied to existing buildings thus increasing the safety of their use.

The system can output the results of the ascertainment acts in a few seconds after the seismic shock thus avoiding the overloaded damage ascertainment processes. The technological methods and systems proposed in this study will serve not only for the modernization of the national emergency system but also as a valuable source of data for other subsequent studies of seismology or construction techniques.

CONFLICT OF INTERESTS

The authors would like to confirm that there is no conflict of interests associated with this publication and there is no financial fund for this work that can affect the research outcomes.

REFERENCES

[1] Iniewski K. (2013). Smart Sensors Smart Sensors for Industrial Applications, CRC Press, Florida, USA.

[2] Bolton W. (2015). Mechatronics Electrical control System in Mechanical and Electrical Engineering, Pearson Press, London, United Kingdom.

[3] Albanian National Patent (2020). AL/P/2020/00769. http://dppi.gov.al/en/.

[4] Kulloraj A., Sharko G., Dume G. Integrated Earthquake Alarm System for Monitoring the Bridge and Road by SFG-0 and RDM Sensor, *1st Croatian Conference on Earthquake Engineering*, Zagreb, Croatia, 2021, p. 545-554.

[5] Coskunturk Y. Design of a Robust Controller Using Sliding Mode for Two Rotor Aero-Dynamic System. *International Journal of Innovative Technology and Interdisciplinary Sciences*, 2019; 2(2); 119-132.

[6] Chopra A.K. (2000). Dynamics of Structures: Theory and Applications to Earthquake Engineering, Prentice Hall College Div, London, United Kingdom.