A proto-type On-Site Earthquake Warning System

[1]Vrinda Gahalaut, [2]Neha Vats, [3]Shreya Ravi, [4]Shubha Bhardwaj

[1,2,3,4]Department of Electronics and Communication Engineering, Manipal University Jaipur, Rajasthan, India
Email: vrindagahalaut1997@gmail.com

Abstract: Earthquakes are one of the most destructive natural disasters whose occurrence cannot be predicted. However, their effects can be mitigated and the damage to life and property can be avoided by providing a warning of earthquake occurrence. In this article we aim to identify and characterize the earthquakes a few seconds after it begins and estimate the likely intensity of ground shaking at the target region by recording the ground acceleration. The ground shaking is measured through an accelerometer which is controlled through Arduino microcontroller. For warning the user, a Global System for Mobile communication is used which receives and transmits data when the safe and pre-assigned limit of ground acceleration is exceeded. This system can be easily installed at any engineering structure or housing complex and has multi user facility. Also, it focuses on safety of transit networks, infrastructure and human life.

Index Terms: Accelerometer, Arduino, earthquake, GSM, intensity, magnitude, on-site earthquake warning

I. INTRODUCTION

Earthquake is the sudden movement of earth caused by the release of a large amount of strain energy over a fault that has accumulated over a long period of time. It is a natural hazard caused as a result of plate tectonics operating within the Earth. Thus in an earthquake, the ground movement is caused when the two blocks on either side of the fault slide past each other.

Earthquakes generally occur in sequences. An earthquake is followed by smaller earthquakes, we call the larger event as the main shock and the events following are called aftershocks. The events preceding the main shock are called foreshocks. The energy released during an earthquake is in the form of seismic waves. Broadly, these are of three kinds: P-waves, S-waves and surface waves. P-waves (Primary waves) are longitudinal in nature and travel faster than the other waves. S-waves (Secondary waves) are transverse in nature and arrive after the P-waves due to their lower speed. Surface waves travel along the Earth's surface and are almost entirely responsible for destruction and damage. Their speed is slower than that of P and S waves.

The magnitude of an earthquake is a measure of energy released by it. An earthquake of magnitude more than 5 is capable of causing damage to property and loss of lives. In India, earthquakes are frequent in the Himalayan region, NE India and Andaman Nicobar Island belt, as these are the regions where the Indian plate collides or interacts with the neighboring Eurasian plate. Several damaging earthquakes have occurred in these regions due to this collision. The most recent Himalayan earthquake is the 2015 Gorkha earthquake, which occurred in central Nepal and caused about 10,000 deaths. The earthquake was felt very strongly in the northern India. In fact a few people lost their lives due to damage in Bihar and western Uttar Pradesh. Interestingly, the places of damage in India are about 100-150 km from the earthquake epicenter (point where the earthquake originates) and from the region of maximum damage in Nepal. As earthquakes can neither be predicted nor can be prevented, one way of coping with the loss of lives due to earthquakes is to build safer structures, houses and government buildings. However, another way of coping with the loss of lives due to earthquakes is somehow issue the warning of incoming earthquake waves. Because of better instrumentation and faster and cheaper communication methods, it has become possible, and is now known as earthquake early warning (EEW).

II. BASIC CONCEPT OF EARTHQUAKE EARLY WARNING

EEW is a system which alerts public and a few critical facilities when significant shaking due to an earthquake is going to be experienced at a site. The main concept here is that the speed of earthquake waves (~3-5 km/s) is slower than that of the electromagnetic waves (3,00,000 km/s) used in communication. Thus a region located about 100 km away from the earthquake epicentre can, in principle, receive an advance warning of 20-33 seconds before the earthquake waves actually reach this region. This is known as the "lead time".

The seconds to minutes of advance warning or the “lead time” can allow people and systems to take actions to protect life and property from destructive shaking. Even a few seconds of warning can enable protective actions such as people to come out safely from buildings or to cover themselves properly; switch off gas stove, stop vehicles, nuclear power plants, electric trains, elevators. It can also guide doctors to stop delicate procedures. Emergency responders can also prepare themselves to respond to the distress calls.

There are two types of earthquake warning system in the world [1].

(i) Regional earthquake early warning system and (ii) On-site earthquake early warning system [2, 3]. In case of regional earthquake warning system (Fig.1), the sensors are installed in the source zone and in the event of an earthquake, the sensors detect the P waves and calculate the magnitude and location of the earthquake and transmit the information to the target zone. In case of an on-site earthquake early warning system, the sensors installed in the target zone analyze the P waves and calculate the magnitude and location of the earthquake and then estimate the arrival of more damaging waves before they actually arrive. Both systems require a robust and reliable methodology and algorithm to compute the earthquake magnitude and location from a few seconds of data. This is quite tricky. The 2011 Tohoku earthquake is the latest example to cite. The magnitude estimated by the early warning system was about 8, whereas the actual magnitude of the earthquake turned out to be 9, about thirty times larger in terms of energy than estimated by the EEW.

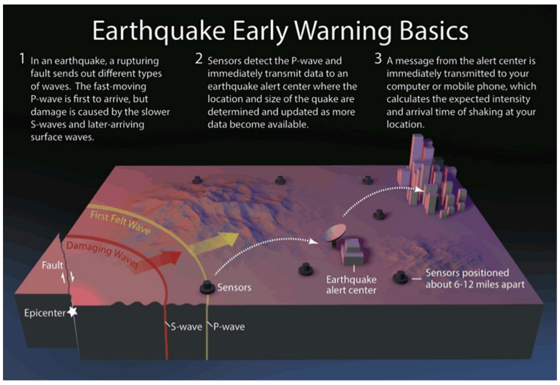

Fig.1 This diagram shows how such a system would operate. When an earthquake occurs, both P waves and S waves radiate outward from the epicenter. When the alert message is received by computers and mobiles, the expected arrival time and shaking intensity is calculated at the location (https://earthquake.usgs.gov/research/earlywarning/overview.php)

A simplification in the on-site earthquake early warning is the estimation of only the damage potential of the earthquake waves by analyzing the extent of shaking using a single sensor (accelerometer) with no capability of transmission. In case the threshold of incoming P waves exceeds the pre-assigned thresholds then a warning is issued. Warning levels could be different, depending upon the extent of shaking. In this case no effort is made on estimating the earthquake location. A large earthquake at far distance will not cause high acceleration in higher frequency range to cause any damage and hence no warning would be issued for such earthquakes. Whereas, earthquakes of even low magnitude at small distance can cause moderate acceleration in high frequency range and can cause damage locally. Such a system helps in alerting people about the incoming S and surface waves before these damaging waves actually arrive at the site, though it may not estimate the time of their arrival. Thus, it can help in reducing damage and loss of lives. Our designed system falls in this category.

III. DESIGN AND FABRICATION OF AN ON-SITE EARTHQUAKE WARNING SYSTEM

With the above concepts, now we proceed to explain the design and fabrication of an on-site warning system. To make an on-site warning system, the following main components are required.

An accelerometer is an electromechanical device used to sense acceleration forces. These forces may be static or dynamic to detect movement or vibrations. A sensor serves as a link between vibrating structures and electronic measurement equipment. It is a device that is frequently used to detect and respond to electrical or optical signals. It converts the physical parameter into a signal which can be measured electrically. Sensors can be of analog or digital nature based on the output they produce. Accelerometer should be chosen carefully taking into consideration important factors such as accuracy, environmental conditions, range, calibration, resolution, cost and repeatability. There are numerous different principles upon which an analog accelerometer can be built. Two very common types employ Capacitive Sensing and the Piezoelectric Sensing to sense the displacement of the mass proportional to the applied acceleration. The piezoelectric sensor works on the principle of piezoelectric effect. In this type of accelerometer, charge accumulates on the crystal and is translated and amplified into either an output current or voltage. This accelerometer only responds to AC such as vibration or shock. They have a wide dynamic range, but can be expensive due to their high sensitivity. A capacitive accelerometer (vibrational sensor) is another type of accelerometer that measures the acceleration on a surface using capacitive sensing techniques. It has the ability to sense static and dynamic acceleration on equipment or devices - enforced by human or mechanical forces - and converts this acceleration into electrical currents or voltage. ADXL335 is a three component accelerometer with regulator. This Accelerometer module is a three-axis analog accelerometer IC, which reads the X, Y and Z acceleration as analog voltages. By calculating the amount of acceleration, it can find out the speed and the direction in which the device is moving. The accelerometer can be easily interfaced with an Arduino Micro-controller using analog pins. It measures acceleration with a range of ±3g. This accelerometer is low-power device and has very low noise consumption. The required current typically falls in the micro (µ) or milli-amp range. Voltage requirement is 3-6V DC.

Arduino is an open-source platform consisting of both, physical programmable circuit board and a piece of software that works on the computer and is used to write and push the code to the physical board. It has 14 digital input/output pins and 6 analog inputs, a USB connection, a power jack, a reset button. It is connected to the computer with the USB cable or is powered with a AC-to-DC adapter or a battery.

A GSM modem is a device which can be either a mobile phone or a modem device which can be used to make a computer or any other processor communicate over a network. It necessitates a SIM card to be operated and operates over a network range subscribed by the network operator. It can be connected to a computer through serial, USB or a Bluetooth connection.

The accelerometer ADXL335 has three outputs, one each for X-, Y- and Z-axes. The three analog outputs are wired to Arduino Uno pins. Input for the x-axis and the y-axis are taken at the analog pins A0 and A1 as the continuous readings of the sensor have to be monitored. When the threshold is reached, the LED and the buzzer which are connected to the digital pins turn on. They are connected to the digital pins so as to obtain HIGH (logic1) and LOW (logic0) (Fig.2). There is a resistor connected to the LED to protect it from damage in case of large current flow. When the buzzer sounds, a GSM (Global System for Mobile Communication) module is activated which stores the data and notifies the user.

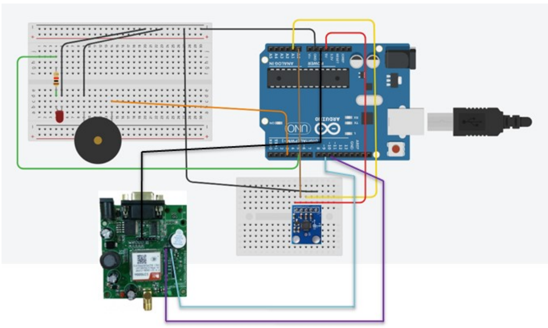

Fig.2 Interfacing of accelerometer, GSM module, buzzer and LED with the Arduino board

IV. TESTING

The Arduino setup reads the analog value of the accelerometer and communicates the acceleration to the computer. As and when an acceleration is imposed, the analog value can be read using Analog Voltage Read. The initial step is to read the analog value for the accelerometer at rest, which is the acceleration caused due to gravity ($g=9.81m/s^2$). At rest, the system has values x = [355] and y = [346]. The ground shaking is enforced by giving manual tremors and the new readings for x and y are obtained (Fig.3).

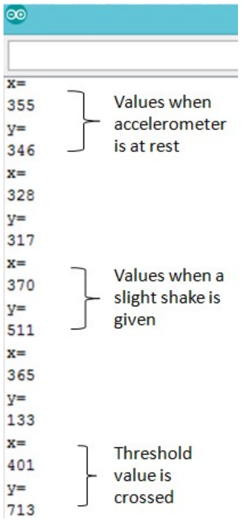

Fig.3 As the intensity of acceleration of these tremors is increased, it is observed that the values of x and y also increase. These set of values decide the threshold for the system. This threshold symbolically represents the crossing of the safety limit. As soon as the threshold is crossed, the GSM gets activated and sends the warning to start the mitigation process to the user.

The analog readings can be calibrated with the standard Richter scale magnitude values and Modified Mercalli scale (intensity of damage). The later makes it easier for common people to understand the extent of damage (Fig.4).

Intensity (Mercalli)	Observations (Mercalli)	Richter Scale Magnitude (approx. comparison)
I	No effect	1 to 2
II	Noticed only by sensitive people	2 to 3
III	Resembles vibrations caused by heavy traffic	3 to 4
IV	Felt by people walking; rocking of free standing objects	4
V	Sleepers awakened; bells ring	4 to 5
VI	Trees sway, some damage from falling objects	5 to 6
VII	General alarm, cracking of walls	6
VIII	Chimneys fall and some damage to building	6 to 7
IX	Ground crack, houses begin to collapse, pipes break	7
X	Ground badly cracked, many buildings destroyed. Some landslides	7 to 8
XI	Few buildings remain standing, bridges destroyed.	8
XII	Total destruction; objects thrown in air, shaking and distortion of ground	8 or greater

Fig.4 Richter scale measures the energy released during an earthquake and Mercalli scale is an observation that depicts the effects caused by the earthquake

V. CONCLUSION AND DISCUSSION

The On Site Earthquake Warning System focuses on automating the manual work of shutting off transit networks, gas pipelines and nuclear power plants. The aim is to mitigate the secondary damages that occur after an earthquake through sending a GSM warning alert.

This system is cost efficient, user friendly, accurate and robust so that it can be put to use in both rural and urban areas. The system can be used in remote areas by giving it an internal power house and using MQTT protocol which works on publish - subscribe model. This allows a

large group of people to access the data and get notified before the damage is caused.
For further development in this system, we propose that it can be calibrated using actually recorded earthquakes on seismometers/accelerometers and various warning thresholds may be set. The sensitivity of the accelerometer used here and its frequency response may be enhanced with better electronics.

ACKNOWLEDGMENT

This research was supported and assisted by Dr. V. K. Gahalaut who provided insight and expertise and made the project successful. We would also like to show our gratitude to the respected faculty of Electronics Department and all those who have supported us furthering our project experience through feedback and presentation opportunities.

REFERENCES

[1] Groot Robert de - ShakeAlert Coordinator for Communication, Education, and Outreach, https://earthquake.usgs.gov/research/earlywarning/overview.php. Accessed 4 February 2018

[2] Wu, Yih-Min, Hiroo Kanamori.(2005). Experiment on an Onsite Early Warning Method for the Taiwan Early Warning System. Bulletin of the Seismological Society of America, Vol. 95, No. 1, pp. 347–353.

[3] Allen, Richard M., Hiroo Kanamori. (2003). The Potential for Earthquake Early Warning in Southern California. SCIENCE, 300, pp.786-789.