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Earthquake Alarm Detector Microcontroller based Circuit for issuing Warning for vibration in Steel Foundations

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Abstract

The proposed study involves design and development for the earthquake alarm detection circuit based on electronic devices only which will be highly helpful for the determination of high frequency vibrations which will trigger an impulse when the S wave is detected by the earthquake sensor which in this case is a shaft with load that represents a steel or building structure that shakes vibrations when the corresponding surface wave reaches the ground. In this analysis we have identified the need for an electronically monitored high frequency detector circuit which triggers a pulse when the vibration occurs for earthquake occurrence for p wave followed by surface wave. The circuit is activated to read for 10 seconds with the use of an Arduino microcontroller that latches the output as high for 10 seconds and reads the shaft output vibration data for further diagnosis. If the p wave arrives, the s wave arrival is estimated to occur for the next 9 seconds for an intermediate depth based earthquake. This alarm detector circuit can be used in conjunction with steel based structures with a drill made to house the electronic instruments shown below and a microcontroller hereby to start an alarm for earthquake and also detect aftershock occurrences in steel based shafts and joint for better operation. One major limitation of geophones is the electrical damping. We applied a shunt resistor using back electromotive force which acts as damping. The maximum electrical damping is limited by the value of the passive resistor. We present the general architecture of the circuit with description and operation, design flow chart and implementation of the sensor. We create boolean sensing range for earthquake alarm detector and analyze how an inner and outer circle can identify the 'Earthquake Preparation Zone' or the seismogenic zone corresponding to an earthquake occurrence in the city to identify disaster region.

Keywords: *Sensor, Electronic Control Module, Earthquake Warning, Earthquake Monitoring Unit*

1. Introduction

Despite all the scientific advances in the field of earthquake prediction, the idea of accurate alarm and monitoring of incipient earthquakes using electronic monitoring tools for detection still remains a vision of the future. Although many techniques have been implemented and the avenues of scientific warning based on interdisciplinary analysis of electronic instrumentation, geophysical explanation and a consistent time margin between a potential warning and its eventuality remains a dream for scientists around the world; there is

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also a need to simultaneously get rid of any possibility of erroneous detections leading to false alarms associated with the different earthquake patterns and associated stress-strain interactions between the geophysical parameters and precursors. In order to extend the scope of analysis of the temporal and spatial evolution of stress in the different stages of the fault system associated with the complexity of the fault geometry, heterogeneity, and anisotropy of the rock for the host rock media exhibiting highly variable behavior in the incipient region (Schulz et al., 1973, Srivastava,1983) so that a plausible earthquake early warning system can be developed for earthquake risk mitigation for the region. There are three basic reasons we feel that earthquake prediction analysis has suffered due to the absence of reliable diagnostic precursors for different geo-tectonic settings responsible for earthquake genesis.

Existing Earthquake Warning Systems (EWS) are often based on a deterministic approach which led to many false alarms after the strong faulting segments accumulate strain to become areas of instability (Dutta et al., 2012 a,b). Secondly, sudden occurrence of earthquakes and their incipient source showing precursory behavioral patterns (Dutta et al., 2013) occurring in different parts of the world were associated with smaller response time that pre-detect a certain cluster of earthquake patterns (Dutta et al., 2012c). Thirdly, adoption of available earthquake resistant building codes assimilated up to a particular size of earthquake by several earthquake prone countries is also not apt to ensure reduced degree of earthquake hazards to infrastructures and vital structures located in seismically active regions.

The strategy to define the efficacy of an Earthquake Alarm uses seismometers to detect the first signature of an earthquake (*P* wave), to process the waveform information, and to forecast the intensity of shaking that will arrive after the (*S* wave). For local EEW installations, the *P* wave is detected onsite (i.e., at the user location), and the difference between the *P*- and *S*-wave arrival times defines the maximum alert time. For regional networks, the *P* waves are detected by sensors closest to the epicenter, and estimates are immediately relayed to earthquake alerting applications of the expected arrival and intensity of shaking at their location. It has been found from previous studies that velocity of the seismic body waves are directly proportional to the square root of the rigidity modulus. Elastic wave velocity is the square root of stiffness over density. For structures, as the density of the material increases so does the stiffness. The key here is that stiffness increases at faster rate than density. It is found that velocity tend to be faster in denser materials (Santamarina et al.,2001) for soils which are denser. A slight increase in density increases the shear modulus or rigidity of the material largely.

This causes increase in elastic wave velocity in denser medium. In case of P waves the velocity is proportional to sqrt((bulk + 4/3rigidity) modulus /density) where as for S wave velocity is only sqrt(rigidity modulus/density). As the bulk and rigidity modulus are positive quantities which increase at a greater rate than the density below the surface. In essence, P wave velocity is a measure of bulk modulus and S wave velocity of shear modulus so the vibration of the structure will also vary under the effect of high frequency vibrations. The constraint that is the kinetic energy per unit volume for vibrating medium is to be considered as constant. These constraints are prevailed because the process of earthquake genesis is found to be dynamic and the generating mechanism remains completely uncertain in terms of size and its depth of occurrence (Mishra,2007). An idea of detecting ground motion immediately after an earthquake occurrence and controlling automatic shutdown of systems and the like had already been adopted by a number of systems before the development of the EEW. The use of the microcomputer meter commonly found in Japanese homes whereby a ground motion detector is installed within a gas meter, and records a warning when the sensor detects ground motion exceeding a specific level, In all of these cases, the automatic shutdown system functioned as expected. Elevators, which are often used in our daily lives, also employ a function to automatically stop at the nearest floor when detecting ground motion. In reality, however, there are constant accidents where elevators stop upon an earthquake without the door opening, and people are trapped inside the elevators for many hours. The following instrumentation describes the some preferred embodiments of the present innovation which are purely for the sake of understanding the performance of the innovation and not by any sort of limitations.

Scientists all over the world have used the scenario of earthquake alarm diagnosis and design based on the detection of Primary(P) waves before the subsequent advance of the Surface(S) waves that can intensify to cause large scale destruction. Several earthquake detection instruments are already known and acknowledged primarily meant to detect earthquake waves such as the P waves. Intensified earthquake waves which propagate from the focus or the place of origin are mainly the P waves and S waves in that order. It is found that the intensity of the P waves and the S waves depend on the magnitude of the earthquake and also the distance from the focus or the place of origin.

In such areas which usually originate from the focus are of very low intensity and no consequence. In that context, the device needs to be set to detect the intensity of the P wave and asses thereafter the evacuation of the people based on the alarm sound. Furthermore certain locations are also prone to very large scale erosions and landslides due to mining. The device should detect the presence of the earthquake wave to respond to earthquake waves in predetermined scale of range. The earthquake detection device in accordance with the present electronic sensor based design is aimed to address the disadvantage of the earthquake detection devices in the form of the alarm and can be made available at a reasonable price due to the low manufacturing cost and also low maintenance costs due to the simplified construction. The instrument can also be made into global applications to monitor the state of the steel structures in varying geographical locations for domestic and administrative buildings for the purpose of simple and fairly easy operation. Further it is common knowledge that earthquakes of higher degree is followed by a subsequent earthquake at intervals of small span ranging from few hours to few days.

The device in accordance with the present invention is adapted to be automatically adjustable for detecting the series of earthquakes from source in the event of issuing an alarm for indicating possible earthquake events. A sensor is able to monitor the following application using intricate electronic engineering tools. This component senses the speed input signal, integrates it to deduce the angular position, and uses this position along with an internal reference signal to generate amplitude modulated output signals that resemble those that would be generated by a typical sine-cosine resolver. This component is designed to be connected to the shaft of the machine components. It presents neither an inertial nor a frictional load to the shaft for application of magnetostrictive effect with respect to interference of a longitudinal wave (P wave) forms the tool for the detection process. When a longitudinal wave passes through a ferromagnetic system (consisting of a ferromagnetic rod suspended between a well calibrated system of electromagnets providing a constant magnetic field), each and every particle of the wave suffers a shift in its velocity profile due to the domain shifting process in the material (Klark, 1951). As a result, there occurs a suitable increment in the wave velocity after the longitudinal wave crosses the system. The variation in temperature in medium causes a drastic change in elastic property of the wave. The particles of the P wave spectrum undergo systematic shift in their velocity profile due to which the velocity of the wave sharply decreases with the increase in temperature. The process of decrement of wave velocity as the wave passes through a high temperature medium provides a unique mark

When a p-wave is detected by a seismograph, the wave's frequency and amplitude is recorded for four seconds in order to decrease the possibility of false positives caused by local activity such as road traffic or construction (Ryall, 2008). This data is then sent to Arduino Micro controller which will trigger a pulse to detect the initial impact of the p wave and followed by an S wave for detection and issue a warning after the earthquake has released its initial seismic waves. The EEWS is most useful for regions that are located at least 100km from the earthquake's epicenter. This distance translates into an approximately 20-50second warning. The area located within the 100km radius is known as the blind zone and is too close to the hypocenter to receive a warning. Because of this blind zone, it is important that this system is complemented with on- site earthquake detection mechanisms, particularly in heavily populated urban areas or near critical factories handling dangerous machinery or chemicals. In this way, earthquake detection relies not only on seismographs, but also locally installed and operated seismograph devices, which helps to improve both accuracy and reliability of earthquake detection for the purposes of disaster mitigation.

2. Overview of the Proposed Model

We have designed an electronic device which will help us to identify the detection of the initial tremor due to fracture on the surface and identification of the primary wave and the surface wave respectively in the elastic rock medium. The surface wave is transverse resulting in horizontal displacement causing maximum damage on the surface. So the detection of the first triggered s wave parameters, named as PI (P wave index) and DI (Damage Intensity) of seismic motion are proposed to be able to define destructiveness of the earthquake and effectively realize P wave alarm system. DI is defined as an inner product of acceleration and velocity vectors, at each time step.

Multiplication of DI with mass received seismic motion indicate a power of motion acting to the object. With a P wave arrival, DI increases drastically and after S wave arrives it reaches to its maximum value. This value (maximum of DI) is named as DI value. PI is defined as maximum of DI calculated at the time step around P wave arrival and this value is suggested to be used for realizing P wave alarm. DI value is directly related to the seismic intensity and earthquake damage. With a continuous calculation of DI, P and S wave alarm can be issued (when PI exceeds the preset level P wave, and when ordinary monitored values or DI value exceed preset level S wave alarm can be issued).However the process of detection of the tremor was so far done using only pendulum, electro-mechanical devices and piezometers. We have changed the study to identify the nature of the s wave on the steel structures and the associated frequency components which is a significant analysis for Damage Index identification. Our motive for doing this study is to detect the presence of damage done on the steel structure and identify the process of alarm when the earth vibrates that is identified as a seismic occurrence. We have modeled our study based on two approaches using a sensor based design involving a shaft which moves on detecting a large vibration and a drives a load resistor of 1M in parallel with a 5.1v Zener diode just to protect the IC's against any large voltage spikes in the event of a large physical bump.

The raw output of the piezo unsuitable for direct input to the Arduino as it is typically a very small voltage signal and needs amplification, so the signal is amplified as the signal from the piezo with a 221 gain non-inverting op-amp using one side of an LM358 the other side of the LM358 for a comparator. The sensitivity of the vibration sensor is controlled using a potentiometer for the threshold (negative) input into the comparator. The other (positive) input to the comparator comes from the amplifier of the piezo signal. The output of the comparator provides a direct input to Arduino Uno digital pin 8. When it senses vibration, a simple piezo buzzer driven directly from Arduino Uno pin 13. A 0.1 micro farad was later connected for the output from the piezo element to the input of the op-amp, also grounded on the op-amp side using a 100k resistor. This acted as a DC decoupler and effectively lowered the comparator threshold required to detect vibration.

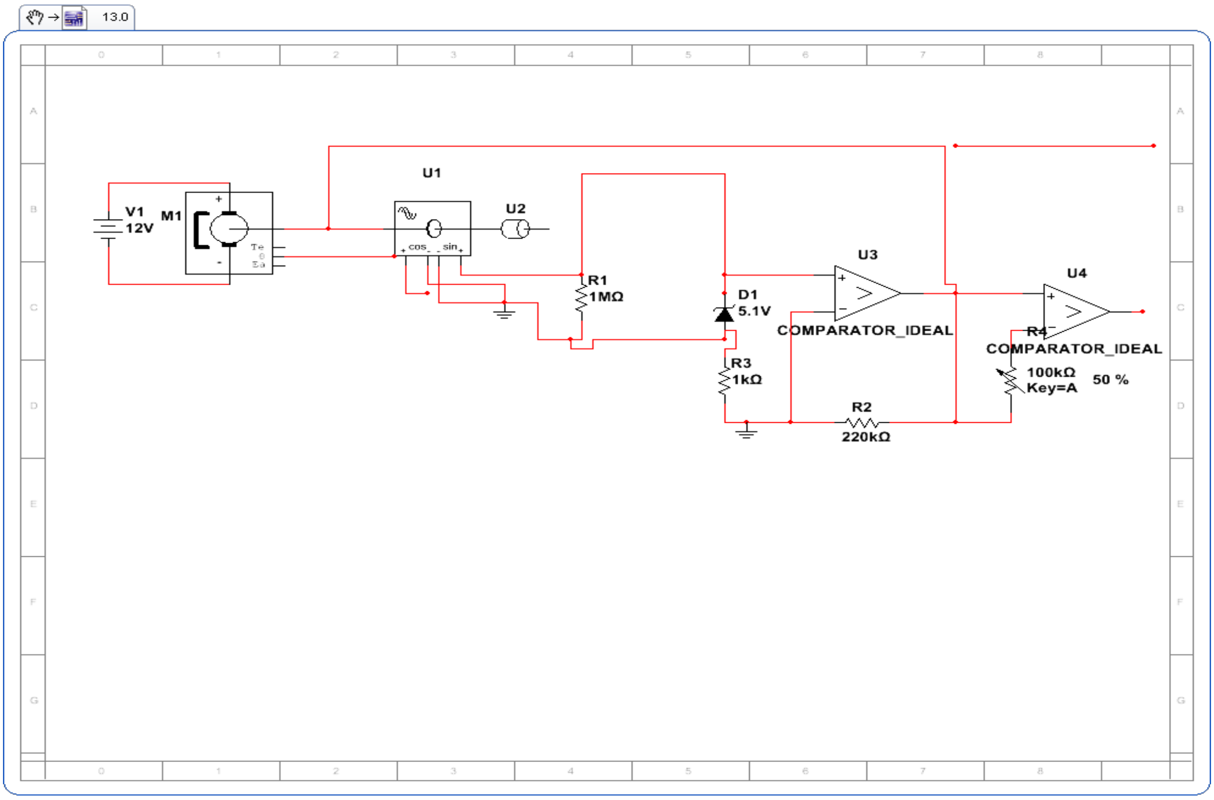

Figure 1: Circuit Diagram of the Proposed Electronic Model

3. Circuit Model and Hardware of the Circuit

In steel oriented structures, it is hard to define a certain position where the maximum impact of vibration will be felt. In order to generalize, we normally consider the joints of the steel based structure to carry the maximum burden of the load and can certainly develop bends which leads to fractures in the nearby corners. Special hoist (logging-hoist) is used in which measuring equipment is set and connected by digital communication channel with the central point of control according to RS-232 mode based on the received signal strength (Dutta et al., 2015).

When piezoelectric ceramics are used as sensors, there is usually some noise in the measure voltage. All sensors located with merged in modern radio channel (Dutta et al., 2013b) which analyzes the data obtained for their size and approximately the expected power events, as well as the position of the epicenter. In the present earthquake sensor circuit, we have used a high frequency vibration detection monitoring circuit which can be used for the detection of seismic detector unit as the detecting agent as shown in **Figure 1**. The circuit design of a Electronic module is shown in Figure 2. The top module has been designed by feeding pulses through an AC source that simulates the output from a detector counter.

The Arduino program sketch has been shown in the code to follow as shown in **Figure 2**. It is found that the sketch of the program is given below as shown whereby the setup code of the program and the loop shows the coding involved. We have set up a time scale of 8000 ms or 8 secs. It can be seen when the revolver circuit extracts the information along the vibrational input pin which is High when the first vibration is detected. Thereafter the processing signal latches the circuit and keeps on reading the circuit for another vibration. When a high frequency signal is detected within the next 8 secs, the output is detected as high and the LED will blink and the BUZZER circuit will be active. The circuit is based on the principle of latching that is used for earthquake alarm.

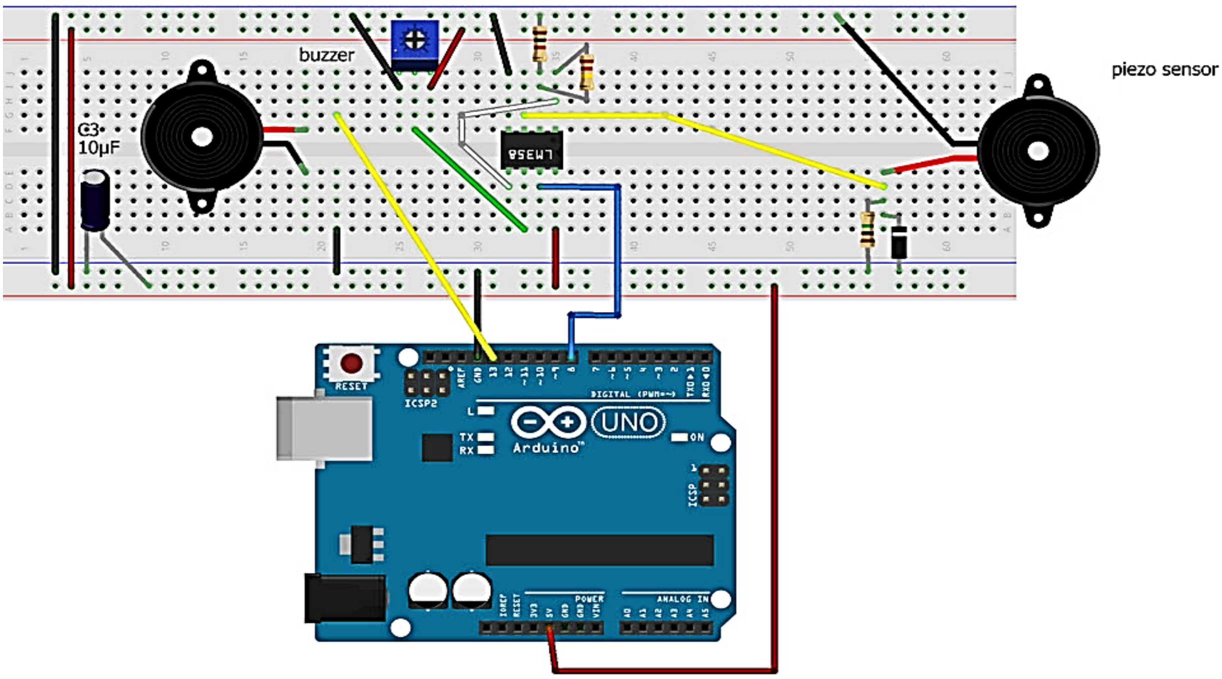

Figure 2: Hardware Schematic of the Proposed Electronic Model

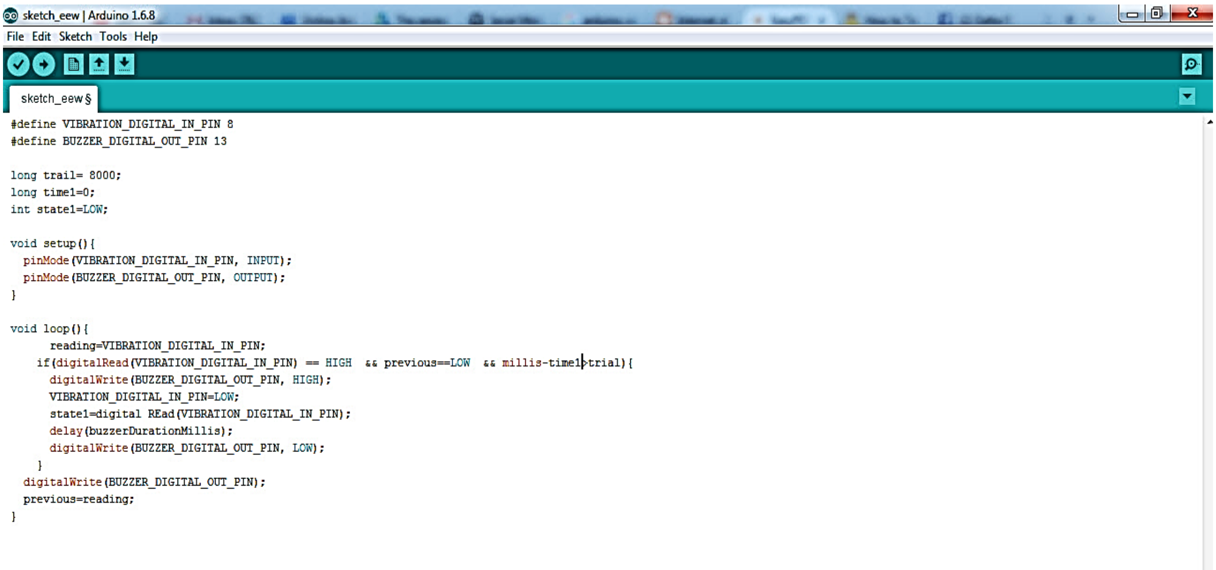

Figure 3: Coding and analysis of the Proposed Electronic Model

4. Identification of the sensing seismogenic zone

The study warrants ‘‘target zone’’ has been defined as the study area which constituted from porous cracked saturated rocks and with high capacity of cracks growth during increasing tectonic stress. The natural pre-earthquake phenomena such as gravity variations, radon emanation, anomalous electric field and changes in meteorological parameters like temperature and relative humidity can be found statistically and empirical relation can be drawn in respect to a regression equation based on geo-spatial variables (Dutta et al., 2011, Dutta and Mishra, 2017a, Dutta, 2016, Dutta, 2017).

The concept of Earthquake Preparation Zone which is the first sign of an imminent earthquake is described. According to this concept all the ground based pre-earthquake signals are generated all over this zone. The size of this zone is dependent upon the size of the earthquake under preparation and may have a radius of more than 300 km for an earthquake of magnitude 6. Furthermore, use of dedicated satellites to monitor earthquake precursors from space (Dobrovolsky, 1971) has been defined for a centralized prepare zone; not for a wide area. As the target zone is a circle of radius 5 km and the monitoring station located at the center of this area, the uncertainly parameter is considered 5 km.

4.1. Earthquake Preparation Zone

The concept of earthquake preparation zone was developed by different scientists, Dobrovolsky(1971), Keilis-Borok and Kossobokov(1990) and Bowman et al.(1998). This is an area where the local deformations and their effects caused by the future earthquake are observed. For example, the deformations cause strain accumulation in the crust which can be measured by strain gauges and tilt meters (Yoshihisa et al., 2002) as well as by GPS (Kostoglodov,2003), predict formation of cracks within the preparation zone and this will result in changes in seismic wave velocity, density, electric resistivity, ground water level(Khalilov, 2005). All these changes can be monitored experimentally. Continuous Monitoring of the above precursors and their real-time recording at a Central Station have been planned at CES. This will be more effective and advantageous than random measurements taken now and then elsewhere so far. Also, for the non-circle target zone, it is better to fit a circle to the range of study area and then finding this value. Afterwards, for each disturbed station (stations which show anomaly), a circle of radius R = R'+ dr has been drawn which called 'investigation circles' (In.Cs). After drawing the In.Cs, 'Expectation circle' (Ex.C) is defined as a circle of radius R which its center being within the target zone And finally, the springs which located within the Ex.C are called 'Expectation Springs' and denote by Ex.Ss.

For Early Warning based on WSNs, the stations (the seismological term) or nodes (networking term), are deployed in the city itself, that is, where the damaging is to be expected. This approach is called an On-site system – in contrast to Front-detection systems, where the stations would be placed near to the hot springs. D/R ratio is described which D is the strain radius and R is distance between monitoring station and earthquake epicenter (km). Radius of the zone within which precursory phenomena may be manifested (so-called strain radius R in Dobrovolsky equation). First of all, the ''target zone'' has been defined as the study area which constituted from porous cracked saturated rocks and with high capacity of cracks growth during increasing tectonic stress. In this distinctive zone, a radon monitoring measurement in soil and groundwater has been implemented using Electronic circuit based analysis as shown in (Dutta, 2016) (radon precursory study in soil and groundwater is quite difference in measurement methods, but not in interpretation with seismic events).

If any anomaly has been observed in two or more than two monitoring stations, the distance between the farthest of them and the center of target zone (R`) has been measured. In this study—and by most scientists—an anomaly defined as radon concentration spike crossing ¯x +dr where ¯x is the average and dr, the standard deviation . Then several kilometers according to vastness of target zone must be added to this measured value as ''uncertainly parameter'' (dr). Dobrovolsky equation has been defined for a centralized prepare zone; not for a wide area. For example, if the target zone is a circle of radius 5 km and the monitoring station located at the center of this area, the uncertainly parameter is considered 5 km. Also, for the non-circle target zone, it is better to fit a circle to the range of study area and then finding this value.

Afterwards, for each disturbed station (stations which show anomaly), a circle of radius R = R` + dr has been drawn which called 'investigation circles' (In.Cs) as shown in Figure 4. After drawing the In.Cs, 'Expectation circle' (Ex.C) is defined as a circle of radius R which its center being within the target zone And finally, the springs which located within the Ex.C are called 'Expectation Springs' and denote by Ex.Ss. Proposed algorithm establishes a new high accuracy method to obtain the range of location and magnitude of a coming earthquake for a target zone. In the first step, we assume that between these hotsprings, three of them indicate anomaly in radon concentration (for example A1, A2 and A3). In the second step, according to proposed algorithm distance between A3 and center of city X—which introduced as target zone—is about 84.6 km (R0) which is more than the other distances. So, we nominate the A3 as the farthest station which anomaly has been observed. In third step, by considering the vastness of Xth city, it is inferable that dr = 10 km should be added to R0. R= R0+ dr= 84:6 + 10 = 94:6 km. In the next step, we draw a circle of radius 94.6 km to the center of Xth city as Ex.C (red circle). Between the all selected hot-springs, four of them located within this circle: A1, A2, A3 and A4. Then we draw four circles of radius R in the center of these hot-springs as In.Cs. The area of interface between these four In.Cs becomes 1,477 km2 which illustrate the location of coming earthquake. Also, between the undisturbed hot-springs, Station C is the nearest station to Xth city which lies outside of Ex.C. Therefore, considering dr = 10 km for X—as described before—we have: $L = L_0 + dr$ = 109:2+ 10 = 119:2 km.

The capability of proposed algorithm to implementation in all kind of geological structures because Dobrovolsky equation has been examined in different structures whereby capability of proposed algorithm to design various continuous radon monitoring networks in soil and groundwater to predict earthquakes. – Proposed algorithm can be used for all geochemical precursors to predict earthquake. Have some sensing range and complete coverage of detected area D if A_i denotes the size of area covered by i^{th} placed sensor node. Minimum number of working nodes is equivalent of minimum of size of overlap region and can be calculated as shown below.

Our research is based on boolean sensing model where sensor node can detect only events that are within certain range of it for a circular article. Let r denote the sensing range of each node, and l denote the radio range. It has been proved that if the radio range is at least twice the sensing range, complete coverage of a convex area implies connectivity among the working set of nodes. Assuming that n sensor nodes are randomly distributed over radius R region. Set of {S1 ,S2 ,S3,… } , for all$1 \le i \le n$, let Ai denote the size of area that is covered by the ith placed sensor node, As sensor nodes are uniformly distributed, G_i is expected to be the proportion of the uncovered area to the whole deployment area.

$E[G_i]=A-E[C_{i-1}]/A$

$E[C_i]=E[C_{i-1}]+ A-E[C_{i-1}]/A^* E[A_i]$

which A_i^j denote the size of j -covered area after i sensor nodes have been placed in j

Y_i denote the extra area to the sensor region of i th placed sensor node to the size of j -covered region, P_i^j is the proportion of Y_i^j to A_i .

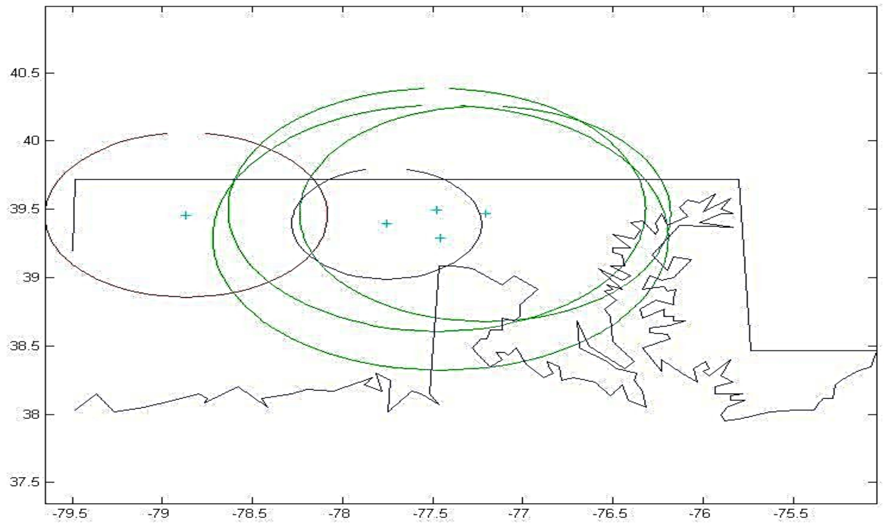

Figure 4: Sensing Range Identification based on Inner and Outer Expectation Circles

Our study hereby shows that the process of identification of reducing the overlapping area to reduce the number of working nodes, the lifetime of wireless sensor networks can be prolonged. Since E[A]/A is the probability of link occurrence p, $A = \pi r^2$, and E[Cn] expressed as follows: we can obtain the result to k-coverage problem.

For all $0 \leq i \leq n$, $0 \leq j \leq k$, and i j.

$E[Cn]=[1-(1-r^2/R^2)^n]A$

The equation will help us to analyze network life vs number of nodes with full coverage R and initial amount of energy of each node for considering a cellular pattern of k range

$0 \leq i \leq n, 0 \leq j \leq k$ and I_j. $E[A_i^j]=E[A_{i-1}^j]+E[Y_i^j]$ $E[Y_i^j]=E[P_i^j]+E[A]$

Whereby A_i^j is size of the j covered area after i sensor nodes has placed ; Y_i^j is extra area to sensor region of ith placed sensor node to the j covered region. P_i^j is proportion of Y_i^j to A_i .

$E[P_i^j]=E[Y_i^j]/E[A]= E[A^{j-1}_{i-1}] - E[A^j_{-1}]/A_i$ $0 \leq l \leq i-j$

$E[A_i^j]=(1-p) E[A_{i-1}^j]+p E[A_{i-1}^{j-1}]$. Lemma 1:if Si Є{S1,S2,..Sn}

This will correspond to the sensing range and complete coverage of detected area D if A_i denotes the size of area covered by ith placed sensor node. Minimum number of working nodes is equivalent of minimum of size of overlap region for A`=|| D size of area covered by ith node for degree of overlapping coverage at any point where H(x)= If x $I_R(x)=1$ or else $I_R(x)=0$; And if $x \in$ $I_i(x)=1$ or else $I_i(x)=0$; $L=n|A_i| -|D|$. By reducing the overlapping area to reduce the number of working nodes the lifetime of sensor networks can be prolonged.

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Consider a deployment region of size A. Let a denote the size of nodes sensing region outside the detected area R'' , P denote the probability of n sensor nodes coverage. Given a fixed sensory range such that the expected node coverage is E[N], the number of sensor nodes is suffice for this inequality. As the proportion of the sensing range of nodes to the range of de deployment area is known, the number of nodes needed to placed to achieve the multi-coverage fraction can be estimated that achieved the coverage and connectivity requirement. Our study can be modified further with the application of the optimization algorithms which can identify the spatial framework through the interaction of stress and strain framework(Dutta and Mishra, 2017b).

Log(1-P) <n< log(1-P)

Log (1-E[N]/A) / Log (1-E[N]/A+a)

Size of the sensing is πr^2 ignoring the bordering effects probability of each point p(x,y)ЄD covered by at least one node is equal to the probability of the node distributed in the neighborhood. The probability of one node sensing whole area is $\pi r^2/A$

Probability of two nodes $P^2=P(A)+P(B)-P(A)$

$$=p+p-(p*p)=2p-p^2$$

Probability of three nodes $P^3=P^2+p-P^2*p$

$$=2p-p^2+p-(2p-p^2)*p$$

$$=1-(1-p)^3$$

By mathematical induction we can deduce that $p=1-(1-p)^n$

$N=\log(1-p)/(1-\pi r^2/A)=\log(1-p)/\log(1-\pi r^2/A)$

$n>\log(1-P)/\log(1-\pi r^2/A)$

This shows if the proportion of sensing range to range of deployment area is known, the number of nodes needed to be placed to achieve multi-coverage fraction can be estimated that achieved coverage and connectivity requirement.

Conclusion

The design of the device is a representation of an innovative approach in construction of an earthquake warning and alert system. Reducing the capacitor further enhances the response time of the circuit. The system uses two different subsystems and detects the change in the strain pattern by the subsystems. All sensors used are readily available and cheap thus making it a user friendly and affordable product. Initially spurious readings, plus the trigger is sometimes late. It seems like the results are much worse using long (~3 M) leads between the circuit and the piezo element. Is the amplifier strong enough to pick up electromagnetic interference from the leads, or sensitive to the extra impedance from the longer leads.Secondly, the low frequency characteristics can be changed based on the RC time constant in the circuits involved. Proposed algorithm establishes a new high accuracy method to obtain the range of location and magnitude of a coming earthquake for a target zone. Increasing the accuracy of results could be obtained with increasing the number of seismic monitoring stations.

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