Design and Construction of a Multichannel Microcontroller Based Seismograph for Field and laboratory Use

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ABSRACT

The recent integration of technology requires today's geosciences students to develop solid geotechnical skills. Advances in analog to digital technology and the availability of low cost integrated circuits, microprocessors, microcontrollers and high capacity Laptops enable easy and inexpensive construction of a multi-channel seismic data collection system that can be used to teach students the fundamentals of seismology and also for the collection of natural and artificial seismic data acquisition. In this research the step by step of design, construction, programming and coding of the real time, smart multichannel microcontroller based seismograph was constructed and the analysis was done to ascertain the functionality of the system for field and classroom work. The system comprises of over six different units such as the pre-amplification unit, filtering unit, amplification unit and the Analog to Digital conversion as well the sensing unit. ATmega 8 was used as the microcontroller unit and was programmed using C-language, the filtering section was made up of four different filters (Low Pass, High Pass, Band Pass and All Pass) this is to allow the system to be able to sense and read any frequency no matter how small and each filter units are referred to as channel. Relay was used to select the channel after receiving instruction from the GUI. Graphical User Interface (GUI) software was written using a simple VisualBasic.Net system, it sends and receive signal in real-time which is displayed in waveform on the screen of a computer. The system shows a perfect accuracy and precision in measurement and expected conformity with the existing seismograph. The achievability of this purpose would increase the practical knowledge of students undergoing courses such as geophysics, geology and civil-engineering, us reduce foreign exchange also save life's and properties of Nigerians and will be a source of income to the Department of Physics and University of Uyo in general if it could be invested on for mass production.

Keywords: Seismograph, ATmega, GUI, multi-channel and Interface.

INTRODUCTION

Seismology without instrument would be a very different science without instruments. The real big advance in seismology happened from around 1900 and onwards and was mainly due to advancement in making more sensitive seismographs and devising timing systems so that earthquakes could be located. Later the importance of accurate measurement of the true ground motion became necessary for studying seismic wave attenuation and Richter magnitude scale depend on being able to calculate the ground displacement of a seismogram (Jen and Gerador, 2002). A seismograph is a device for measuring the movement of the earth and consists of a ground motion detection sensor called a seismometer coupled with a recording system. A simple seismometer that is sensitive to up and down motions of the earth can be understood by visualizing a weight hanging on a spring (Lee and Stewart, 1981).The spring and the weight are suspended from a frame that moves along a vertical ground motion. If a recording system is installed such that a rotating drum is attached to the frame and a pen is attached to the mass, the relative motion between the weight and the earth can be recorded to produce a history of ground motion called a seismogram (Lawrence, 2001). The ability to do earthquake location and calculate magnitude immediately brings us into two basic requirement of instrumentation keeping accurate time and determining the frequency dependent relation between the measurement and the real ground motion in Figure 1.1 (Jen and Gerador, 2002).

Earlier, analog instruments were usually made to record one type of ground motion like velocity. Traditionally, seismologists prefer recording weak motion displacement or velocity, for easy interpretation of seismic phases, while engineers use strong motion acceleration, whose peak values are directly related to structures seismic load. Today, it makes less of a difference, since due to advancement in sensor and recording systems, the weak motion instruments can measure rather strong motions and the strong motion sensors are almost as sensitive as the weak motion sensors.

Table 1.1 typical frequencies generated by different seismic sources (jen and gerardo, 2002).

Frequency (Hz)	Type of Measurements
0.00001-0.0001	Earth tides
0.0001-0.001	Surface waves, earthquakes
0.001-0.01	Earth free oscillations, earthquakes
0.01-0.1	Surface waves, P and S waves, earthquakes with M > 6
0.1-10	P and S waves, earthquakes with M> 2
10-1000	P and S waves, earthquakes, M< 2

Seismic Waves Theory and Definitions

Two basic types of elastic waves or seismic waves are generated by an earthquake; these are *body waves* and *surface waves*. This wave causes shaking that is felt, and causes damage in various ways. These waves are similar in many important ways to the familiar waves in air generated by a hand-clap or in water generated by a stone thrown into water (Kayal, 2016 and Shelby *et al*; 2014).

Body Waves

The body waves propagate within a body of rock. The faster of these body waves is called Primary wave (P-wave), or longitudinal wave or compressional wave, and the slower one is called Secondary wave (S-wave) or shear wave (Shelby *et al.*, 2014).

P-wave

The P-wave motion, same as that of sound wave in air alternately pushes (compresses) and pulls (dilates) the rock (Fig 1). The motion of the particles is always in the direction of propagation. The P-wave, just like sound wave, travels through both solid rock such as granite and liquid material such as volcanic magma or water. It may be mentioned that, because of sound like nature, when P-wave emerges from deep in the Earth to the surface, a fraction of it is transmitted into atmosphere as sound waves. Such sounds, if frequency is greater than 15 cycles per second, are audible to animals or human beings. These are known as *earthquake sound* (Kayal, 2016).

Elastic constants E (Young's modulus), σ (Poisson's ratio), K (bulk modulus), μ (rigidity modulus), λ (Lame's constant) and density ρ is given by equation 1.1 as follows:

$$V_\rho = \left\{\frac{(\lambda + 2\mu)}{\rho}\right\}^{\frac{1}{2}} \quad \text{Equation 1.1}$$

S-wave

It is known that the S-wave or the *shear wave* shears the rock sideways at right angle to the direction of propagation (Fig.1). As shear deformation cannot be sustained in liquid, shear waves cannot propagate through liquid materials at all. The outer portion of Earth's core is assumed to be liquid because it does not transmit shear waves from earthquakes. The particle motion of the S-wave is perpendicular (transverse) to the propagation. If the particle motion of the S-wave is up and down in vertical plane; it is named SV wave. However, S-wave may also oscillate in horizontal plane, which is called S wave which is written mathematically as equation 1.2.

$$V_s = \left(\frac{\mu}{\rho}\right)^{\frac{1}{2}} \quad \text{Equation 1.2}$$

Equation 1.3 show the relationship between S-wave velocity Vs, the elastic constants and density is given as:

The velocity ratio

$$\frac{V_\rho}{V_s} \quad \text{Equation 1.3}$$

Comparing the equations (1.2) and (1.3), we find that the ratio of compression to shear wave velocity as equation 1.4:

$$\frac{V_\rho}{V_s} = \left(\frac{k}{\mu} + \frac{4}{3}\right)^{\frac{1}{2}} = \left(\frac{1-\sigma}{\frac{1}{2}-\sigma}\right)^{\frac{1}{2}} \quad \text{Equation 1.4}$$

For most consolidated rock $\frac{V_\rho}{V_s}$ ~ 3. In this context, it may be mentioned that amplitudes of S-waves are generally five times larger than those of P-waves. This follows from the far field term of Green's function when modeling earthquake shear sources taking into account $V_p \sim 3V_s$. Also, the periods of S-waves are longer, at least by a factor of 3, then those of P-waves due to differences in wave propagation velocity (Kayal, 2016).

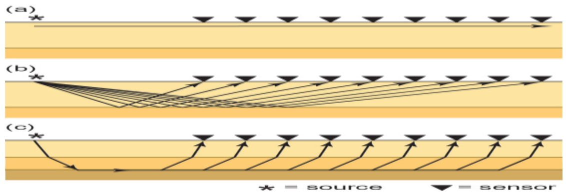

Figure 1: The travel path of a (a) direct wave, (b) reflection, and (c) refraction.

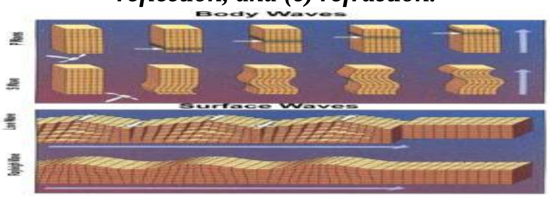

Figure 2. Showing Rock Dilation deal to effect of wave (Body wave, Love wave and Rayleigh Wave (Kayal, 2016)

Geophones

Geophone is a device (sensor) that converts ground movement (velocity) into voltage which may be recorded at a recording station (Wikipedia); the deviation of this measured voltage from the base line is called the seismic response and is analyzed for the structure of the Earth. Geophones have historically been passive analog devices and typically comprise a spring mounted magnet mass moving within a wire coil to generate an electrical signal. (John, 2011*)*. Recent design has been based on micro electromechanical systems (MEMS) technology which generates an electrical response to ground motion through an active feedback circuit to maintain the position of a small position of a small piece of silicon. The response of coil magnet geophone is proportional to ground velocity, while MEMS have a much higher noise level (50dB velocity higher) than geophone and can only be used in strong motion or active seismic applications (John, 2011). The term Geophone means: Ge mean the Earth and Phone Means Sound i.e. detecting the earth sound.

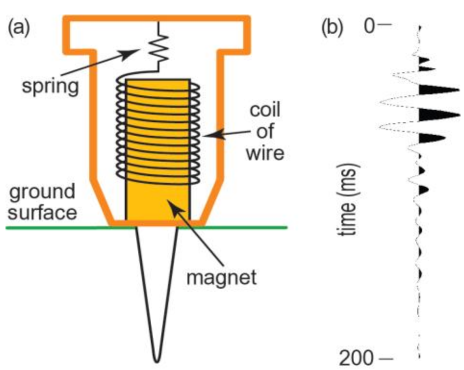

Figure 3: Internal Structure of a Geophone showing induction coil.

Material and Method

The system was designed with both passive and active components and modules. The components used in this work include: geophones, microcontroller, IC programmer, Analog to Digital Converter, Battery, Laptop, Amplifier, USB Cable and the active components used are resistors transistors and diodes. Other measuring instruments such as voltmeter and ammeter were also employed in measurement of voltages and current. The method employed in actualizing this research work is in three major stages. The design of circuit diagram, programming the microcontroller with basic language (C- language) and simulation of circuit using Proteus software to determine the virtual switching behavior of the circuit components before proceeding to system implementation. Secondly, the circuit construction will be actualized which will be used to obtain data and plot graphs for proper findings.

Third is the writing of software using Visual Basic.Net for interfacing the seismograph waveforms display in real time.

System Design

The system design involved the block diagram, Flow chart diagram and Programming of microcontroller chip as well as circuit diagram which is used to describe the hidden details and components interconnectivity.

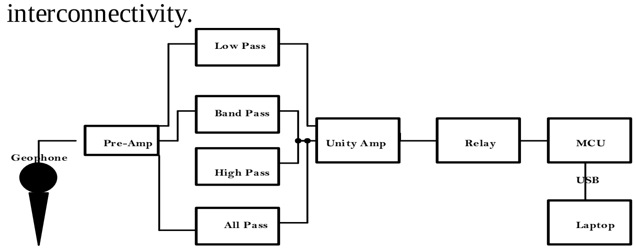

Figure 4: Block Diagram

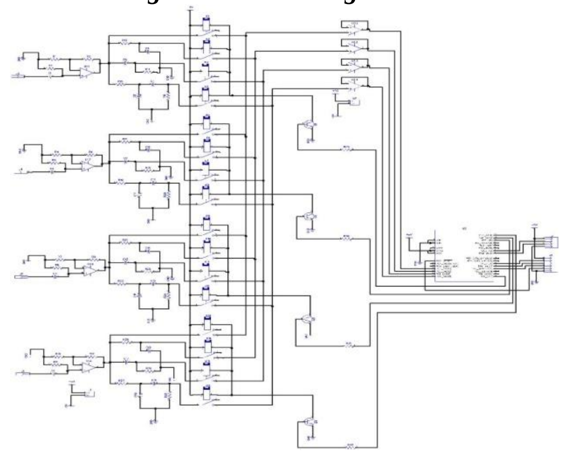

Figure 5: 4Channels Multichannel Seismograph Complete Circuit

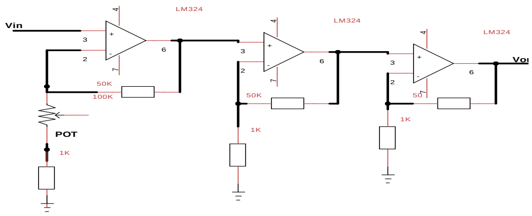

Figure 6: Cascaded Amplifier

The gain equation for a cascaded amplifier used is given as:

$$A_V = 1 + \frac{R_f}{R_i} \qquad \text{Equation 1.5}$$

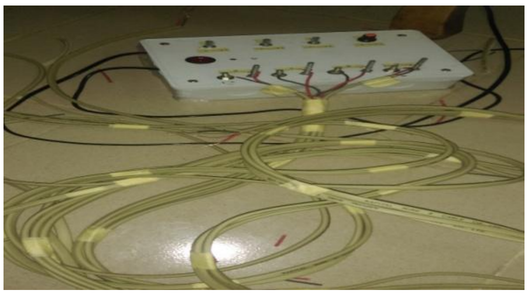

Figure 7: Complete System

Figure 8: GUI App

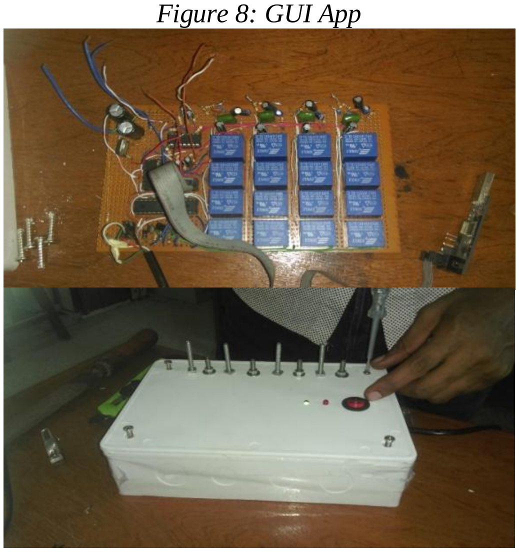

Figure 9: Constructed and Coupled Seismograph hardware showing all the components and units.

Figure 10: Field experiment

Result and Conclusion

In this research a real time wireless seismograph has been constructed using available component and resources available in Nigeria and software has been developed which serve as the (GUI) interface between the hardware system and the laptop, the seismograph was calibrated using a readymade system which was borrowed/obtained from University of Calabar Geophysical Laboratory and artificial seismic signal was generated and measured in real time. The final construction displayed a perfect measurement after being calibrated and compared to the data for the readymade system seismograph put under the same conditions. The obtained results show a very close signal waveform to the readymade system. Figure 12 below is the picture of the constructed seismograph and the waveform display during the test. The waveform result for the test conducted after the calibration showed a perfect waveform with the frequency along the X-axis and the time along the Y-axis also the readings is digitally displayed below the graph along with the co-ordinate for the sensors location and adds menu show the sensors location name.

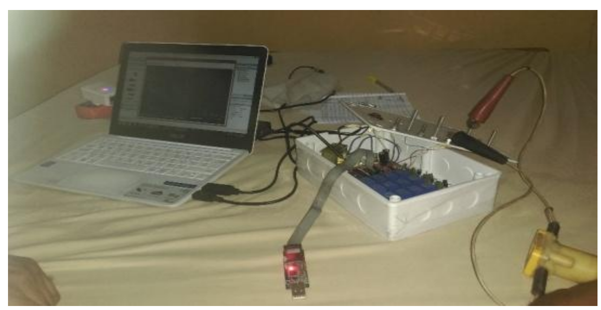

Figure 11: Implemented Seismograph put under test with the Geophone

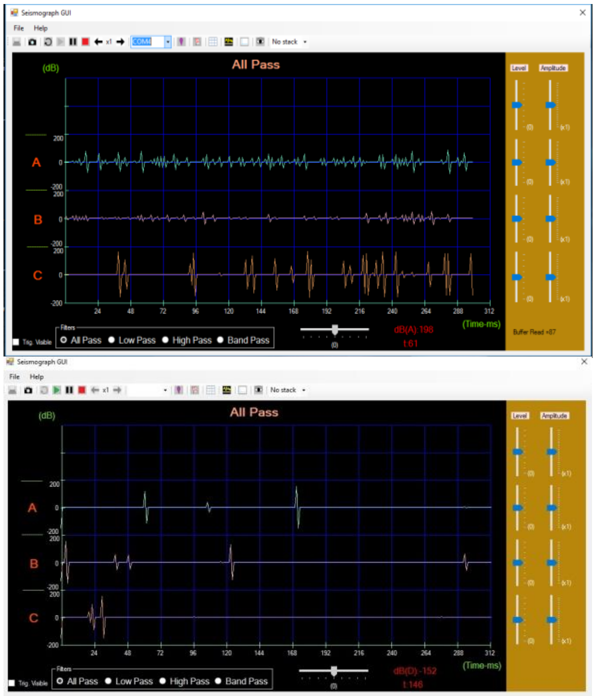

Figure 12: GUI showing the waveform for APF, LPF, HPF and BPF for Geophone A and B

CONCLUSIONS

The integration of technological techniques to the scientific instrument locally in Nigeria is of very important because of the economics and technological improvement in Nigeria. Geological principles are continuously being integrated with fast and efficient high tech equipment and techniques to improve our understanding of the Earth. Geology and Geosciences students need to improve their knowledge of seismology and all other advanced geophysical methods to complete in their transient environment. The construction of inexpensive microcontroller based seismograph for data acquisition can widely be used for field work and as well as for the classroom experiment for the students in order to broaden their knowledge in seismology.

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