DESIGN OF A LOW COST ACCELEROMETER MEASURING AMBIENT VIBRATION USING PIEZOELECTRIC DEVICES

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DEDICATION

Special dedication to people that I love most, I would like to present my project work to my family in their support and moral since I learn from standard one until now, my lovely mother and my supporting father. The project work now is a gift that I have design and hope it will be useful to people. Not forgetting also to give special thanks to my brothers and sisters that always gives me their support and happiness.

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ABSTRACT

Vibration and shock are present in everywhere. It may be generated and transmitted by machine tools, human body and buildings. An accelerometer is a device with sensor that measure vibration or acceleration of a motion structure. In this report we look at issues related with designing and developing a low cost accelerometer measuring ambient vibration by using piezoelectric devices. We survey existing technique and technology of accelerometer. However, these accelerometers do not fulfill the constraints imposed by people in term of cost and its performances. Additional constraint that we impose by using piezoelectric cantilever is hard to be integrated. In this project, the low cost accelerometer consists of piezoelectric sensor and charge amplifier. The charge amplifier is constructed and signal output is analyzed. The piezoelectric electric sensor element made up by PZT material and with physical size (0.51mm × 3.2mm × 31.8mm). The use of charge amplifier to amplify the voltage output from piezoelectric accelerometer. At the end of this project, the expected outcomes are analyzing a cantilever-based accelerometer which can be used to measure vibration acceleration level and frequency.

ABSTRAK

Getaran dan kejutan wujud di merata tempat. Ia boleh dijana dan dihantar oleh alat-alat mesin, badan manusia dan bangunan. Pengukur pecutan adalah satu alat dengan peranti yang mengukur getaran atau pecutan struktur pegerakan. Dalam laporan ini kita melihat isu-isu yang berkaitan dengan merekabentuk dan mencipta alat pengukur pecutan kos rendah yang mengukur getaran sekeliling dengan menggunakan peranti piezoelektrik. Kami meninjau teknik yang sedia ada dan teknologi pengukur pecutan. Walau bagaimanapun, pecutan ini tidak memenuhi kekangan yang dikenakan oleh orang ramai dalam bentuk kos dan prestasinya. Tambahan pula, kekangan yang kita timbulkan adalah dengan menggunakan julur piezoelektrik amat sukar untuk digabungkan. Dalam projek ini, pecutan kos rendah terdiri daripada alat peranti piezoelektrik, dan penguat caj. Penguat caj dibina dan keluaran isyarat dianalisa. Elemen sensor piezoelektrik pula terdiri oleh bahan PZT dengan saiz fizikal (0.51mm × 3.2mm × 31.8mm). Penggunaan penguat caj adalah untuk menguatkan keluaran voltan dari pecutan piezoelektrik. Pada akhir projek ini, hasil yang dijangkakan adalah menganalisis pecutan berasaskan julur yang boleh digunakan untuk mengukur tahap kelajuan getaran dan kekerapan.

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LIST OF ABBREVIATION

Acronym	Definition
AC	Alternating Current
ADXL 335	3-axis accelerometer
ADC	Analog to Digital Converter
BW	Bandwidth
DC	Direct Current
DNA	Deoxyribonucleic acid
$FeCl_3 6H_2O$	Ferric Chloride
G-level	Ground vibration level
IEEE	Institute of Electrical and Electronic Engineers
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MEMS	Micro-Electro Mechanical Systems
NaOH	Sodium Hydroxide
OP-AMP	Operational Amplifier
PCB	Print Circuit Board
PWM	Pulse Width Modulation
PVDF	Polyvinylidene fluoride
PZT	Lead-Zirconate-Titanate
RoHS	Restriction of Hazardous Substances
UV	Ultraviolet
V_O	Voltage Output
V_S	Voltage Source
WEEE	Waste Electrical and Electronic Equipment

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter will be briefly explained the background of this project. Starting with background of the project, that is why this is chosen. Later, this chapter will also cover about the problem statement that brings to idea to realize this project. Other parts of this chapter will also discussing about the objectives that are the solution to overcome the problem in the project. Scope of the project related to the limitations of this project due to achieve the objectives of the project. Lastly, the significant contribution of this project will be discussed in this chapter.

1.2 Background

Shock and vibration are present in all areas of our daily lives. It may be transmitted and generated by machine-tools, turbines, motor, towers, bridges, and even by the human body. Vibration and shock also may desirable, disturbing and even destructive. It depends on the place and what type of source of vibration that occurs. In 1880, piezoelectricity was discovered by Jacques Curie and Pierre Curie and the inverse phenomenon named the converse piezoelectric effect [6]. There are several types of accelerometer in measuring vibration such as piezoresistive, piezocapacitive, geophone and others. The piezoceramic accelerometers are the better choice at low frequencies and low acceleration. The piezoelectric accelerometers are wide accepted as the best choice for measure absolute vibration in all areas [3]. There are several important advantages of piezoelectric sensor compared to the other types of sensors such as: extremely wide dynamic range, excellent linearity over the dynamic range, low output noise that suitable for shock or vibration measurement as well as for almost imperceptible vibration, wide frequency range that can be measured at very high frequencies, self-generating mean no external power required, compact yet highly sensitive, no moving part – no wear, great variety models available for any purpose and the integration of output signal (acceleration signal) can provides velocity and displacement [4].

Piezoelectric sensors are most popular to be versatile tools for measurement of various processes. The piezoelectric sensor is devices that use the piezoelectric effect to measure acceleration, pressure, force and strain by converting mechanical motion to an electric charge. For purpose of an accelerometer, piezoelectric material can be categorized into two: quartz and PZT. The first one is single crystal material usually quartz. It is a natural piezoelectric material that never loses piezoelectric properties. These materials have a long life span in terms sensitivity. Quartz is more widely used in sensing applications. In order to have higher piezoelectric constant (sensitivity) than quartz, the ceramic materials are more low cost and inexpensive to produce an accelerometer. This is other materials is ceramic material normally called ferroelectric materials. It found to have ability to become “magnet” but some can made into

piezoelectric ceramic. There are several ceramic use as piezoelectric ceramic such as barium titanate, lead-zirconate-titanate, lead metaniobate, and other material whose composition is considered proprietary by the company responsible in their development. Lead-Zirconate-Titanate (PZT) is piezoelectric ceramic used in most industrial transducers [1][2].

An accelerometer is an electromechanical device that measures proper acceleration, which is the acceleration it experiences relative to freefall and the acceleration force felt by people or objects. This acceleration act like constant force of gravity pulling the feet, or it could be dynamic caused by moving or vibrating the accelerometer. These accelerations are popularly measured in term of g-force [23]. An accelerometer at rest of the surface of the earth will measure an acceleration $g = 9.81ms^{-2}$ straight upwards due to its weight. Accelerometers are also available that can measure acceleration in one, two or three orthogonal axes used to detect the magnitude and direction of the proper acceleration. It is typically used in one of three modes: As an inertial measurement of position and velocity; As a vibration or shock sensor; As a sensor of inclination, tilt, or orientations in 2 or 3 dimensions, as referenced from the acceleration of gravity $1g = 9.81ms^{-2}$ [16].

The important specification of an accelerometer for a given application is its type of output. There are two types of output accelerometer: analog and digital. Analog accelerometer output a constant variable voltage that depends on the amount of acceleration applied. Digital accelerometer output a variable frequency wave, a method known as pulse-width modulation (PWM) [14]. There are many different way to make an accelerometer. Several accelerometers use the piezoelectric effect they contain microscopic crystal structure that get stressed by accelerative forces, which cause a voltage to be generated. Another ways to do it are by sensing changes in capacitance [3]. Accelerometer can be used to measure vibration on vehicles, machines, buildings, and safety installations. They also can be used to measure seismic activity, biological sciences, dynamic distance and others.

In attempt to design a low cost accelerometer measuring ambient vibration using piezoelectric device by analyzing a cantilever-based accelerometer which can be used to measure vibration sources and develop an accelerometer. The material usage is piezoelectric material that is PZT. The physical cantilever size is (0.51mm × 3.2mm × 31.8mm). Piezoelectric accelerometer has to be operated more than 1 kHz and measure ambient vibration less than 2 g-level. The signal produced under vibration excitation at low frequency is too small and high impedance. To overcome this problem the charge amplifier is needed to amplify the value of voltage. Then, the output signal can be measure through oscilloscope. For further addition for this project, by using analog to digital converter to convert the signal in term of digital and through microcontroller the LCD will display the output value.

1.3 Problem Statement

There are recent research in piezoelectric sensor and research of ambient vibration especially in area of developing and fabrication of accelerometer. However, there is only a little information that can be obtained from the literature with respect to characteristic of vibration such as frequency, amplitude, and acceleration. From previous research (A. Carlosena, 2005) [13]; based on characteristic of piezoelectric cantilever accelerometer, to have a good accelerometer the frequency response of vibration has to be linear. The normal response of an accelerometer is nonlinear. The goal of this project is to design a low cost accelerometer measuring ambient vibration using piezoelectric device that fulfills the constraint imposed by the people. The problem is the accelerometers are expensive due to its performances. By knowing exactly the characteristics of ambient vibration source, material and frequency that we tend to use, we may able to identify which the type of accelerometer that can work best and suit to the vibration source. In this scenario, we want to design a low cost accelerometer using piezoelectric that can be mounted on machine surface or application that vibrate for purpose of its periodical

parameter monitoring. Hence, we need to know the characteristic of the vibration source that we tend to place at, which is the machine or vibrate application in lab. It is primary importance for this process to work well on frequency range random acceleration data, which is the type of data generated by the ambient vibration. In addition, the filtering effect to reduce noise of the signal and filter the signal. In this project is using piezoelectric cantilever for conversion of the mechanical motion into an electrical signal produces a current and voltage value. In other to do this experiment, the problem are low sensitivity and the signal too small that usually in the range of few micro-amps for electric current and the voltage is mile-volt from previous research work (Levinzon, 2005) [20]. Therefore, a charge amplifier act as integrator is needed to detect the signal and make the signal high sensitivity. The integrator make the signal emphasizes the frequency data to get acceleration signal. By having a summary of data for the ambient vibration that we test, we can design a low cost accelerometer measuring ambient vibration using piezoelectric device.

1.4 Objectives

The objectives of this project are:

- To design a low cost accelerometer measuring ambient vibration using piezoelectric device.
- To construct a PCB of a charge amplifier for the piezoelectric sensor.
- To analyze the output signal from piezoelectric device.

1.5 Scope of Work

First of all, we study the characteristic of piezoelectric and vibration. The scopes or limitations of this project in order to achieve the objectives of the project by designing a low cost accelerometer measuring ambient vibration using piezoelectric device are specification of the project and the cost of the project. The laboratory is the suitable place to test the product and analyze all of factor that affects the low cost accelerometer. The important specification of the project is to get a piezoelectric cantilever work an accelerometer by using low cost material usage and easily available piezoelectric materials is ceramics (PZT). The physical size of MEMS devices is about (0.51mm × 3.2mm × 31.8mm) to be mounted as a piezoelectric cantilever based sensor. The piezoelectric cantilevers have to be operated as low frequency ≥ 1 kHz. Identify the range of signal and use charge amplifier to amplify the signal in order to emphasize the signal and to get a linear output with an error around 5%. In other to achieve others objectives are to construct a PCB of charge amplifier for piezoelectric sensor, analyze the signal and develop the low cost accelerometer. Before construct the circuit, use Multisim8 software to stimulate the charge amplifier circuit and use oscilloscope to analyze the frequency response. Then, construct and test the entire component that use in produce accelerometer on the bread board. If it all component good in condition, proceed with built in electronic microcontroller and construct display. Structure the design of accelerometer follow by the electronic designs for the project with fabricates PCB of charge amplifier with op-amp ICs circuit. The vibration level (g-level) for test the accelerometer is less than 2 g (1 g = 9.81ms^{-2}) by using vibration generator to vibrate the piezoelectric cantilever. Before the project complete, we must analyze the several factors that affect the low cost accelerometer. After the circuit complete constructed, we must test the circuit to see the performance of the circuit and do some additional or reconstruct if have problem with the circuit. Then, proceed with the packaging of the low cost accelerometer.

1.6 Significant Contribution

The low cost accelerometer consists of piezoelectric sensor (ceramic), charge amplifier, filter, ADC, microcontroller and display. In this project, the major contribution is to analyze the output signal from a piezoelectric cantilever as a vibration sensor element which is considered as a low cost accelerometer able to measure ambient vibration sources with levels ≤ 2 g at higher than resonant frequency ≥ $1kHz$. The low cost accelerometer is designed and developed using piezoelectric cantilever size (0.51mm x 3.2mm x 31.8mm). This piezoelectric accelerometer is designed to be as a cantilever when excited by external vibration sources and low cost prototype accelerometer. Figure 1.1 shows the block diagram of the complete low cost accelerometer system. However, the focus on this system is as shown a dotted box consists of the piezoelectric sensor, charge amplifier and filter.

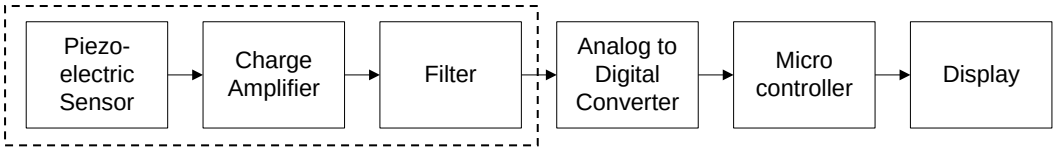

Figure 1.1: Block diagram of the low cost accelerometer.