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MEMs Accelerometers and Gyroscopes: Application in Electrochemical Seismic Sensors

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ABSTRACT

This journal is intended to provide an initial overview or introduction to an electrochemical seismic sensor device assisted with vibration detection features using a liquid resistance mass. This research introduces the first electrochemical seismic sensor that uses a liquid resistance mass (electrolyte solution) as a detecting element to convert environmental vibrations into active ion imbalances between electrodes, resulting in an electric current output. This paper will describe the use of MEMs in motion or vibration (seismic) analysis, validating the validity of concepts that have been widely fabricated, ranging from the use of conventional electrodes to earthquake detection and recording. In addition, this study discusses the operating principle, sensing mechanism, and applications of MEMS- based accelerometer and gyroscope sensors, where accelerometers measure linear acceleration and gyroscopes detect angular motion due to Coriolis acceleration. The comparative analysis shows the important role of MEMS sensors in various fields, such as shipping, aerospace, robotics and smart devices, and reveals the efficiency of MEMS-based electrochemical seismic sensors in earthquake monitoring with lower power and fabrication costs. This research opens up opportunities for the development of MEMS-based seismometers for environmental and geological monitoring applications, with recommendations for continued research for optimization of electrochemical materials and system integration to improve overall seismic response.

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1. INTRODUCTION

There are devices called MEMs (Microelectromechanical systems). This device is a combination of physical materials in the form of mechanical and electron-charged materials arranged in micrometre dimensions. This device is categorised in the semiconductor class which is intended to be a bridge for all electronic elements to sensors or integrate mechanical devices to other devices in a silicon substrate array. Some of the things that are considered are the availability of key components in MEMS systems such as mechanical elements, sensing mechanisms, and ASICs or microcontrollers. This writing is able to overview and describe in general about MEMS in accelerometer and gyroscope sensors. Researchers discuss and dissect the operating principles of MEMs, MEMs sensing mechanisms, varied applications in the utilization of MEMs in equipment in human life, and the significant impact felt by humans in everyday life. MEMS sensors have features that assist users in measuring real-time linear acceleration or multiple axes, or angular motion about one or multiple axes as input to control the system (Figure 1). And usually MEMs in accelerometer equipment functions as a device that connects mass displacement measurements with changes in position. The calculation will be converted into digital data with the help of ADC. In gyroscope devices, mass displacement and position changes are caused by the Coriolis acceleration factor.

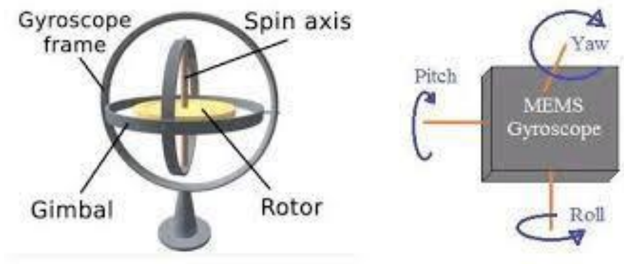

Figure 1. Use of MEMs in gyroscopes

2. RESEARCH METHOD

A. Acceleration Sensors

a. Accelerometer Device Manual

Issac Newton who discovered Newton's law, which one of the laws is the second newton's laws which says and argues that the acceleration of an object will be directly proportional and in the same direction as the force acting on the object, but will differ in ratio to its mass. The short conclusion of the second law is that the smaller the value of the force acting on the object, the greater the acceleration that occurs. The thing to note is the direction of the force acting on the object, because the resultant force is strongly influenced by the summation of the resultant force in the same direction.

$$\vec{a}(m/s^2) = \frac{\vec{F}(N)}{m(kg)} \tag{1}$$

The following discussion will explain how acceleration can create a force and be passed on in data by an accelerometer. That is, an accelerometer is defined as a sensor device that captures movement or velocity signals. This device is a feature that is utilised in accelerometers as a vibration sensor. Then for the calculation of the acceleration of the earth's gravity, it is necessary to measure the static velocity that occurs in an object. So the accelerometer is called an electromechanical component consisting of several holes, cavities, springs, and requires channels with microfabrication technology.

b. Accelerometer Sensing Principle

In principle, the application of accelerometers is a capacitance method, which utilises the difference or Gap between the capacitance of the moving mass and the capacitance of the moving mass (Figure 2). This method helps to obtain stable and more accurate data to support this research. And its advantage is the lack of noise caused by the diversity of temperature changes. The bandwidth of the accelerometer is limited to 100 hertz because it depends on the physical geometry factors in the form of springs and air stored in the IC. It is explained that ε0 = Dimension or free zone; εr = Relative material on the plate; A = surface area of the plate; d = Distance between plates.

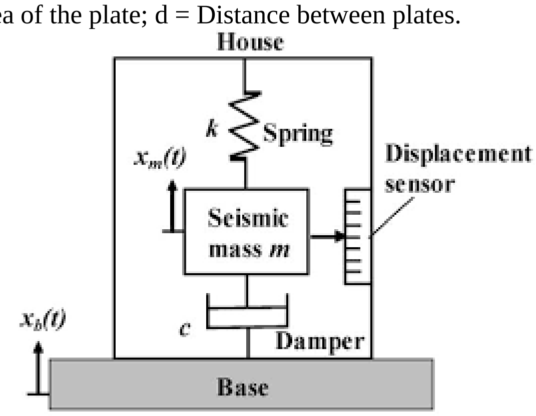

Figure 2. Accelerometer with a single moving mass

Generally, capacitors are arranged using single-sided or differential pair methods. As seen in Figure 3 which is arranged as a differential pair. This accelerometer uses a method consisting of one moving mass (one plane) and a mechanical spring placed between two solid reference silicon substrates or electrodes (another plane). And it is clear that there is movement of the mass (x movement) relative to the fixed electrodes (d1 and d2), resulting in changes in capacitance (C1 and C2). By calculating the difference between C2 and C1, we can know the variable movement of mass and its direction.

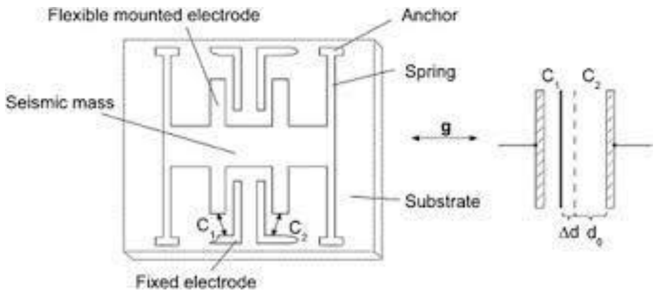

Figure 3. moving mass and capacitance

The variable displacement of a mass that can be engineered to move (micrometers) is caused by acceleration, and this will create a very small change in the amount of capacitance for precise detection (Equation 1). This makes the device very crucial in the movement of electrodes and can connect all parallel configurations. Therefore, the utilisation of electrode features is advantageous in integrating all configurations in parallel. Such configurations will be realised with greater capacitance resolution in order to improve the precision of data capture and facilitate more adequate sensing.

The foregoing can be briefly summarized. Force can cause mass transfer that changes its capacitance by connecting several electrodes in parallel, so that greater capacitance can be achieved, and speed up the reading or detection (Figure 4). At point V1 and point V2 which have been connected to a capacitor that will make a divider point for the voltage around the ground.

The analog mass voltage flows through charge amplification, signal conditioning, demodulation, and lowpass filtering before being converted into the digital domain using a sigma-delta ADC. The serial digital bit stream from the ADC is then fed back to a FIFO buffer that can convert the serial signal into a parallel data stream. The parallel data stream will be converted to be used as a serial protocol such as I2C.

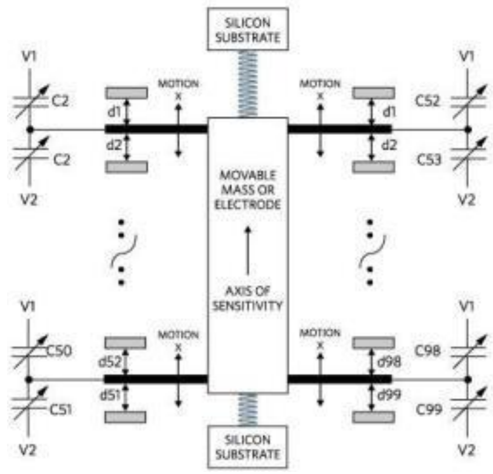

Figure 4. Accelerometer with a multiple moving mass

Sigma-delta ADCs are highly recommended for accelerometer applications due to their low signal bandwidth and high resolution. With the output value set based on the number of bits, sigma-delta ADCs can be configured into units of “This Sigma-delta ADC device is intended to capture a small signal bandwidth but good or high resolution. With the output results expressed in bits, the device can configure to the unit “g” to the Accelerometer device.g” for accelerometer applications more easily. “g” is a unit of acceleration equal to the Earth's gravity at sea level: or SPI before it can be sent to the host to facilitate further processing (Figure 5). For reference, if there is an X-axis reading from the researcher's 10-bit ADC equal to 600 of the 1023 available (210 - 1 = 1023), and with 3.3V as a reference, and this can obtain the voltage for the X-axis specified in “g” with the following equation:

$$X - voltage = \frac{600 \times 3.3}{1023} = 1.94\ V \tag{2}$$

Each accelerometer has a zero-g voltage level, which is the voltage corresponding to 0g. This research will process the data on the shift of the voltage difference from the zero-g voltage which has been set at a value of 1.65V as: The researcher will first calculate the voltage shift from the zero-g voltage (specified in the datasheet and assumed to be 1.65V) as:

$$1.94\ V - 1.65\ V = 0.29\ V \tag{3}$$

This can then be divided by 0.29V by the accelerometer sensitivity which has been assumed to be 0.475V/g.

$$0.29\ V/0.475\ V/g = 0.6g \tag{4}$$

c. Multi-axis Accelerometer

As per Figure 3 and adding an actual manufactured accelerometer (Figure 5). Now the output can clearly relate each component of the accelerometer to its mechanical model. Then by mounting the accelerometers differently (90 degrees, shown in Figure 6), a 2-axis accelerometer required for more sophisticated applications is obtained.

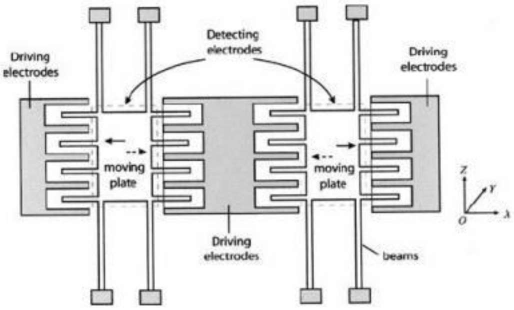

Figure 5. Mechanical Model Accelerometer

Then by mounting the accelerometers differently (90 degrees, shown in Figure 6, a 2-axis accelerometer required for more sophisticated applications is obtained

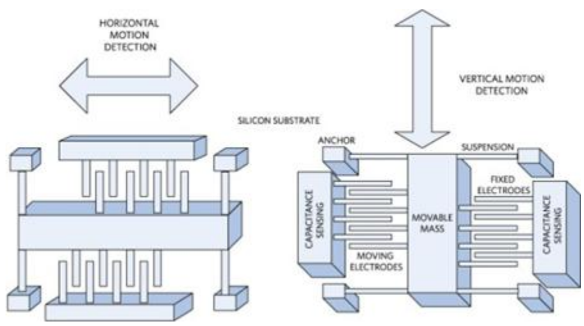

Figure 6. A 2-axis MEMs

There are two ways to make a two-axis accelerometer: first, place two different single-axis accelerometer sensors perpendicular to each other, or use a single mass with capacitive sensors arranged to measure motion along both axes.

d. Selecting an Accelerometer

When selecting an accelerometer for a given application, it is important to consider some of its key characteristics:

1. Bandwidth (Hz): the difference between the upper and lower frequencies in a continuous band of frequencies. It is usually measured in hertz (symbol Hz).
2. Sensitivity (mV/g or LSB/g): The ratio of the change in acceleration (input) to the change in output signal. It defines the ideal straight-line relationship between acceleration and output (Figure 1, gray line). Sensitivity is determined at a given supply voltage and is usually expressed in units of mV/g for analog output accelerometers, LSB/g, or mg/LSB for digital output accelerometers.
3. Voltage noise density (µg/SQRT Hz): a measure to describe the intensity of noise in electrical signals, particularly in the context of accelerometers or other sensors that measure acceleration or force. It expresses the noise level in terms of voltage per root frequency (√Hz), where the unit is micro-g (µg) per √Hz.
4. Zero-g voltage: Specifies the output level when there is no acceleration (zero input). Analog sensors usually express it in volts (or mV) and digital sensors in code (LSB). The zero-g bias is

determined at a specific supply voltage and is usually ratiometric to the supply voltage (most often, the zero-g bias is nominally half of the supply voltage).

5. Frequency response (Hz): the ability of a system to respond to different frequencies. Frequency response can also be interpreted as a measure of how consistently a system can process various frequencies of input signals without distortion.
6. Dynamic range (g): the range of acceleration values that can be measured by the sensor, from the lowest detectable value (noise level) to the highest value that can still be measured without distortion or saturation.

In other words, dynamic range describes the difference between the weakest and strongest signals that an accelerometer can measure with acceptable accuracy.

B. Gyroscope Sensors

a. Accelerometer versus Gyroscope

Before identifying some MEMS applications, it is necessary to understand the difference between accelerometers and gyroscopes. Accelerometers are typically used to measure linear acceleration (specified in mV/g) along one or more axes. Gyroscopes, on the other hand, are used to measure angular velocity (specified in mV/deg/s). If it is necessary to capture data on an accelerometer and impose a rotation on it (e.g., a twist) (Figure 7), the distances d1 and d2 will not change. As a result, the output generated on the accelerometer will not respond to changes in angular velocity.

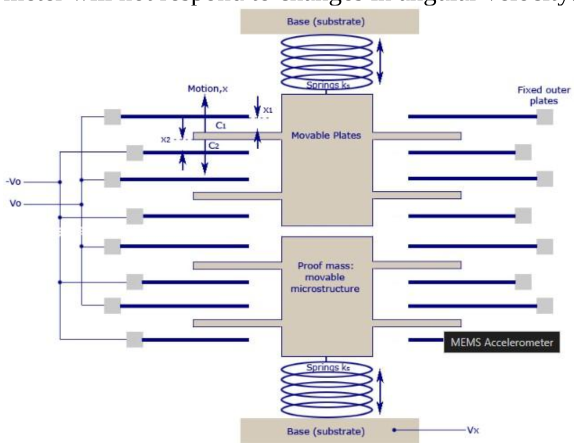

Figure 7. MEMs immunity rotation

Researchers can build the sensor differently, causing the inner frame containing the resonating mass to be connected to the substrate with a spring at 90 degrees relative to the resonating motion (Figure 8). Researchers can then measure the Coriolis acceleration through a capacitance sensing method on electrodes that have been installed between the inner frame and the substrate.

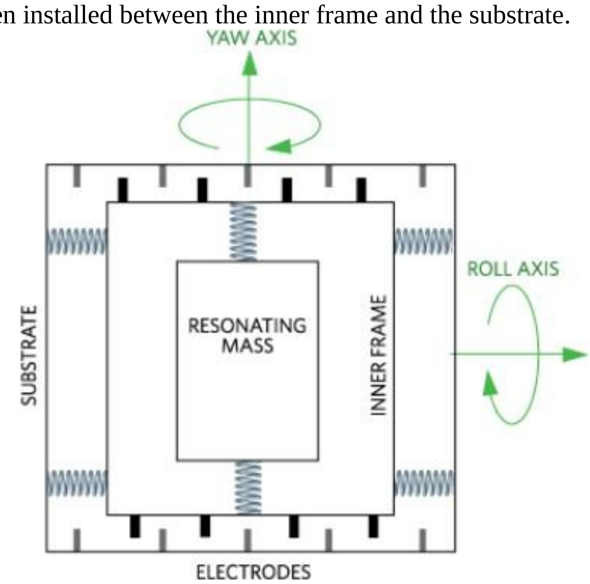

Figure 8. Representation moving mass

3. RESULT AND DISCUSSION

Accelerometers have long been intended for cars in order to detect car accidents and deploy airbags at the right time. Mobile devices have many applications such as: Switching between portrait and landscape orientation, moving to the next song with a tapping gesture, tapping your clothes when the device is in your pocket, and using anti-shake shooting and optical image stabilization.

A. *Indoor Navigation*

Acceleration is the rate of change of velocity.

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} \tag{5}$$

Researchers can obtain information in the form of velocity and distance data from the acceleration output by utilizing single or double integration. By adding measurements to the gyroscope, researchers can then use specialized techniques to detect the object-oriented position or location relative to a known starting point. Such information is used for indoor navigation without external references or GPS signals (Figure 9).

Figure 9. Navigation sensor gyro in phone

B. *Optical Image Stabilization*

In fact, the human hand vibrates at a very low frequency in the range of 10 Hz to 20 Hz. When taking photos with a smartphone or camera, jitter occurs which makes the image blurry as the focus of the camera decreases. Features such as optical zoom increase the susceptibility value which exacerbates this problem, resulting in blurry and unclear images. If using an SVGA camera with a resolution specification of 800 x 600 pixels plus a field of view of 45 degrees, taking into account a sensor with a horizontal deviation of 0.08 degrees. 45/800 = 0.056 degrees, which is equivalent to a blur of 1.42 pixels. As the camera resolution increases, the blur covers more pixels and the image becomes more distorted.

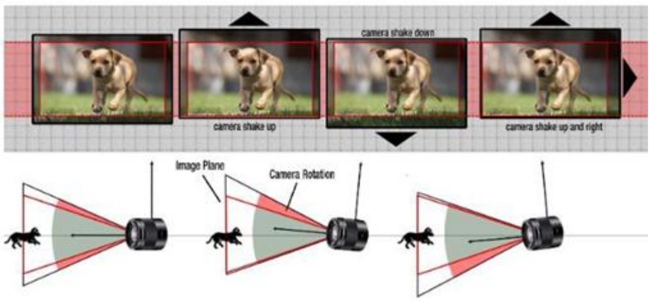

Figure 10. Image Blurring is removed using optical image stabilization

Gyroscope-based optical image stabilization with correction software (Figure 10) corrects image blur by sending the measurement data of a mechanical gyroscope to a microcontroller and a linear motor to drive the image sensor.

C. *Gesture-Based Control*

In everyday life the use of MEMS accelerometer sensors for motion-based control is commonly found in wireless mice, or wheelchair directional controls, or gyroscopes on Wii® consoles. Other examples include smart devices that use motion to control a cursor on a TV, or “virtual” knobs, or even motion commands to control external devices with handheld wireless sensor units.

4. CONCLUSION

After the above explanation, it can be concluded that MEMS accelerometer and gyroscope sensors are utilized for various applications in shipping, aerospace, industrial robotics, and automobiles. However, their application versatility has now spread to become an auxiliary component in smart phones where MEMs provide users with new ways to interact with gestures and signals with smart devices. Understanding MEMS behavior and the characteristics of accelerometers or gyroscopes allows designers to design more efficient and low-cost products for high-volume applications. These MEMS devices also enable humans to create new applications that profoundly change how users' movements, gestures, and movements impact the way humans live.

A comparative analysis reveals that the prototype electrochemical seismic sensor can deliver performance comparable to established seismometers while exhibiting a lower power spectrum in response to random environmental vibrations. This finding underscores the potential of electrochemical sensors to serve as a viable alternative in seismic monitoring applications, especially in settings where power efficiency and cost-effectiveness are critical.

The advancements seen in the prototype electrochemical seismic sensors suggest promising implications for the development of MEMS-based seismometers. With their notable performance, simple structure, and low fabrication costs, these sensors could pave the way for widespread deployment in various geological and environmental monitoring scenarios. Future research should focus on optimizing the electrochemical materials used and exploring integration with existing monitoring systems to enhance overall seismic response capabilities

REFERENCE

[1] Ahn, Chong H., Allen, Mark. 1998. Micromachined Planar Inductors on Silicon Wafers for MEMS Applications. IEEE Transactions On Industrial Electron.

[2] Ariffin, N. H., & Arsad, N. (2017). MEMS GYROSCOPE AND ACCELEROMETER BASED NORTH FINDING SYSTEM. 12(22). www.arpnjournals.com

[3] Chang, H., Xue, L., Qin, W., Yuan, G., & Yuan, W. (2008). An Integrated MEMS Gyroscope Array with Higher Accuracy Output. Sensors, 8, 2886–2899. www.mdpi.org/sensors

[4] Chen, Deyong., Li, Guangbei. 2013. A Micro Electrochemical Seismic Sensor Based on MEMs Technologies. Sensors adn Actuators, A : Physical.

[5] Choi, Bumkyoo and Lovell, E. G. 1997. Improved analysis of microbeams under mechanical and electrostatic loads. J, Micromech. Microeng

[6] Choudhary, Nitin., and Kaur, Davinder. 2016. Shape Memory Alloy Thin Films and Heterostructures for MEMs Apllications : A Review. Sensors adn Actuators, A : Physical.

[7] Dadafshar, M. (n.d.). Accelerometer and Gyroscopes Sensors: Operation, Sensing, and Applications.

[8] Faisal, I. A., Purboyo, T. W., Siswo, A., & Ansori, R. (2020). A Review of Accelerometer Sensor and Gyroscope Sensor in IMU Sensors on Motion Capture. In Journal of Engineering and Applied Sciences (Vol. 15, Issue 3).

[9] Fu, Yongqing., Du, Hejun., Huang, Weimin. 2004. TiNi-based thin films in MEMS applications: a review. Sensors adn Actuators, A : Physical.

[10] Gazzola, Chiara., Zega, Valentina. 2023. On the Design and Modeling of a Full-Range Piezoelectric MEMS Loudspeaker for In-Ear Applications. Journal of Microelectromechanical System

[11] Gibbs, M. R. J., Hill, E. W., Wright, P. J., 2004. Magnetic materials for MEMS applications. Journal of Physics D : Applied Physics

[12] Goel, Malti. 2004. Recent developments in electroceramics: MEMS applications for energy and environment. Ceramic International.

[13] Guo, F. M., Zhu, Z. Q. 2003. Study on low voltage actuated MEMS rf capacitive switches. Sensors adn Actuators, A : Physical.

[14] Hou, Yue., Jiao, Rui. 2021. MEMS based Geophones and Seismometers. Sensors adn Actuators, A : Physical.

[15] Kanno, Isaku. 2018. Piezoelectric MEMS: Ferroelectric thin films for MEMS applications. Japanese Journal of Applied Physics.

[16] Kavitha, S., Joseph Daniel, R. 2016. Design and Analysis of MEMS Comb Drive Capacitive Accelerometer for SHM and Seismic Applications. Measurement : Journal of The International Measurement.

[17] Kobierska, A., Podsędkowski, L., Poryzała, P., & Rakowski, P. (2017). The measurement of displacement with the use of MEMS sensors: Accelerometer, gyroscope and magnetometer. Journal of Automation, Mobile Robotics and Intelligent Systems, 11(2), 42–47. https://doi.org/10.14313/JAMRIS_2-2017/15

[18] Kumar, Ashish., Varghese, Arathy. 2022. Recent Development and Futuristic Applications of MEMs Based Piezoelectric Microphones. Sensors adn Actuators, A : Physical.

[19] Lo, Lennart., Gad-el-Hak, Mohamed. 1999. MEMS applications in turbulence and flow control. Progress in Aerospace Sciences

[20] Miyajima, Hiroshi., Mehregany, Mehran. 1995. High-Aspect-Ratio Photolithography for MEMS Applications.

[21] Mansoor, Saad and Khan, A. A. 2019. RF MEMS Capacitive Switch with High Isolation for 5G Communication. International Conference on Communication Technologies (ComTech 2019).

[22] Niarchos, D. 2003. Magnetic MEMS: Key issues and some applications. Journal of Microelectromechanical System.
[23] Rebello, Keith J. 2004. Applications of MEMS in Surgery. Sensors adn Actuators, A : Physical.
[24] Tai, Yu-Chong. 1996. REVIEW: MEMS and Its Applications for Flow Control. Proceedings of The IEEE.
[25] Zavracky, Paul M., Majumder, Sumit. 1997. Micromechanical Switches Fabricated Using Nickel Surface Micromachining. Journal of Microelectromechanical System.