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Analysis of MEMS sensor application and prospects

Xineng Na

The High School Affiliated To Yunnan Normal University, Kunming, Yunnan, China, 650106

NAXN10248@outlook.com

Abstract. The development trends in modern science and technology are miniaturization, integration, and intelligence. Microsensors have developed rapidly with the development of micro-electromechanical systems (MEMS) and micromachining technology. In this paper, the concepts and types of MEMS sensors are summarized by literature and case analyses, and their research statuses and application fields are briefly introduced. The development trends of MEMS sensors are discussed. This paper finds that combining sensors with intelligent products can achieve another application climax of MEMS sensors.

Keywords: MEMS, Sensors, Microsystem.

1. Introduction

In this paper, the development and Prospect of MEMS are understood by investigation and literature research, mainly focusing on its framework building and its application in different industries like sports and vehicles. A few figures researching on the sensor in various situation has been done in this paper. Micromechanical systems is an interdisciplinary frontier research field developed on the basis of microelectronics technology. After more than 40 years of development, it has become one of the world's major scientific and technological fields. It involves electronics, machinery, materials, physics, chemistry, biology, medicine and other disciplines and technologies, and has broad application prospects. With the development of MEMS sensors, it can be applied to medical research and patient treatment.

2. Background

2.1. History of MEMS

Micro-electromechanical systems (MEMS) are a new type of sensor developed through microelectronic and micromachining technologies. The sensor has the advantages of small size, light weight, low cost, low power consumption, high reliability, suitability for mass production, easy integration, and intelligence. Moreover, its nanoscale characteristics facilitate performing better than conventional mechanical sensors. The first microsensor was developed in 1962, which pioneered MEMS technology. Since then, MEMS sensors, an important branch of MEMS technology, have been of concern to the United States, Japan, Britain, Russia, and other countries. With the rapid development of microelectronic technology, integrated circuits, and processing technology, MEMS sensors have gradually replaced mechanical sensors in the fields of consumer electronics, automobiles, aerospace, machinery, chemical

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industry, medicine, biology, etc., in the miniaturization, intelligence, networking, and versatility of sensors.

2.2. Microsystem

A microsystem is a type of computer system that is essentially a virtual/embedded operating system. Many people can install a lot of software in any partition of non-window systems, especially on U disks, mobile hard disks, external hard disks, MP3, MP4, cards, and other mobile devices. If the system is reinstalled or software is installed on other computers, the previous data will be saved.

2.3. Microsystem technologies

Microsystem technology, abbreviated to MST, is a basic process technology for silicon corrosion and bonding. The development of microsystem technology mainly focuses on MMIC, MCM, MEMS, SOC, SIP, and other technologies.

2.3.1. Micro-optics: digital mirror device (DMD). Digital mirror discovery (DMD) is an array composed of a plurality of high-speed digital lights. The DMD is composed of numerous small aluminum mirrors. The number of lenses depends on the display resolution, and each small lens has a single pixel. DMD has higher reflectivity and lower contrast than TFT-LCD (LCD). The target is imaged on the DMD device, and each image point is individually scanned onto the detector using the pixel control characteristics and fast inversion frequency of the DMD device. Under visible light, the target is passively scanned at high speed. Scanning can be performed effectively by adding a suitable light source.

2.3.2. Microfluidics: cell culture environment. The combined knowledge of biology, biochemistry, engineering, and physics is used to develop instruments and technologies for cell culture, maintenance, analysis, and experiments. This technology is combined with microfluidic technology, which can process microliquids in artificial microsystems (50. NL, PL), including cell cultures maintained and grown in a controlled laboratory. Microfluidic technology has been applied in cell biology because the size of microfluidic channels is compatible with the physical size of cells (10 μm).

2.4. MEMS

MEMS sensors refer to the most popular sensor manufacturing technology, and they are an important impetus for the miniaturization and intelligence of sensors. MEMS technology has promoted the development of sensors. MEMS have a micro three-dimensional structure, and it is the general name for systems that process various input and output signals.

These systems make up a high-value-added component that integrates mechanical parts, electronic circuits, sensors, and actuators on a circuit board using micromachining technology.

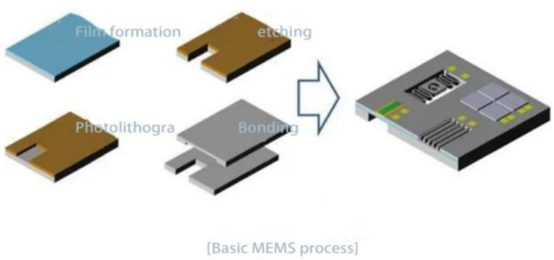

Figure 1. Basic MEMS process.

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2.5. MEMS inertial sensors

MEMS sensors exhibit high accuracy, low cost, and suitability for various industrial applications. This type of sensor adopts a chip-based technology called a micro-electrical system. They are used to detect and measure external stimuli, such as pressure, and then respond to pressure with mechanical action. The best example is the rotation of a motor to compensate for pressure changes.

MEMS integrated circuits can be made of silicon, and a small number of material layers can be placed on the silicon substrate using other methods. Additionally, it is selectively fixed, producing three-dimensional microstructures, such as diaphragms, beams, rods, springs, and gears.

The fabrication of MEMS devices involves numerous technologies such as oxidation, diffusion, ion implantation, low-pressure chemical vapor deposition, and sputtering. Additionally, these sensors adopt special processes, such as micromachining.

2.5.1. Structure diagrams of accelerometer. Figure 2 shows a sectional view of a capacitive accelerometer with an inertial weight sandwiched between an upper cover and base. The mass (Fig. 2) is supported by four silicon springs. The intervals between the upper and lower panels are D1 and D2, respectively. All three parts were made of micromachined silicon wafers. Figure 3 shows a simplified circuit diagram of a capacitor voltage converter similar in many respects to the circuit in Fig. 4.

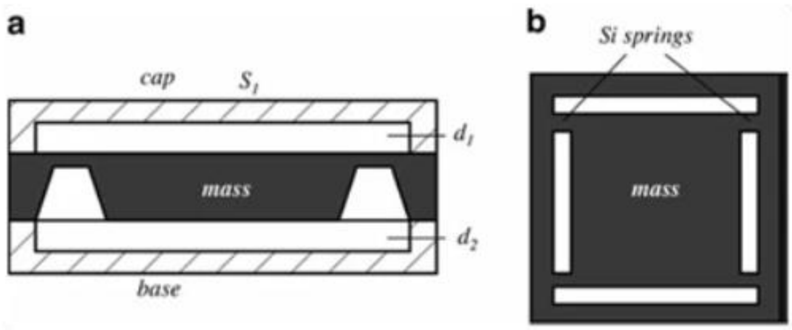

Figure 2. (a) Side sectional view of capacitive accelerometer with differential capacitance. (b) Top view of inertial mass supported by four silicon springs.

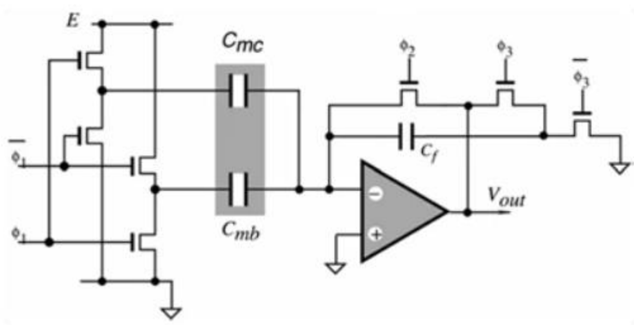

Figure 3. Circuit diagram of capacitor to voltage converter suitable for integration on silicon chip.

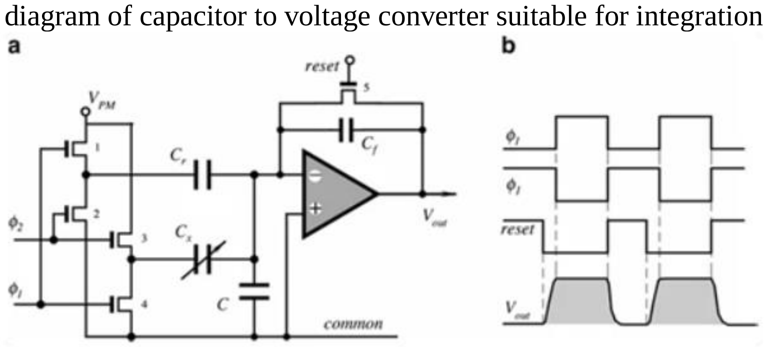

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Figure 4. (a) Simplified schematic diagram of differential capacitor to voltage converter. (b) Timing chart.

2.5.2. Structure diagrams of gyroscope. Figure 5 shows the working principle of a MEMS gyroscope. The outer frame swings in the reverse direction during rotation. When an object rotates, the comb-like structure inside the flexes changes the spacing between the comb-like structures, thereby changing the capacitance and measuring the angle[1].

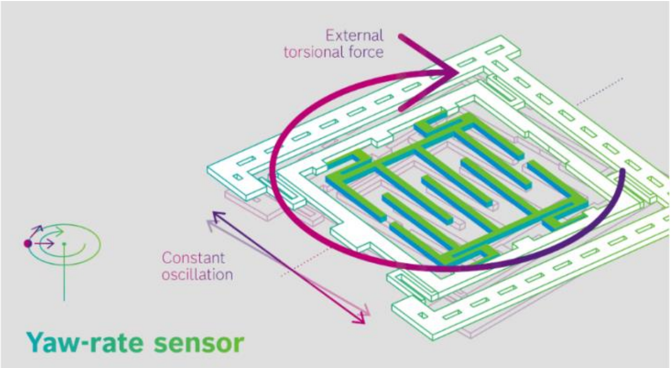

Figure 5. Gyroscope operation view.

The MEMS sensor is a significant device for the realization of the miniaturization of various sensing devices. It has been widely used in space satellites [2], carrier rockets, space equipment, aircraft, various vehicles, biomedicine, and consumer electronics.

3. Applications

3.1. MEMS sensor in sports assistant training system

3.1.1. Design of hardware. It can be located in the head, upper limbs, lower limbs, hands, or other positions. Inertial sensors include accelerometers, gyroscopes, and magnetometers [3]. In practical applications, it is necessary to correct the measurement data, detect and compensate for errors, and perform data fusion to analyze and track human motion.

3.1.2. Logical framework. A complete teaching system structure was designed according to the different needs of the users. The overall structure of the system was determined by teaching, action collection, test scoring, three-dimensional reconstruction, and other modules.

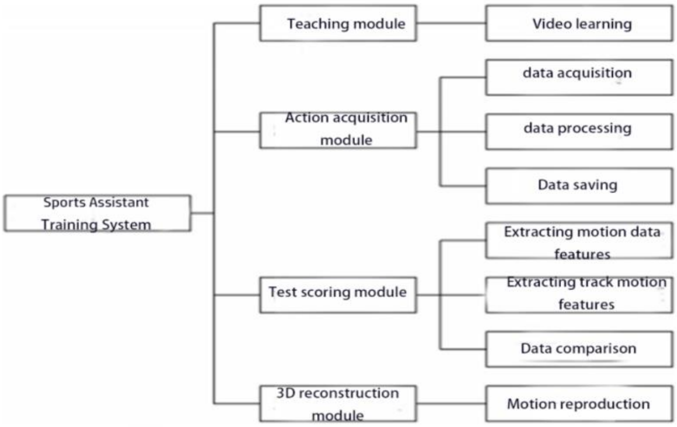

Figure 6. Logical framework diagram of sports auxiliary training system.

3.1.3. Software design. When the motion assist training sensor is moving, owing to the influence of inertia, the capacitor plate in the middle generates a relative offset, which leads to a change in the spacing between the capacitor plates [4]. It can be deduced from Maxwell's equation that the motion-assist training sensor can calculate the displacement of the capacitor plate by controlling the area of the capacitor plate. From the above results, the motion-assist training sensor can simultaneously detect the acceleration of the athlete in three vertical directions as shown in Fig. 7.

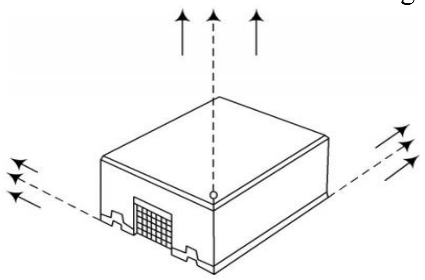

Figure 7. Data acquisition direction of motion assistant training sensor.

3.1.4. Characteristics of motion. where F represents the feature quantity of the motion trajectory on the three coordinate axes, and FX, FY, and FZ represent the motion trajectory feature quantities of the x-, y-, and z-axis signals, respectively.

$$F = \sqrt{F_X^2 + F_Y^2 + F_Z^2} \tag{1}$$

3.1.5. Finding the angle of arm motion of athletes. When the motion-assist training sensor moves, the capacitor plate in the middle moves relatively, and the distance between the capacitor plates is obtained using Maxwell's equation [5]. The motion-assist training sensor calculates the displacement of the capacitor plate by controlling it. In the figure, the sports assistant training sensor simultaneously measures the acceleration of the athlete in three directions. Figure 5 shows that the observation variable Z of sports assistant training is the attitude angle of the MEMS sensor θ INS、 γ INS、 φ INS、 φ Attitude angle between ins and motion assistant training sensor θ AZ、 γ AZ、 φ. The difference of AZ, the observation equation of motion assistance training, and the motion state space equation in the mathematical model of the Kalman filter are

$$X = FX + GW \tag{2}$$

$$Z = HX + V \tag{3}$$

where X= (Δθ, Δγ, Δφ) represents a state vector, Δθ indicates the pitch angle error of the athlete's arm, Δγ represents the roll angle error of the athlete's arm, Δφ represents the angular error of the athlete’s arm, G is the noise driving matrix used in the exercise assisted training, W represents the noise vector of the motion assistance process for training, Z is the observation variable of sports assistant training, H is the observation matrix of sports auxiliary training, and V represents the noise vector observed in the exercise assisted training.

3.1.6. Estimating the posture of athletes. The posture estimation method of athletes adopts the Bayesian method, which classifies the posture of athletes to obtain a complete set of posture images. First, let P (x | z) be the edge distribution of the posture sample set when the athlete performs auxiliary training. Its expression is as follows

$$p(x|z) = \sum p(x|z)p(c) \tag{4}$$

where X and Z represent the state variables of the athlete's auxiliary training, and P (c) represents the variable in the motion assistance training posture sample library C. It is assumed that the state variable

X of the posture of a specific part of an athlete and the posture sample bank C of sports auxiliary training are independent of one another.

3.1.7. Test MEMS sensor in sports. This work uses the MEMS sensor as the research object and studies its application in the sharing of sports assistant training methods and guidance efficiency. Figure 8 shows the experimental results of the three types of auxiliary sports training.

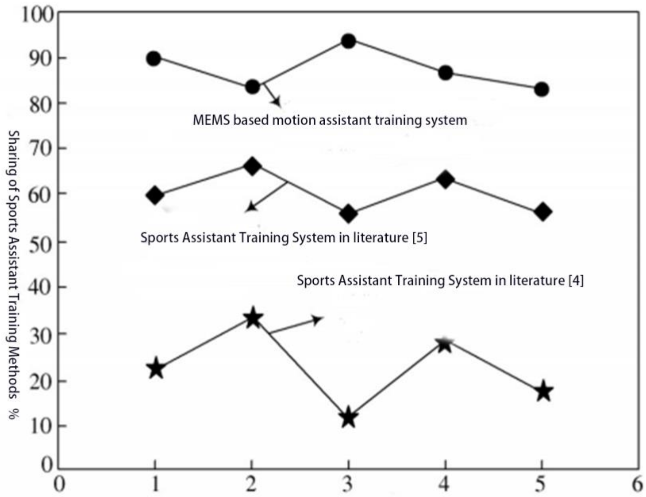

Figure 8. Sharing test results of sports-assisted training methods.

3.2. Types of MEMS sensors for vehicles

Approximately 1 / 3 of the sensors used in automobiles are MEMS; the more advanced the automobile, the more MEMS sensors are used [6]. MEMS sensors are mainly used in engine operation management, vehicle dynamics control, adaptive navigation, vehicle driving safety systems, vehicle monitoring, and self-diagnosis [7]. Physical MEMS sensors are the most commonly used sensors in automobiles, which are involved in all aspects of automobile electronic control. Chemical MEMS sensors mainly refer to gas sensors that measure the gas composition in automobile systems. Bio-MEMS sensors are widely used in the field of vehicle driving safety, such as predicting driving fatigue [8].

4. Overall outlook for MEMS sensors

Sensor networks are a significant driving force for China's economic development, and their development will directly affect China's political and economic status worldwide [9]. As a significant part of the perceptual network, the "sense" has pushed China's MEMS technology to a new height. In the next five years, the domestic MEMS market will have a strong recovery, and the market scale will accelerate. China's semiconductor industry will experience competition in technology and develop in the direction of standard competition. MEMS will be a new growth point of emerging technologies in the 21st century, and consumer electronics will be its main application field. Investment enthusiasm will certainly be high, and the development of MEMS will span history.

4.1. Review the domestic modern MEMS sensor technologies

The research on MEMS in China began in the early 1990s, which was not too late. During the eighth and ninth five-year plans, the Ministry of Science and Technology, the Ministry of Education, the Chinese Academy of Sciences, the National Natural Science Foundation of China, the National Science and Technology Commission, and other departments had strong support for MEMS. After more than ten years of development, China has had a variety of microsensors, micro-actuators, and some microsystems of technical reserves and has initially formed regions with strong scientific research strength.

However, there is still a big gap between MEMS technology and foreign countries, mainly because MEMS have great differences in materials, structures, processes, functions, and signal interfaces; therefore, the requirements for micro-MEMS technology are also relatively high. The technology R&D and industrialization levels of foreign companies are far higher than those in China, and the patent layout of foreign companies has not yet taken shape.

4.2. Global review of modern MEMS sensor technologies

The entire country is greatly concerned about this issue. In the early days, government actions were major. For example, in 1992, the National Key Technology Project of the United States included "micron and nanomanufacturing" in "technologies that were significant for economic prosperity and national defense security." The National Nature Fund of the United States considers micron/nano a key project. The "micro / nano and microsystem development plan" proposed by the US Defense Advanced Research Project (DARPA) emphasizes "developing and producing new electromechanical equipment with the same technology and materials as microelectronic components and with the advantages of miniaturization, diversification, and integration." Japan started a large-scale scientific research project in 1991, that is, the ten-year micro-machine project.

4.3. Future of MEMS sensor

We are facing a third wave of MEMS applications, which is driven by the increasing understanding of MEMS mobile sensing capabilities. The first wave was the automobile safety system in the 1990s, and the second was the development of consumer products in the 21st century. MEMS was widely used in the early 1990s. In the next decade, the second wave of MEMS technology was driven by consumer trends, and it is the third wave of MEMS today. MEMS accelerators and gyroscopes are widely used in various fields. An increasing number of people have realized that MEMS sensor manufacturers have broken through the barriers of reliability, cost, and large-scale manufacturing, and the requirements of users for MEMS performance are constantly improving.

5. Conclusion

With the progress of science and technology and the deepening of basic research, the level of MEMS design and manufacturing has had a profound impact on science and technology, production methods, and people's living standards in the 21st century. With the attention of governments toward MEMS technology, it has gradually become an important part of sensor networks. Under such a large environment, China's MEMS industry faces numerous opportunities and challenges. In five years, the entire MEMS market will show strong recovery, and the market scale will continue to expand. China's semiconductor industry has shifted from technical competition to scale and standard competition. In the near future, research for the MEMS can be focused on wearable medical devices and industrial intelligence. Intensifier the ability of system solutions, including the development of hardware platforms and corresponding software algorithms and the investment of technical personnel related to system applications.

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