# Current Status and Application of Micro-electromechanical Systems (MEMS)

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**Abstract.** MEMS (Micro-electromechanical systems), a technology that produces devices with tiny size and various abilities, has shown its great potential in many areas, but there are still many parts that wait to be improved. This paper would give a brief introduction of the technology with its features, superiorities and drawbacks. Based on these characteristics, several applications of the technology would be introduced with some specific examples. In this paper, current status with the advantages and disadvantages of MEMS would be discussed, and some improvements would be mentioned related to the problems that has been recently discovered in order to make the best use of the benefits and bypass the drawbacks. Next, applications of MEMS would be introduced and exemplified with the principle of how MEMS woks in specific areas. In the prospects and discussion part, several expectations would be predicted based on the current situation and some essays, which would also be analyzed. Finally, the part of conclusion would summarize the parts that have done as well as the opinion of future development of MEMS.

**Keywords:** MEMS; Sensors; Accelerometers.

## 1. Introduction

In the past few centuries, the machinery and electronic industry had considerable progress through the efforts of experts. MEMS technology (micro-electromechanical systems) is now widely applied in many ways in daily life. In the 1980s, MEMS started to be used in car industries to ensure the deployment of safety air bags. Later, it is quickly applied in other systems in car industries in the form of MEMS sensors. After realizing its features and benefits, producers in all kinds of industries created new openings by MEMS technologies in many other fields, such as in physics, chemistry, and biology. Further research on MEMS may improve the productivity and efficiency of machines and technology, encourage innovation and stimulate birth of new industries.

MEMS is integrated circuits, involving satisfactory microcircuit and micromachine components based on microelectronics technology (semiconductor manufacturing technology) which is composed of sensors, controllers and micropower. Most MEMSs are ranging in size from micrometers to millimeters. Micro simulation components resembling typical mechanical tools and parts, such as channels, cantilevers, membranes, cavities, and other devices, are frequently used in MEMS. However, MEMS device processing technology is not mechanical. On the contrary, they use micro manufacturing technology like batch processing of integrated circuits. Relating to physics, chemistry, material engineering, electronic engineering, information engineering and so on [1], MEMS is considered to have a wide application in a variety of fields, such as artificial intelligence, military systems, aerospace technology and physical treatment. MEMS can be used in a wide variety of industries due to its many other benefits, which include but are not limited to tiny size, lightweight, low cost, and low power consumption. However, the performance of sensors must be evaluated by various characteristic parameters like sensitivity, size and constructions.

As a result, in this paper, current status with the advantages and disadvantages of MEMS would be discussed, and some improvements would be mentioned related to the problems that has been recently discovered in order to make the best use of the benefits and bypass the drawbacks. Next, applications of MEMS would be introduced and exemplified with the principle of how MEMS woks in specific areas. In the prospects and discussion part, several expectations would be predicted based on the current situation and some essays, which would also be analyzed. Finally, the part of

conclusion would summarize the parts that have done as well as the opinion of future development of MEMS.

## 2. Current status of MEMS

The first stage of MEMS, especially for the MEMS sensors, was about 1990 to 2000, when these kinds of sensors were popular in electronic devices of cars such as the supervision system of pressure in the wheels. With the increasing in demand for the new sensors, European, Japan and American entrepreneurs started to pay attention to research, development and production on them. From 2000 to 2010, the consumer electronics like smart phones and tablets stimulated the process in MEMS technology to become smaller and lower energy consumption. In the next decade, as the Internet of Things (IoTs) develops quickly, the MEMS had a huge growth space in more newly developed industries like artificial intelligence. After 2020, higher targets have been set up [2].

MEMS devices is now widely used in a lot of different areas. MEMS devices can perform many tasks just like macro devices with many unique advantages. As an emerging technology, it has had striking progress in functions, appearance and accuracy. Innovation on MEMS can further lead to the creation and burgeon in micro equipment or even make the size of circuits too small to be seen. However, since MEMS is newly developed technology, it also has many current issues to deal with.

### 2.1. Advantages of MEMS

As a popular advanced technology, MEMS has a lot of merit compared to the previous technology that is attracting and helpful to the emerging production. Unlike the previous technology like electronic technology and mechanical technology, MEMS technology is composed of many different components that are designed based on a wide range of subjects such as material sciences, physics, designing and engineering. By combining all the significant knowledge from different subjects, MEMS can better leverage strengths and avoid weaknesses in some ways, such as having a smaller size and wider range of application.

#### 2.1.1. Smaller size

As the development of manufacturing process, the size of MEMS products is much smaller than that of related products in the past.

Consider the pressure sensor as an example. Processing technology, such as silicon-based sensors and other pressure sensors, was crucial in lowering the size of the pressure sensor [3]. Due to rusty processing and outdated technology, pressure sensors' lengths were often in the centimeter range in the middle of the twentieth century. The size of MEMS sensors can currently reach the nanometer level, though. The diameter pressure sensitive diaphragm, especially for the one that is made of graphene, can be less than 30 micrometers or even down to five micrometers (Figure 1).

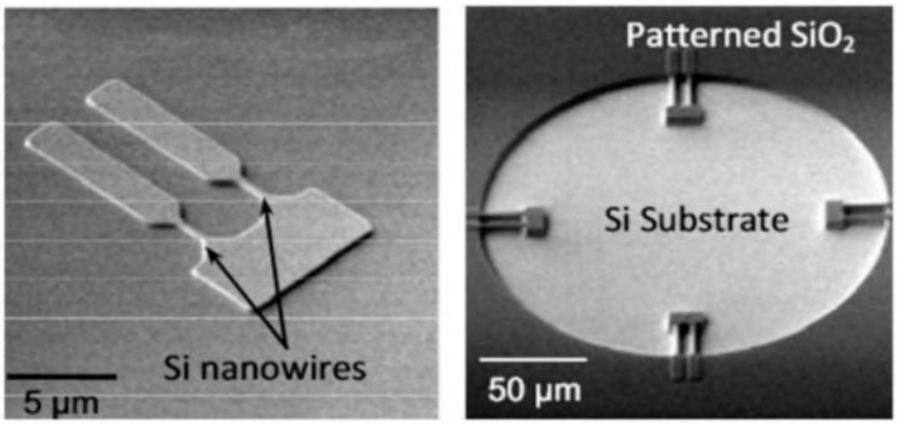



**Fig 1.** SEM image of a pair of patterned silicon nanowires on the $SiO_2$ layer. Using reaction ion etching, silicon nanowires were fabricated, with a size of 10 μm×100 nm×100 nm.

In the size of micro level, it is small enough to be manufactured by batch production processes like current integrated circuits. In normal situation, batch production of MEMS devices can significantly reduce the cost of production. At the same time, less raw material is needed to produce MEMS devices than devices with greater size but the same function, which makes MEMS more efficient and economical.

### 2.1.2. Wider range of application

Due to the characteristic of MEMS technology, in several tiny equipment and devices, the MEMS devices played a more significant role than the traditional technology. It combines a variety of technology, including mechanical and electronic technology. Moreover, because of small size and low energy consumption, it is more dependable for MEMS products to be put into many portable equipment. They can work without large volume and large power supply in particular fields. Another point is that integration in MEMS products is quite simple. Since they take similar manufacturing procedure as Application Specific Integrated Circuits (ASIC), MEMS construction can easier achieve microelectronic integration. Although to combine MEMS with other systems can be difficult, many producers and experts has tried mixed methods to realize the destination.

A specific example is Texas Instruments Digital Micromirror Device (DMD) (Figure 2). DMD is TI DLP, the core of technology, which is widely used in commercial and teaching projector devices and digital cinema. Each sixteen square micrometer micromirror uses the potential between it and its underlying CMOS memory cell for electrostatic actuation. The grayscale image is generated between the opening and closing states of the mirror modulated by the pulse width. A single chip and a color ring or RGB LED light source can be used to add color, or a three-chip method can be used (each primary color corresponds to a different chip). By rotating the color ring and showing each color continuously and quickly, the design utilizing the latter technology enables DLP chip synchronization, allowing viewers to perceive a complete spectrum image.

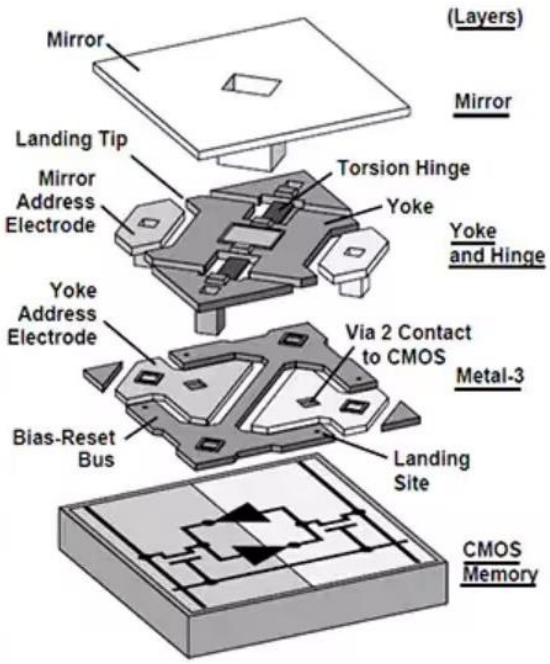



**Fig 2.** The Texas Instruments Digital Micromirror Device (DMD).

Through this example, it is easy to see that due to the features of MEMS, it can be applied in many micro fields with high qualified needs of multiple skills.

### 2.2. Disadvantages of MEMS

Apart from all the advantages, MEMS also has some disadvantages as this technology only has a short development history. Experts in this area has not found out the best use of it, and the construction of MEMS products are still developing in many ways. Due to the limited size of MEMS products,

their accuracies are less than some bulkier ones, which means a variety of errors might occur to prevent MEMS products from getting more accurate data.

### 2.2.1. Different types of error

The errors can be approximately divided into two parts, which are systematic errors and random errors. Random errors are difficult to compensate for, including turn-on errors (which took place when the power supply is just on), drift due to long-term operation, etc. Systematic errors are caused by incomplete measuring steps, such as thermal error, wear-out error, Abbe error, etc. Such errors can be avoided if adequate preparations are made in advance.

In the case of accelerometers and gyroscopes, they have measurement errors indeed, which is the same as any physical sensor. Sensor calibration is a serious problem since the error causes are complex and linked. For these kinds of sensors, the errors are mainly divided into two parts: the random error, which mentioned above, and deterministic error. Deterministic mistakes, such as zero-bias error, scale factor error, cross-axis sensitivity, misalignment error, and others, are brought on by improper factory calibration (or wrong conversion parameters in the datasheet). Although the error has considerably reduced through continuous effort on mathematical model and algorithms, this kind of errors still cause serious problems. It is because the size of MEMS is extremely small, which leads to lower accuracy than some other sensors. As a result, the deterministic errors could lead to much larger problems than random errors.

In the dimension of construction of hardware, most MEMS sensors are made of silicon, which is a material that is very sensitive to change in temperature. Its physical properties are easy to change due to change in temperature. Moreover, it can also be harmful when there is aging effect as it is normal but irreversible. In addition, other impacts brought on by changes in the external environment, such as variations in altitude and climate, can also produce a variety of issues with the accuracy of the dedicated products. A more detailed table is in the figure 3 below.

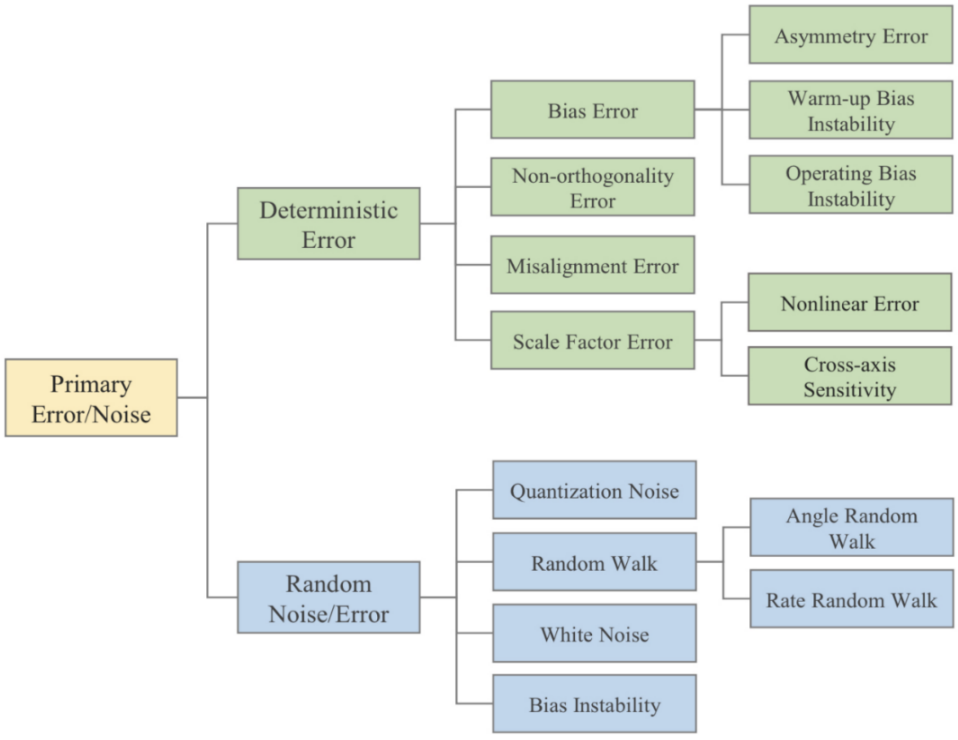



**Fig 3.** Some significant mistakes and noise classification of inertial sensors [4].

When used for MEMS cantilever, the conventional damping estimation would produce findings that are either incorrect or imprecise. This is due to the lack of accuracy and precision in the frequency domain techniques as well as the logarithmic decrement procedures [5]. More than the unexpected mistakes described above, several other problems can be encountered in different devices.

### 2.2.2. Wear and Tear

Because of the limited size, the rate of war and tear is likely to be an essential factor that prevent MEMS devices from being used in some specific areas. The devices have to be changed regularly to guard against sudden malfunction. The typical MEMS failure modes, particularly for switches, are depicted in the table below.

**Tab 1.** Analysis of MEMS switches failure modes [6].

| Failure Mode | Failure Factors | Improvement Methods |
|---|---|---|
| Creep | Temperature, power, interior stress | Creep resistant alloy; improving heat dissipation; |
| Stiction | Humidity, adhesion force, power | Reducing contact area; choosing harder contact materials; reducing the power |
| Dielectric charging | Electric field intensity, temperature, humidity | Lower actuation voltage; signal isolation; changing the dielectric |
| Fracture | Repeated loading, shock | Reducing stress; change the composition of alloys; shock absorption |
| Wear | Repeated contact | Increasing the hardness of the contact material |
| Layered | Temperature change, residual stress, microparticles | Improving temperature stability; transition layer to increase adhesion |
| Failure of package | Temperature change, impact | Shock absorption; heat dissipation |

Instead of mechanical issues, charging issues are the main issue that impacts capacitive switches. The continual accumulation of electric charge in the dielectric layer, which ultimately results in the latch-up effect's driving voltage drift, is thought to be the cause of this failure.

Contact fatigue is the primary factor in the failure of resistive switches. Mechanical stress normally deforms and wears the contact surface, whereas electrical stress primarily causes electromigration and melting of the contact surface.

## 3. Application of MEMS

As mentioned above, MEMS technology is still changing fast to achieve highly qualified targets by reducing size and widening its working fields. Due to the features of MEMS, it can be used in a variety of ways, especially the industry of advanced fields, such as the aerospace, information technology, robotics, medical engineering sports, medical treatment diagnosis, chemical analysis, environment, bio and so on.

MEMS is famous for several typical products, which are sensors, drives and switches. As the rapid development of modern society has witnessed the closer connection between humans and machines, demand for smart human-machine interfaces rising.

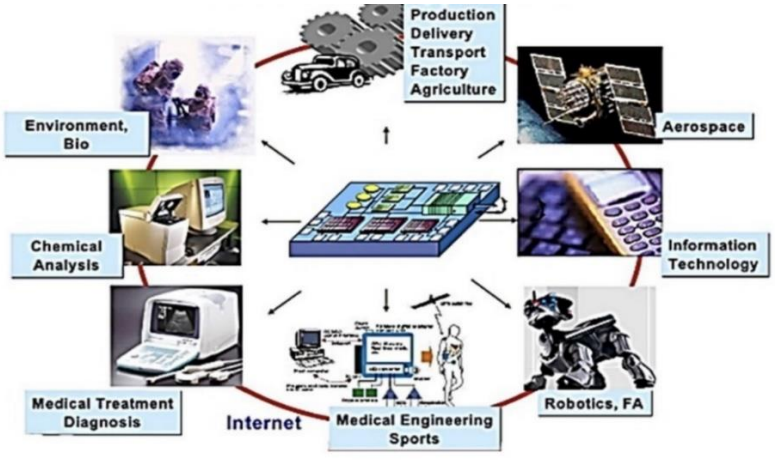



**Fig 4.** Applications of MEMS devices/systems [7].

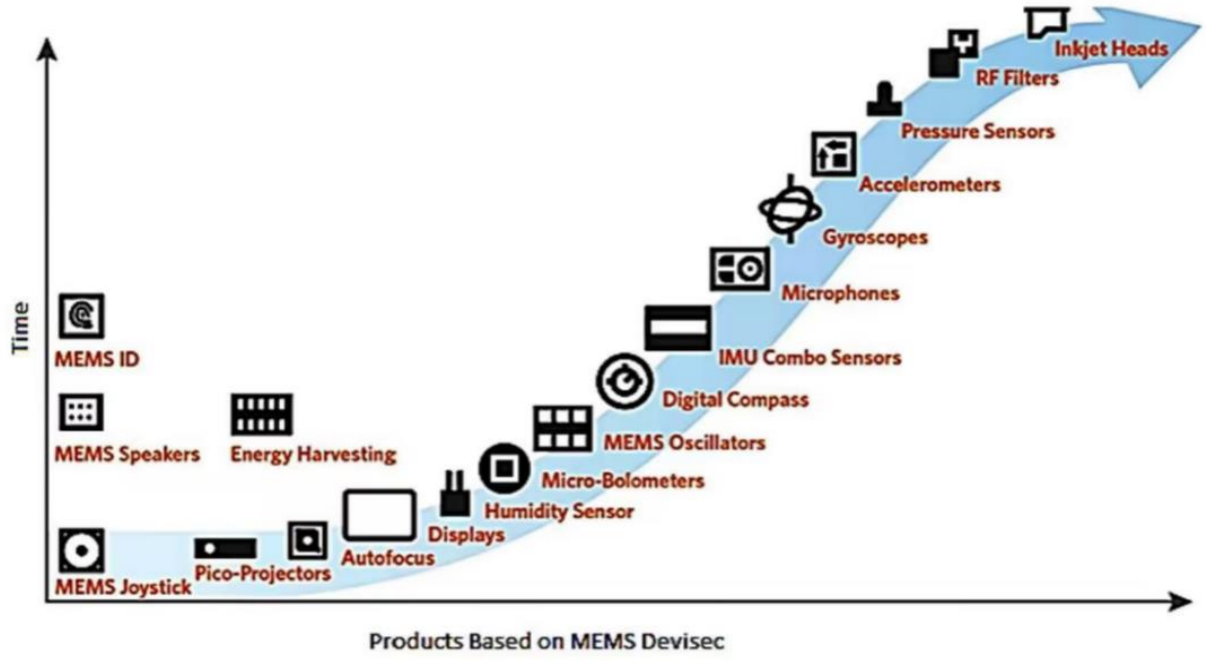



**Fig 5.** Growth in MEMS application-based products [8].

The functionalities of MEMS sensors included but not limited to inertia, pressure, temperature, light, heat and strain. The sensor is a type of detection equipment, which means it can receive the data from the equipment which is detected. In addition, they can output the data in a certain rule in the form of electrical signal or other forms due to different functionalities. Because of the expansion of information industry and human-machine interface technology, MEMS sensors are already the light of choice for emerging technology in many ways. In the parts below, MEMS application in medical treatment and car production would be introduced.

### 3.1. Medicine

Medicine is a subject to help people deal with their illness and keep healthy. The most significant thing during treating patients is, for doctors and machines, is to be careful and accurate. In recent years, the equipment has become more and more advanced due to the new technologies. For MEMS, it is also a new chance to enter a new field and to develop more useful devices for human beings.

There are numerous applications for MEMS technology in medicine. One significant advancement of MEMS in medicine is the wearable MEMS sensor array for tracking heart rate, detecting atrial fibrillation, and monitoring arterial pulse waveform. One of the most promising sensing modalities for remote health monitoring is the use of MEMS pressure sensors, which have proven to be important in the remote monitoring of vital signs. Due to its small size, the patients do not need to be monitored in the hospital all the time with a huge size of machine. The only thing for patients to do is to wear a monitor machine in the size of a watch, and the other people can receive the current information of the heart rate and atrial fibrillation at any time.

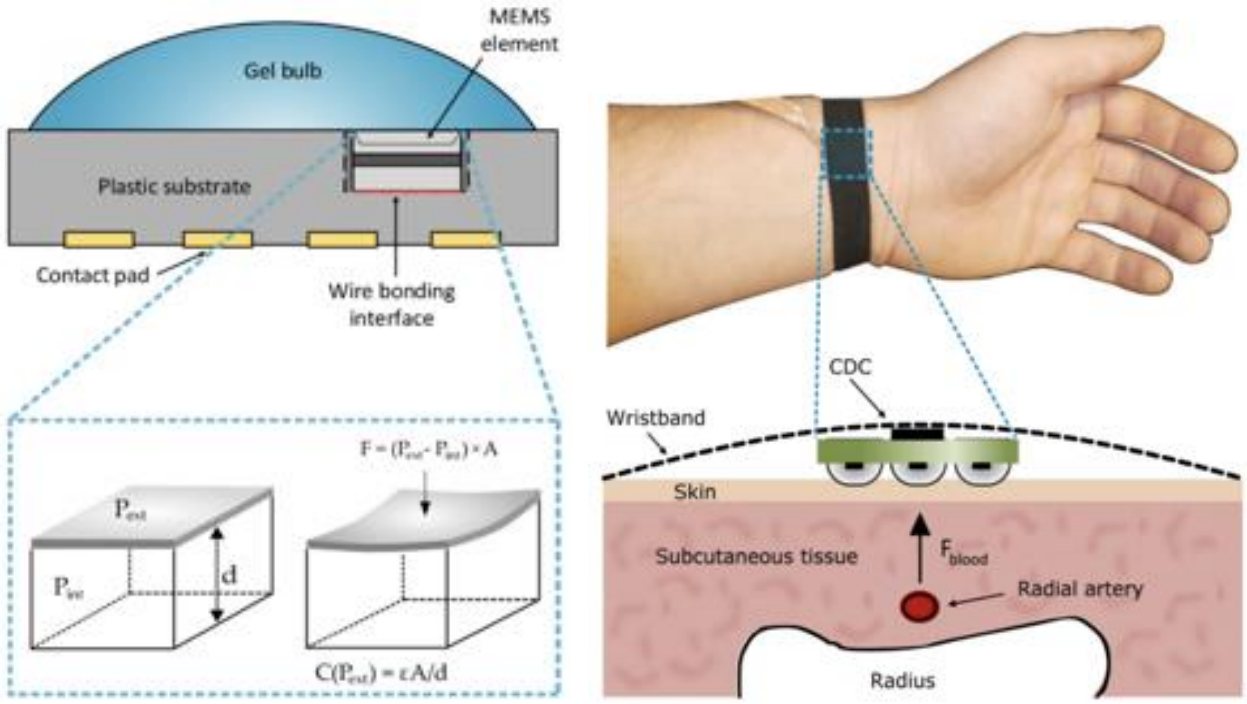



**Fig. 6** The capacitance of the element changes as a function of the external pressure deforming the diaphragm, the sensor's operating principle (left). A cross-section of the tissue and a healthy study volunteer were strapped to the array at the measurement site, which was mounted on a flexible wristband. The sensor array receives the majority of the force generated by radial artery blood pressure (right) [9].

Besides, the MEMS devices also has a wide range of use in medicine, like sensors for measuring the blood pressure [10], scanning mirror for identifying osteonecrosis [11], microscopy system studying glioma study [12], accelerometer for baby apnea monitoring [13], etc.

### 3.2. Car production

Starting at car production area, MEMS developed its new way of application there. In the past, producers always used the MEMS sensors in many processes of car production, and a typical example is airbags. Modern MEMS technology, which allows the entire accelerometer to be constructed in the micron range, can currently replace the conventional accelerometers with high linearity and cross sensitivity that are used in modern automobiles. This accelerates the speed of crash detection and airbag deployment. The comb is subjected to an impact load or force when a sudden displacement results from an impact, and this motion is seen using the idea of differential capacitance with air as the medium. In order to get correct findings, the simulations were carried out in COMSOL and compared to the actual theoretical calculations. The electronic control unit receives the obtained capacitance output and sends an impulse signal to the airbag system, causing the airbag to deploy [14].

In past few years, many enterprises paid attention to autonomous driving, which is also in need of MEMS technology. Automotive lidar applications have shown a lot of interest in MEMS-based scanning mirrors because of its lightweight, integrated and low power consumption. Since lidars can provide 3D imaging with high resolution and high accuracy regardless of the weather condition, they play significant roles in high level automated driving systems. The cost and resolution of the majority of older lidar sensors, however, still fall short of the desired levels for the automobile sector. It cannot be regarded as one of the fundamental sensors for ensuring the public's safety when using autonomous vehicles. As a result, MEMS-based scanning mirrors are now in test to be a potential substitute for the lidar sensors. Besides, some MEMS-based laser lidar sensors has developed in a variety of application such as robotics, space application and so on as well [15].

## 4. Prospects and discussion

In the recent years, as both theory research and manufacturing process of MEMS are promoting, not only declined the cost of production on MEMS devices, but also the accuracy and adaptability elevate. Based on the analysis above, although there are a lot of advantages, MEMS still seems to leave room for improvements. Therefore, several assumptions are suggested:

(1) Reduced error. There may be new technology or new materials that is developed to improve the precision and the accuracy of MEMS devices. Some new artificial material may be use in some specific fields, for example, maybe new types of polymers could be used in some sensors or accelerometers to improve the accuracy and prevent some factors from affecting the result of sensors.

(2) Being used more in consumer electronics. Integrated MEMS devices are more likely to be applied wider in some products that are used in daily life for general public, such as virtual reality goggles. Because the technology improves and people become more reliable on machines which they have got along with, demand for consumer electronics is rising rapidly, new IOTs products emerges in an endless stream, followed by increase in need of highly qualified devices. Thus, MEMS devices would be popular in these areas as it is of low cost, low power dissipation and small size [16].

(3) Improved durability. Durability can be influenced in many ways, and devices can also be deteriorated for a variety of reasons. Different material has diverse performance. In order to strengthen the durability, more research should be done on materials and methods that can prevent rusting, breakage, electric leakage, heat-expansion and cold-contraction, etc [17].

## 5. Conclusion

To summarize, MEMS is a newly developed technology with a short history, and it is far more complicated than the other technologies which are popular in the past, combining many different types of previous technology and integrates them into extremely small pieces. This paper gave a brief introduction and overall comments on the MEMS technology, including its current status and potential applications. Some related advantages and disadvantages are concisely analyzed and concluded from other papers. After that, its application in different areas is also discussed, for example, the application in car production and medicine, followed by discussion and prospects.

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