Applications and Prospects of Mems Sensors in Automotive

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Abstract. MEMS sensor is a new type of sensor and is made by micro-electronic and micro-mechanical processing technology. It has many advantages such as small volume, lightweight, low cost, low power consumption, high reliability, suitable for mass production, easy integration and intelligent realization. It is widely used in the automobile, effectively improving the performance of the automobile sensor, promoting the progress of the automobile industry and the intelligent automobile. This paper mainly discusses the market size of MEMS sensors and their applications in the automotive field, focusing on MEMS pressure sensors, MEMS acceleration sensors and gyroscope sensors. The development direction of MEMS sensors in the automotive field is forecasted.

1. Introduction
MEMS, an acronym for micro-electro-mechanical Systems, refers to high-tech devices a few millimeters or less in size. It is a field developed in recent decades on the basis of microelectronic technology. In electronics, machinery, materials, physics, chemistry, biology, medicine and other disciplines and technologies, MEMS have a broad application prospect. MEMS sensor is an important part of MEMS, it is a new type of sensor produced by micro-electronic and micro-mechanical processing technology. Compared with the traditional sensor, it has the characteristics of small size, lightweight, miniaturization, intelligence, multi-function, high integration, and is suitable for mass production and intelligence.[1] The various characteristics of MEMS sensors enable them to handle larger amounts of data, increasing functionality and flexibility, which makes them suitable for application in the automotive field[2]. According to Nexus market research, a typical mid-level car contains more than 50 sensors, while a luxury car is equipped with more than 100 sensors. About one-third of the sensors are MEMS sensors.[3] It can be seen that memes sensors are widely used in automobiles.

2. MEMS sensor market size
With the rapid development of sensor network and IoT technology, MEMS sensor applications and shipments are also growing rapidly, and the market capacity is also increasing. It is estimated that the global MEMS sensor market will grow at a compound annual growth rate of about 15% in 2019-2023, and it is predicted that it will reach 13.9 billion RMB in 2023.[4] This is also in line with the trend of ‘intelligent’ cars.[4] The global automotive sensor market reached $22.5 billion in 2016. It is expected to reach $30.9 billion in 2020, with a CAGR of 7.72% from 2015 to 2020. MEMS technology has gradually replaced the traditional sensors and becomes the mainstream of automotive sensors. At present, China is the largest automobile production and consumption country, so China is also a big country in the application of automotive sensors. China's automotive sensor market grew to $4.8 billion in 2016 and is expected to reach $9.3 billion by 2020.[5] Automotive MEMS suppliers are...
mainly large companies from Europe, America, Japan and other countries, which have basically formed a monopoly on the international market, such as Bosch in Germany, Sensata in the United States and Toshiba in Japan, etc.

![Market size](image)

**Figure 1.** 2019-2023 Global MEMS sensor market size forecast (Unit: $100 million)

3. The application status of mems sensors in automobiles

MEMS sensor is mainly composed of micro mechanism, micro sensor, micro actuator and signal processing circuit. In automotive applications, MEMS sensor is widely used in engine (ABS), electronic stability program (ESP), electronic control suspension (ECS), electric hand brake (EPB), slope starter auxiliary (HAS), tire pressure monitoring (EPMS), the car engine stabilization, Angle measurement and heartbeat detection and adaptive navigation system inside the car. Pressure sensors, accelerometers, gyroscopes and flow sensors account for 99% of MEMS systems.

3.1. MEMS Pressure sensors

MEMS pressure sensor is the most widely used sensor in the automobile, mainly includes several common forms such as capacitor type, piezoresistive type, differential transformer type, surface acoustic wave type and so on. The shape of the capacitive sensor is the horizontal barrier, and the two horizontal barriers above and below can form a group of sensors. When the upper barrier is subjected to pressure, it moves down, which in turn changes the distance between the upper and lower barrier bars. In other words, the electrical capacity between the plates changes. The silicon piezoresistive pressure sensor uses a highly precise semiconductor resistance strain gauge to form a Huygens bridge, so that it can be used as a force-electric transformation to measure the circuit concerned. It has the advantages of low cost, low power consumption and high precision measurement. This sensor, if the pressure does not change, then its output is zero, so almost no power consumption. And MEMS silicon piezoresistive pressure sensor is applied around the fixed, shape for silicon thin film inner stress of the circular cup.

At the same time, application of relevant technology of MEMS can directly put the four high precision semiconductor strain gauge, it can engrave directly to its surface stress of the largest local. So they can form the Huygens bridge, thus can be used as a force to measure electric transformation circuit, which is directly converted into electricity and measuring the pressure. Automobile pressure sensors are usually used to measure the pressure of liquids and gases in vehicles, which are widely used in vehicles. By application, the automotive pressure sensor market is divided into drivetrains, engine control systems, power steering systems, heating, ventilation and air conditioning systems (HVAC), airbags, anti-lock braking systems (ABS) and tire pressure monitoring systems. The pressure
sensor can detect the negative pressure of the cylinder and control the ignition and fuel injection. Detection of atmospheric pressure controls the climbing spatio-temporal burning ratio; The internal pressure of the cylinder is detected to control the ignition advance angle. Monitor the recirculation flow of wastewater, engine oil pressure, brake oil pressure, tire air pressure, etc., and respond to relevant quantities. The tire pressure monitoring system is an important automobile electronic system, which is used to detect the pressure and temperature of automobile wheel platform. When the pressure or temperature exceeds the normal range, the TPMS alerts or displays on the dashboard display to prompt the driver to take steps to prevent an accident. TPMS is divided into direct systems and indirect systems. Direct TPMS uses MEMS pressure sensors on each tire to detect pressure and temperature, monitor and report both parameters to prevent tire blowout or pressure abnormalities. Indirect TPMS is used to determine the relative changes of the two tires through the ABS system, but it cannot work normally when the speed exceeds 100km/h or in case of synchronously changing of more than two tires.

3.2. MEMS acceleration sensor

MEMS acceleration sensors can be divided into three types: piezoelectric, capacitive and thermal sensing. Among them, capacitive MEMS micro-accelerometer has the characteristics of high sensitivity, little temperature influence, simple structure and so on, so it is widely used. The basic structure of capacitive micro-acceleration sensor is the capacitance composed of a mass block and a fixed electrode. Vary the overlap area or spacing of the capacitors as acceleration displaces the mass block. The detected capacitance signal is pre-amplified and processed, then output in the form of DC voltage, so as to realize the acceleration monitoring indirectly. Acceleration sensors are often used in automotive safety systems, such as wheel operation and automatic braking, intelligent airbags and anti-lock braking systems. An important application is the airbag, which usually has acceleration sensors around the car. When a car collides, the acceleration measurement value of MEMS accelerometer will increase sharply, and the accelerometer will immediately send the signal to the electronic controller. The electronic controller then calculates and evaluates the impact intensity, number of passengers and seat, seatbelt position, along with data from sensors distributed throughout the car, and activates the airbag with the Squib Driver as soon as possible and pop the airbag out in time to inflate it quickly, and place it between the driver, occupant and windshield or car body to protect the driver and passengers on the car from fatal damage. The general acceleration sensor will be used together with the pressure sensor to detect the state of the body. The airbag has high requirements for the resolution,
activity, rapidity, stability, reliability and so on of the acceleration sensor, so as to ensure that the airbag is opened at the right moment.

The accident experiment proved that about 35ms after the collision, the body of the member will tilt, and it is necessary to inflate the airbag thoroughly in this moment to achieve the desired protective effect. The MEMS acceleration sensor has high precision, high stability and versatility to meet the needs of airbags. In addition, MEMS acceleration sensor is also playing an important role in the navigation system. It is mainly beneficial to GPS satellite signals to achieve positioning. When entering the area or environment with poor satellite signal reception, such as tunnels, high-rise buildings and jungle areas, the navigation function will be lost due to the loss of signal. 3 axis accelerometers based on MEMS technology together with components such as gyroscope or electronic compass can create DR (Dead Reckoning) systems for complementary applications to GPS systems.

3.3. MEMS gyroscope sensor
MEMS gyroscope is mainly divided into vibration type and rotor type. Vibratory micromechanical gyroscope uses the vibration mass made of monocrystalline silicon or polycrystalline silicon to detect the angular velocity by the Coriolis effect when driven by the base. The rotor of the rotor-type micromechanical gyroscope is made of polycrystalline silicon, and the angular velocity is measured through the short force rebalancing loop.

At present, the most widely used micromechanical gyro is vibration gyro. Traditional gyroscopes mainly use the principle of conservation of angular momentum, so it is mainly a rotating object, its axis of rotation does not change with the rotation of the bracket carrying it. But MEMS gyroscopes don't work that way, because it's not easy to fabricate a rotating structure on a silicon substrate using micromechanical technology. MEMS gyroscopes use Corioli forces (the tangential force exerted on a rotating object in radial motion).

When an object is driven back and forth in a radial motion or oscillation, the corresponding Coriolis force is constantly moving back and forth in the lateral direction, and may cause the object to oscillate slightly in the lateral direction with a phase difference of just 90 degrees from the driving force. MEMS gyroscopes usually have removable capacitor plates in two directions. A radial capacitor plate with an oscillating voltage forces the object to move in a radial direction, and a transverse capacitor plate measures the capacitance change due to the transverse Coriolis motion. Because the Coriolis force is proportional to the angular velocity, the angular velocity can be calculated from the change in capacitance.

Most micromechanical gyroscopes rely on alternating Coriolis forces caused by orthogonal vibrations and rotations. Vibrating objects are suspended above the substrate by a soft elastic structure. The global dynamic system is a two-dimensional elastically damped system in which vibration and rotor-induced Coriolis forces transfer energy proportional to angular velocity to the sensor.[8] An important application of MEMS gyroscope sensor is ESP system. ESP is Electronic Stability Program, and is a kind of active safety system through the peripheral sensors to collect the rotations in the steering wheel Angle, lateral acceleration. Transverse angular velocity is the pilot operation and vehicle running status information, and through the micro device for calculation and processing the information, then sent out by hydraulic brake braking instruction to implement the sideslip correct, in order to improve the Stability and safety of the car.

The working principle of the ESP system is that several acceleration sensors and gyroscope sensors monitor the state of the car body at the same time. When a car meets an obstacle and needs to turn in an emergency, it is easy to roll over or swing its tail without good balance. The acceleration and angular velocity of the car are detected by the gyroscope sensor and acceleration sensor at any time to judge whether the state of the car is at the critical point of rollover. If the car is critical, the signals generated by the sensors drive the control system to apply short, emergency brakes on certain wheels to maintain balance and drive in the right direction.
4. Future development trend of MEMS automotive sensors

4.1. Multi-functionalization
Multifunctional means that a sensor can detect two or more characteristic or chemical parameters, thus reducing the number of sensors in the car, improving the reliability of the system, and reducing the space occupied by the car.

4.2. Passive sensor
Passive sensor is also called energy control sensor, mainly composed of energy conversion components, and it does not need external power supply. For example, sensors based on piezoresistive effect, thermoelectric effect and photovoltaic emf effect are passive sensors. An induction sensor that does not require the use of external sensors connects to power and can obtain unlimited energy from the outside. Car temperature sensors, speed sensors, water temperature sensors, fuel sensors will use passive sensors. Some detection sensors in autonomous driving vehicles also need to be passive. At the same time, the application and development of passive sensors can save electricity energy and improve the life and working stability of the system.

4.3. Cost reduction
It is important for the auto industry to control costs. Enterprises can develop diversified manufacturing technology, adopt more processing means and methods, increase the level of mass production, and constantly reduce the manufacturing cost of MEMS sensors. But it also has to be safe and functional.

4.4. The combination of MEMS sensor and CMOS integrated circuit
As a signal processing module, CMOS integrated circuit has a mature manufacturing technology. MEMS, as a microsensor for acquiring signals and a microactuator for executing commands, is integrated into a single chip to realize the integration of sensors, actuators, signal acquisition and processing, and control circuits on a three-dimensional silicon chip, which can greatly improve the intelligence and integration of MEMS automotive sensors. Compared with traditional MEMS automotive sensors, it has the following advantages:

- Using the standardized scale effect of mature CMOS process, the cost of device processing and packaging is greatly reduced;
- The highly integrated embedded MEMS automotive sensor module will greatly reduce the development cycle and cost of products;
- The existing mature CMOS process is used to design and manufacture materials, so that MEMS automotive sensors have better performance and reliability.[9]

4.5. Universality
In the future, with the development and popularization of driverless vehicles, MEMS sensors will play an increasingly important role. It will have a widely used in various parts of the car, such as ADAS (Advanced Driving Assistance System), electronic stability control, electronic control unit, heating and heating ventilation System, safety and security, on-board navigation, camera stabilization System, in-car microphone, tire pressure monitoring, automobile engine management System, fuel injection System, seat monitoring System, peripheral pressure sensor and oil pressure sensing, etc. It can be predicted that in the future electric vehicle market and driverless vehicle market, the demand for MEMS sensors will further increase and be more widely used in cars.

5. Conclusion
MEMS sensors have developed rapidly in recent decades. Due to their features of miniaturization, lightweight, high integration and low cost, MEMS sensors are very suitable for automobile applications. With the development of new intelligent vehicles such as new energy vehicles and driverless vehicles in the future, MEMS sensors will occupy a greater share in the automotive sensor
market. Vehicle MEMS sensors are mainly used in vehicle driving state adjustment, vehicle data detection and vehicle safety and stability improvement. Among them, the most common applications are pressure sensors, acceleration sensors and gyroscope sensors. The future development trend of automotive MEMS sensors will focus on multi-function, passive, low-cost, universality and the combination with CMOS circuits. MEMS sensors will drive innovation and development in the automotive field.

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