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The Role of MEMS Technology in Automobiles: A Review on Sensors and Innovations

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ABSTRACT: This paper provides a summary of main MEMS-based sensors for automobiles now in use, along with the system applications that go along with them.
The automotive sector has adopted MEMS sensors in an effort to boost reliability, lower costs, and increase performance.
The potential for further exploration and the development of next-generation technology have always been obstacles in the automotive sector. The silicon revolution has spurred a great deal of research and commercial activity in micro/nano manufacturing in recent decades. The technology of micro-electro-mechanical systems (MEMS) was developed as a counterpoint to the identical fabrication platform to create intricate physical structures at the micro level. In the automotive sector, it is imperative to install these sensors and use them to enhance the vehicles' performance qualities. This chapter focuses on key Applications of MEMS-based sensors in the motor vehicle sector, including engine control systems, tire tracking along with pressure systems, and passenger safety with vehicle stability systems.

1. INTRODUCTION

1.1 Overview of mems technology

By combining mechanical and electrical components onto a single silicon chip, Micro-Electro-Mechanical Systems (MEMS) technology produces tiny devices with special features. By utilizing microfabrication techniques akin to those employed in the semiconductor industry, it facilitates the creation of microscale sensors, actuators, and systems.

As a result, The technology of micro-electro-mechanical systems, or MEMS, has become more and more popular. MEMS apparatus turn perceptions into electrical impulses by translating mechanical and electrical components of the environment. Because devices based on MEMS are affordable as well as accessible in many sizes ranging from milli-meters to microns, they offer advantages over conventional sensors. [2]
A key component of MEMS is the MEMS sensor, a special kind of sensor made possible by micro-electronic and micro-mechanical processing technologies. Its portability and low weight are two advantages over a conventional sensor. Challenges in the automobile industry have always included the development of next-generation technology and the potential for more research.

1.2 IMPORTANCE OF MEMS IN AUTOMOTIVE INDUSTRY

Automobiles use a variety of sensors. Table 1 lists the many kinds of automobile sensors.[11]

Vehicle motions including running, turning, and stopping are measured and managed using acceleration and angular rate sensors. The driver's intentions are measured via force and weight sensors, which detect steering torque and brake pedal force, respectively. The pressure, acceleration, and angular rate sensors are referred to as internal sensors since they collect data inside the car. Sonar, radar, and vision are examples of external sensors because they collect data outside of the car. Compact and very accurate structures are achieved by MEMS technology, which is based on semiconductor fabrication technology. Si may be readily employed in an integrated circuit (IC) and digitalized because it is frequently used as a base material. [11]

Type	Sensing target, position
Temperature	Water, oil, intake, exhaust, air, fuel, cabin
Gas	Oxygen, lean, NOx, HC, H_2
Pressure	Intake air, air flow, combustion, supercharging, brake, tire, compressor
Position	Fuel level, cam, vehicle height, seat
Angle	Crankshaft, camshaft, throttle, steering, direction
Speed	Engine, transmission, wheel, vehicle
Angular rate	Yaw rate, rollover
Acceleration	Airbag, chassis, suspension
Force, Load	Brake pedal, steering torque, loading
Vibration	Knocking
Light, Electric wave, Sound	Visible light, IR light, solar irradiation, headlight, Laser, microwave, antenna, voice, microphone, ultrasound
Others	Glow plug, particle, rain, humidity, fingerprint, current

Table 1: Types of Automotive sensors [11]

First, we divide the common MEMS advancements into four classes and investigate various uses. Since then, it has been suggested that MEMS sensors have helped reduce fuel consumption, improve security, and create more affordable cars. They can also easily replace older sensors.[1]

MEMS sensors are widely used in automotive applications, such as engine stabilization, angle measurement, heartbeat detection, Electronic hand brake (EPB), electronic control of suspension (ECS), and electronic stabilization program (ESP), tire pressure monitoring (EPMS), slope starter auxiliary (HAS), and adaptive navigation systems in cars. Flow, gyroscope, pressure, and accelerometer sensors comprise 99 % of MEMS devices.[4]

2. MEMS FABRICATION

1) Micromachining in bulk In bulk micromachining, parts of the substrate are removed selectively to immediately produce a three-dimensional micromechanical structure on the silicon wafer.

2) An anisotropic etching Use the silicon lattice's crystalline structure.

Surface micromachining, the third technique, is based on the procedures that are frequently employed to build integrated circuits. Thus, it is predicated on the creation of patterns using photolithography, which are then put through to certain chemical analysing procedures which may determine the thin film topologies or alter the silicon substrate's characteristics that are created upon it.[7] The process of using sacrificial layers to create thin-film microstructures is known as surface micromachining.[6]

3) Lithography: In MEMS technology, lithography is a crucial microfabrication technique that transfers patterns from a mask onto a substrate. Lithography Steps:

i. Substrate Preparation: The substrate, typically silicon or glass, is cleaned to remove contaminants, ensuring optimal adhesion of the photoresist.
ii. Photoresist Application: A thin layer of photoresist, a light-sensitive polymer, is coated onto the substrate using spin coating.
iii. Soft Baking: The coated substrate is heated (soft baked) to evaporate solvents in the photoresist, improving its adhesion and uniformity.
iv. Mask Alignment: A photomask, containing the desired pattern, is aligned over the substrate.
v. Exposure: The substrate is exposed to ultraviolet (UV) light through the photomask.
vi. Development: The substrate is immersed in a developer solution, which removes the exposed or unexposed regions of the photoresist, depending on its type
vii. Hard Baking: The substrate undergoes hard baking to solidify the remaining photoresist and improve its resistance to subsequent processes.
viii. Etching or Deposition: The patterned photoresist acts as a mask for subsequent processes, such as etching (removal of material) or deposition (addition of material) to create the MEMS structure.

3. MEMS SENSORS FOR AUTONOMOUS VEHICLES

Fitting early airbags required a number of sizable, independent accelerometers on the vehicle's front end, each via its own technology, adjacent to the airbag itself. These days, MEMS, the accelerometer, and circuitry are all combined into one chip. The tiny size allows for faster response to rapid deceleration. It also reacts to abrupt deceleration faster because of its small size and incredibly low cost. The sensitivity of MEMS devices, which determine passenger weight and size to guarantee that each passenger has the appropriate airbag response, is also driving improvements.[6]

Figure: MEMS in Automotive Industry [6]

3.1 Fuel Injector Pressure Sensor-

Fuel is injected into individual cylinders employing the multiple-point injection of fuel method, which is controlled by directives derived from "on board engine management system computer," commonly referred to as the ECU, or Engine Control Unit. An air/fuel mixture is delivered to the combustion chambers via the electronic fuel injection system. at an ideal proportion of a variety of operating conditions.[7] The detectors for intake air temperature, throttle position, and manifold absolute pressure (MAP) are used.

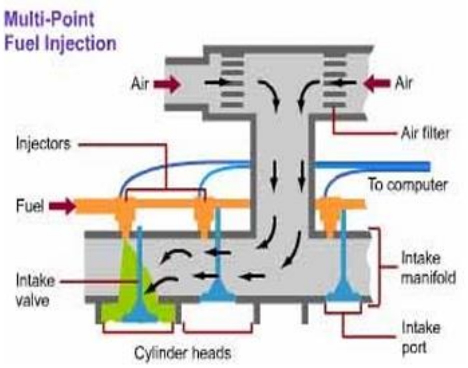

Figure 2: Fuel Injector Pressure Sensor [6]

3.2 Tier Pressure Sensor-

The primary function of the tire pressure monitoring system (TPMS) is to keep an eye on the tire's internal temperature and pressure.[8]
The direct tire-pressure monitoring system includes sensor modules put on every wheel. Each tire's pressure can be determined by the sensors and wirelessly send the information to the car's main receptor. After analysing data, the receiver presents it to the driver. In most cases, The tire's rim contains a tire-pressure sensing gadget. The MEMS device needs to be resistant to high temperatures, hazardous liquids, and noise.[7] Every wheel has sensors that regularly check the pressure and temperature.

Figure 3: Tier Pressure Sensor [7]

3.3Airbag system-

A device that senses or measures accelerations in three dimensions is called an accelerometer. Conventional accelerometers, which have good linearity and cross sensitivity, are currently used in modern autos. Modern MEMS technology, on the other hand, can replace these since it enables the complete accelerometer to be constructed within micro-meters, speeding up airbag deployment and collision detection.[9] Shock loads or strains are experienced by the comb when an impact results in sudden displacement. Air serves as the dielectric in the differential capacitance idea, which tracks this movement. [9]. In this application, the car's acceleration is continuously measured using an accelerometer. When this value is set ad exceeds a microcontroller, a preset threshold determines if there has been a significant net change in velocity by computing the integral of the acceleration.

3.4Dynamic control system for vehicles-

When the car begins to slip, vehicular dynamics control (VDC) systems assist the driver in restoring control. Tire-speed detectors at each wheel, a low-g accelerometer, and a gyroscope make up a VDC device. Tire velocity is calculated and compared to an expected yaw frequency of the vehicle using a gyroscope sensor. To ascertain whether the car is sliding laterally, a low-g accelerometer is additionally utilized. If lateral sliding is seen or if the computed and measured yaw rates differ, To align, torque limitation or singular-wheel braking may be employed to the vehicle.[6]

3.5Sensor for Pedal Location –

One type of attenuator is affixed to the pedal rod. After receiving a signal of voltage, generated by the sensor outputs the fluctuating voltage measurements. When the pedal is opened, the voltage rises. The MAP output and this signal control the amount of air enters the combustion, enabling The computer's ability to react promptly to variations and modify the fuel rate as necessary.

3.6Yaw rate sensor-

For vehicle motion control, a gyro sensor known as a yaw rate sensor was created. Automotive stability controls and automobile dynamics unified administration. The technology enables the prevention of accidents resulting from car spins on roads that are muddy, rainy, frozen, or snowy. The revolution speed that steering aims to achieve is compared with The vehicle's speed of rotation as determined using the sensor for yaw rate measurement. By producing an anti-spin force, the matching wheels automatically brake if the rotation speed is sufficiently high to stop slippage from starting.

One piezoelectric substance that can be used for micromachining is quartz. The lower portion was used for detection, while the higher portion was used for stimulation. Since the quartz crystal is naturally polarized, electrodes were attached to deliver an AC voltage to stimulate it. Coriolis force and a vibration orthogonal to the excitation vibration were produced when the sensor was subjected to an angular rate. A change in charge was identified by the orthogonal vibration produced in the lower tuning fork.[11]

3.7Optical scanner

The ability to detect roads, buildings, vehicles, and people is crucial for autonomous driving. Well-known external sensors include cameras, sound navigation as well as spanning, radio frequency identification and varying, and LIDAR technology. The expectation for LIDAR is high as it can identify a person's shape. LIDAR emits light, determines the separation between the light's flight time, and detects illumination reflected from an object. Using Amplification of light using stimulation of the emission of radiation and multifaceted scanning, distance data is produced as a two-dimensional image. One way to sweep light is with a vibrating mirror (MEMS mirror) or a revolving mirror (polygon mirror).[11]

3.8Side Impact Sensor

This kind of pressure sensor is employed to identify side impacts and collisions. The adverse effect To detect when the airbag deploys, a MEMS sensor analyses the rapid rise in pressure inside the passenger car door cavities.[12]

3.9Front Impact Sensor

The front impact sensor uses MEMS technology to detect impacts by measuring acceleration data. Passenger safety against collision impact is made possible by this feature.[12]

3.10Brake Vacuum Sensor

MEMS sensor technology is utilized to measure the brake booster pressure in start/stop systems. The operational temperature ranges from -40 to +150° C, and the operating voltage is 5V (4.5 to 5.5 V). It has a burst pressure of 5 bar and operates in a pressure range of ± 1.05 bar, which is adjustable for every customer. Over a lifetime, its accuracy is roughly 1.5%.[12]

3.11Rollover Detection

SUV, LUV, vans, semi-trucks, and other vehicles with an elevated balance for gravitation and are therefore more prone to roll over-benefit from this system. A gyroscope is used in the rollover detection system to measure the rolling frequency. Although The rolling frequency is incorporated into determine the rolling degree of the vehicle, roll rate information is insufficient on its own to detect whether a vehicle is rolling over or will.

Because significant roll angles can occur in banked corners where there is no chance of rollover, Additionally, an upward displacement sensor measurement is necessary to detect whether the vehicle is tipping over. To safeguard the occupants, the system activates the side curtain air bags if it is.[12]

3.12Pressure and Flow Sensors for Engine Management

In order to reduce tailpipe emissions, sensor-based engine control modelled after MEMS was introduced in 1979. It was made possible via controlling the stoichiometric fixed air to fuel ratio through a microprocessor-based engines regulation unit, that effectively decreases the amount of fuel that is not burned. This type of monitoring was made possible by the employment of response detectors to identify air intake along with exhaust output. This is accomplished with electro-ceramic sensors at the outlet, multichannel total pressure sensors, plus hot-wire bulk air flow sensors were used to detect direct mass flow and indirect air flow.

Together with a temperature sensor, manifold absolute pressure calculates air density to provide a reliable approximation of the mass air flow into the engine. For closed-loop exhaust gas recirculation systems and altitude compensation, direct mass airflow is measured using silicon-based barometric absolute pressure sensors. Once more, the engine combustion control system uses pressure sensors to measure the in-cylinder pressure. Exhaust gas recirculation, cylinder fuel injection time, and turbocharger functioning are all regulated by the pressure-based feedback signal. The heating plug, which provides force to the ceramic piezoelectric pressure detector in its capacity as a force transfer point, while the rising cylinder pressure creates pressure on the glow plug (Heinzelmann et al. 2006).[13]

3.13 Lidar sensors:

In order to create the immediate environment that is required for autonomous vehicle navigation, sensors initially collect environmental data representations, which perception algorithms subsequently analyse. Cameras, radars, and lidars are examples of active and passive sensors that make up a perception system for autonomous car navigation. Lidars are active sensors that use lasers to illuminate their surroundings. Processing the obtained laser returns from the reflecting surfaces allows for the exact measurement of ranges.[10]

Despite their high cost and moving parts, lidars are being used in numerous advanced autonomous vehicles use visual systems. Lidars are primarily utilized for perception and localization in autonomous vehicles. Thus, in order to correlate to the several layers of information, object detection, classification, tracking, and intention prediction are all done using the lidar outputs. Lidar's great ranging precision makes the physical information it provides extremely dependable.

4. FUTURE SCOPE

Sensors for microelectromechanical systems (MEMS) are expected to become more and more important as conventional cars and electric vehicles (EVs) advance. They are essential for improving vehicle performance, safety, and user experience because of their small size, low power consumption, and great precision.

i. Enhanced Safety and Stability

Advanced driver-assistance systems (ADAS) rely heavily on MEMS sensors, including gyroscopes and accelerometers. They keep an eye on the dynamics of the vehicle, identify situations of skidding or rollover, and allow for prompt interventions to preserve stability. These sensors are essential for controlling battery systems, identifying instances of thermal runaway, and guaranteeing safe operation in EVs.

ii. Autonomous Driving

MEMS sensors are becoming even more important as the automotive sector moves toward more automation. They offer accurate acceleration, rotation, and environmental measurements all of which are critical for autonomous vehicles' navigation, obstacle identification, and decision-making processes.

iii. Energy Efficiency and Emissions Reduction

MEMS sensors track engine characteristics in cars with internal combustion engines to maximize fuel economy and lower pollutants. By keeping an eye on variables like temperature and pressure, they help EV batteries be managed effectively, guaranteeing longevity and peak performance.

iv. Comfort and Convenience

By making technologies like climate control, infotainment interfaces, and adaptive suspension systems possible, MEMS sensors improve the user experience. They enable systems to modify settings for increased comfort by detecting changes in the dynamics of the vehicle and the surrounding environment.

v. Market Growth and Technological Advancements

From 2022 to 2028, the compound annual growth rate (CAGR) was 5%. worldwide MEMS industry is expected to reach $20 billion. Growing demand in the consumer electronics and automotive industries is the main driver of this expansion.

5. CONCLUSION

With an emphasis on their advantages and range of uses, the study emphasizes the significance utilizing sensors made of micro-electro-mechanical systems (MEMS) in the automotive sector. These sensors are essential for improving vehicle stability, performance, and safety because they are small, effective, and affordable. They are essential components of stability control, tire pressure monitoring, and airbag systems. With an emphasis on multifunctionality, energy efficiency, and smooth integration with electronic systems, MEMS sensors will become increasingly important as electric and autonomous car technologies develop.

In summary, MEMS sensors are set to become even more integral to the automotive industry, particularly with the rise of EVs and autonomous vehicles. Their ability to enhance safety, efficiency, and user experience ensures they will remain at the forefront of automotive innovation. Additionally, it describes how a MEMS-based accelerometer specifically designed for airbag actuation and crash detection was developed. By detecting acceleration forces between 6 and 18 grams, this device sends information to the car's control unit so that the airbags can be quickly deployed in the event of an accident. By facilitating quick and accurate reactions in emergency situations, this innovation improves car safety.

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