Automotive sensors: past, present and future

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Abstract. This paper will provide a review of past, present and future automotive sensors. Today’s vehicles have become highly complex sophisticated electronic control systems and the majority of innovations have been solely achieved through electronics and the use of advanced sensors. A range of technologies have been used over the past twenty years including silicon microengineering, thick film, capacitive, variable reluctance, optical and radar. The automotive sensor market continues to grow with respect to vehicle production level in recognition of the transition to electronically controlled electrically actuated systems. The environment for these sensors continues to be increasingly challenging with respect to robustness, reliability, quality and cost.

1. Introduction
Today’s vehicles are pervaded with a diverse range of sensors providing critical data for performance, safety, comfort and convenience functions. The measurement of inlet manifold absolute pressure in early ignition and fuelling control systems was one of the first and most successful automotive applications of sensors, and continues to this day to be an important parameter [1]. Many other sensors including crankshaft position, knock, air mass flow, exhaust gas and temperature sensors have been subsequently used to enhance powertrain performance. The trend towards ever increasing use of electronically controlled electrically actuated systems on vehicles (for example, electrically powered steering, semi-active ride control, slip control systems and adaptive cruise control) has created new challenges and opportunities for sensor developers. Traditional sensors have been complemented by the addition of new sensors for new applications, for example, long range radar, optical steering torque sensors, tyre pressure monitoring systems and yaw rate sensors. Sensor cost continues to be a significant factor in the selection criteria of automotive system designers, recognising the reward of large production volumes if successful. In addition, sensor suppliers must also deliver the robustness and quality targets demanded of this automotive market. Figure 1 provides some examples of sensors used on today’s vehicles.
2. Market Trends

During the past two decades, market studies have continued to track the increasing deployment of sensors to automotive systems. From early market studies circa 1990 with estimates of the total world market of $2.3b, the market has steadily grown to around $10.1b in 2006 with a year-on-year growth of 11% predicting to take it to $15.8b in 2012 [2].

| Year | Market Value |
|------|--------------|
| 1991 | $2.3b        |
| 1995 | $3.8b        |
| 1997 | $4.7b        |
| 2000 | $7.0b        |
| 2006 | $10.1b       |
| 2012 | $15.8b       |

Table 1. Total World Sensors Market

Although the passenger car production is expected to grow at less than 4% during the next few years, during the same period automotive sensor revenues are predicted to grow by 10.1% CAGR as a result of OEM’s responding to increasing environmental and safety legislation as well as consumer expectation by introducing electronically controlled innovations for enhanced performance, safety, comfort and convenience.

Much of the sensor demand comes from the mature established applications, for example, engine emissions control, anti-locking braking systems and airbags. Legislation is an additional market
The automotive sensor business sector is a typical OEM business; there is virtually no consumer aftermarket. The sensor is technically specified by either the vehicle manufacturer or the tier one supplier, depending upon who has system responsibility for that particular system. The sensor supply chain can therefore be grouped into three broad categories:
(a) System suppliers with in-house sensor design and manufacturing capabilities
(b) Semiconductor companies who also possess an automotive sensor business
(c) Sensor companies who target the automotive market

The automotive sensor market remains an attractive and still-expanding market characterised by high production volumes together with high reliability and low cost. Existing sensors will continue to find new applications, building upon their historical track record of performance, and new sensors will emerge to improve system functionality.

3. Sensors & their Applications
A typical top-of-the-range vehicle will comprise over 30 electrical/electronic systems and more than 100 sensors. Although some sensor applications have been dominated by one specific technology, e.g. accelerometers and silicon microengineering, a number of sensor technologies do co-exist and compete within a given application.

Microengineered sensors (or micro-electro-mechanical sensors) have infiltrated the automotive sensor market in both the inlet manifold pressure sensor and the airbag accelerometer [3]. These two applications have dominated the exploitation of this technology with only read/write heads, inkjet print heads and disposable blood pressure sensors competing at the same high volumes in other market sectors. Pressure sensors have been realised in bulk and surface micromachining techniques making use of optimised thin film material properties and reliable batch processes. Inertial sensors have been based upon surface micromachining using advanced processes such as deep reactive ion etching to effect 3D structures. Tyre pressure monitoring and yaw rate sensors continue to demand the attention of this technology.

The use of Hall Effect sensors and magnetoresistive devices have impacted the application of the traditional variable reluctance sensors for speed/position measurement, although there is a trade-off between required functionality and cost.
The advent of electrically power assisted steering systems introduced the steering torque sensor which can also be integrated with a steering position sensor. A number of torque sensing technologies have been used including inductive and optical technologies. In the case of the optically-based sensor, the pattern of light transmitted through two disks attached to the torsion bar is processed by the electronic control unit to determine both steering torque and position.

![Figure 4. Optical Torque and Position Sensor.](image)

Advanced vehicle stability control systems will include an inertial sensor cluster module that comprises a yaw rate sensor (sometimes also a roll rate sensor) and one or two acceleration (lateral/longitudinal) sensors. The yaw sensor can measure the rotation of a vehicle and has a measuring range of +/- 75 °/s. The acceleration sensors measure the lateral and longitudinal acceleration of a vehicle in the range +/-1.5 g. All sensor elements can perform a self test to check their functionality. For future control systems, both the gyroscopes and accelerometers are being integrated with the main circuit board for the application, thus avoiding the need for a separately packaged sensor cluster.

![Figure 5. Inertial Sensing Module.](image)  
![Figure 6. Slip Control System ECU with Integrated Inertial Sensors.](image)

Long range radar sensors are already successfully used as part of adaptive cruise control systems. The radar scans at an operating frequency of 77GHz and at a distance of about 150 metres. Information from the radar is used to maintain a safe safety margin to the vehicle driving ahead through automatic intervention of the braking and engine management systems. Today’s systems operate at speeds over 30 mile per hour, but future systems currently under development will add the “stop and go” system to operate down to zero speed through the use of short-range radar (24GHz). The use of video sensors will add functionality to these systems including blind-spot detection and night vision enhancement. These types of systems are generally referred to as driver assistance systems. Future systems will also interact with the occupant safety systems (airbag deployment and seat belt pre-tensioning).
4. Future Sensor Opportunities
Future development of the active and passive safety systems will enable the vehicle to “sense” and interpret its surrounding environment, recognise potentially dangerous situations and provide a pre-determined level of support to the driver. Blind-spot detection, lane change monitoring and roundabout shunt prevention are examples of systems that could be enabled through the deployment of vision-based sensors and multiple sensor data fusion techniques.

Parking assistance systems are already close to a production reality. Ultrasonic sensors mounted on the sides of vehicles will measure the length and depth of a parking space as the vehicle drives past it. The system then calculates the manoeuvres that are required to steer the vehicle safely into the space. The driver is then provided with sound or visual instructions to complete the task. A future enhancement would involve the use of electronically controlled steering system to execute the manoeuvre automatically.

Sensor development engineers will need to work with vehicle stylists to package and position sensors in the best location that allows sensor functionality without obtrusive body features. Advanced electrical architectures will also focus upon standardisation and sharing of sensor outputs across a range of vehicle systems [4]. The addition of sensor self-diagnostic functions has been realised by many suppliers.

The path to “X-by-Wire”, that is the replacement of mechanical systems by electronically controlled electrically actuated systems (for example, by removal of the steering column or hydraulic braking pipes), is a challenging one and will only be successfully realised through electronics integration and the continued innovation of new sensing technologies [5].

Ultimately, the vehicle will become a cocoon of both inward facing and outward facing electronic monitoring systems that will improve the safety and survivability of its driver and passengers [6].

5. Summary
The past few decades have witnessed the development and deployment of a range of sensing technologies that have both supported and enabled the introduction of advanced electronic systems. The environment for these sensors continues to be increasingly challenging with respect to robustness, reliability, quality and cost. Sensor suppliers face the continuing mandate to deliver more capability at less cost. Existing sensors will continue to find new applications, building upon their historical track record of performance, and new sensors will emerge to improve system functionality and enable future advanced systems.
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