The Limitations of Present Sensor Technologies in the Automotive Industry: A Review

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Abstract—In the modern era of the 21st century, sensor technologies are springing up like mushrooms after the rain. Thus, this phenomenon had caused a variety of sensor technologies used in automotive in the present day. In this paper, we analyse the current sensor technologies used in the automotive field especially in the car which enable us to monitor our vehicles condition, to ensure our vehicle safety and lastly to ensure more significant driving comfort for both the driver and passengers. The types of sensors are presented, and the limitation of the sensors and its application in various systems are discussed in this paper.

Index Terms—Sensor Technologies; Automotive; Limitation; Sensor System.

I. INTRODUCTION

Sensors are essential components for the control systems of automotive electronics. Sensors [1] are defined as "a device that changes physical quantities into output signals that serve as input for control systems". The term transducer is often used instead of the term sensor. The transducer is defined as a device that changes one energy to another energy. Therefore, sensors are known as transducers [2]. In Engineering literature, they normally do not differentiate the terms "sensors" and "transducers". Sensors or transducers are often depending on the application field where they are used. In the automotive field, the devices are referred to as sensors. Powertrain, chassis, and body are the three areas in the automotive systems where sensors are utilised [3].

In the control systems of automotive electronics, sensors are essential as they can be fitted to enhance safety, performance, function and provide convenience to the users. Nowadays, an average car uses more than fifty sensors, and a luxury car uses more than one hundred sensors. Of these, one-third are currently based on micromachined sensors [4] with the proportion expected to increase in the future. Therefore, as the complexity and safety-critical nature of automotive control systems grow, the number of sensors needed also increase [5]. To make the automotive electronic devices more advanced, additional effort regarding design is needed to implement any innovative features. These emerging features leads to new design strategies adopted to the automotive system which would integrate more sensors into the system.

II. LITERATURE REVIEW

Sensors that measure time or speed, occupant safety or security and mass air flow in the automotive system are described in [6]. Telematics systems rely a lot on measurement techniques and sensors, and its operation robustness is considered critical [7]. According to Infineon, all newly developed parts of a vehicle based on ISO 26262 is the development of electric and electronic automotive systems that related to their functional safety, thus allowing direct use in all safety-relevant applications [8].

Today, the uses of primary sensor technologies are reviewed, and powertrain, chassis, and body are the three areas of the application for automotive systems for sensors [9]. To measure the brakes, automatic transmission and engine, revolution sensors are. Since the discovery of GMR effect and their large magnetoresistance ratio, magnetic fields sensors, magnetic heads, and other devices are applied by GMR elements [10].

For magnetic sensors, the direction of the rotating magnetic field is determined by using the AMR-effect directional sensitivity [11]. By using angular magnetic field sensor, high angular resolution measurements are enabled by obtaining a phase shift of 90∘ for two signals. The magnetic field generated by permanent magnet causes constraint in the miniaturisation process. Furthermore, the magnetic field generated by a specific electric circuit also causes the power consumption to increase. In a wheel bearing, the multipolar magnetic seal magnetised in a sequence of 48 pairs of N-S poles integrated is used to produce the sensing field [12]. Magnetostrictive Amorphous Wire (MAW) sensor can measure the pulse frequency to compute the vehicle speed [13]. Besides that, there are few types of gas sensors utilised inside the car structure. The linear temperature micro-hotplate gas sensor array is an innovative micro hotplate-based silicon gas sensor arrays that perform in the car cabin air quality field [14]. The change in the metal oxide semiconductors conductivity is solved by using the air quality gas sensor to activate the recirculation mode of the HVAC system [15]. The linear correlation between concentration and conductance of ethanol in the fuel at room temperature is presented by using the polymeric electronic gas sensor [16]. For hydrogen safety sensor, to identify its performance gaps, the sensitivity of hydrogen sensors and the lower detection limit is measured where there is a critical parameter, and the lower detection limit is a useful indication of the ability of a sensor to detect low concentrations [17].

Also, the pressure sensor is also a critical sensor in the automotive application. To improve the calibration yield, the number of sensors calibrated in a batch is optimised by using the piezoresistive pressure sensors. During production, a pre-check based on the sorting algorithm with a margin that

continuously adjusted is briefly conducted [18]. Pressure Sensor Glow Plug – PSG is designed to reduce the necessary emissions to achieve the demanded NOX aim [19]. In recent years, Tyre Pressure Monitoring Sensor is a hotspot for the vehicle detection system research to ensure the tire life, automobile safety, and performance [20].

During the case of critical driving situations where the steering loses its control, the electronic stability control (ESC) system starts to operate. Nowadays, the micro-electromechanical system (MEMS) sensors are mostly used in automotive ESC systems [21] where it is a derivation of semiconductor process technology that provides benefits to the semiconductor manufacturing technology [22] and hence provides a path for a commercial with automotive MEMS physical sensors [23]. However, yaw rate sensor, steering wheel angle sensor, wheel speed sensor and the lateral acceleration sensor are the most critical sensors for electronic stability control system. The angular speed or rotation rate of the car along the vertical axis can be measured using the yaw rate sensor, while the steering wheel angle sensor is usually based on the Hall effect sensors. To determine the regulating action, the data of the steering wheel angle sensor is compared with the data of the yaw rate sensor. Wheel speed is typically based on contactless magnetic sensors where the speed is measured by wheel speed sensor, while nowadays where the vehicles' lateral acceleration that relies only on the micro-electromechanical system(MEMS)-based single or dual axis capacitive accelerometer is measured by the lateral acceleration sensor. Not only that, the rotation rate of a body concerning the referenced inertial frame can be measured by using the angular velocity sensors [21].

The level sensor is fundamental to the automotive application. The device to determine the level of fuel in the fuel tank that situated in an automotive is fuel level sensor [24]. The function of the fuel gauge sensor is also same as the fuel level sensor. The systems of both sensors consist of two parts which are used for sensing and fuel level indication. To determine the fuel level in the fuel tank, the float type sensor usually is used by the sensing unit, while the amount of the electric current flowing through the sensing unit is measured by the indicator system to determine the fuel level in the fuel tank [25]. The exciting part is the presence of water, and other contaminants in the fuel and storage system of an automotive can cause excessive economic loss [26]. The present Liquid Level Sensors are not sufficient. Traditional systems that use resistance sensors give inaccurate reading whereas smart fuel gauge systems that use ultrasonic sensors are more complicated and expensive. Therefore, a brand-new liquid level sensor idea is configured [27].

Furthermore, the automotive application consists of a wide field of sensors. In the industry, the magnetoelastic torque sensor is a useful sensor in the measurement of torque because it is one of the two fundamental physical quantities that necessary in resolving the rotating drive mechanisms [28]. For SOI rate gyro sensor, the central parts of the sensor elements are made of the active layer of Si and SOI that consists of one mass and two kinds of vibrating beams which are the folded beams and straight ones. The Coriolis effect is used because the SOI rate gyro sensor is vibrated [29]. For humidity sensors, humidity measurement is an area for specialists that have meteorological competency in humidity and have a better understanding of humidity behaviour [30]. An automatic braking system that is used by sensor automotive can brake automatically when the sensor of the automotive senses an obstacle without the driver's input. High accuracy measurements and short distance measurement that needed to be improved can achieve by using the Automatic Braking System [31].

Next, the electrode material is usually printed or painted on the dense electrolyte substrate in a usual mixed potential sensor. Decreasing the amount of heterogeneous catalysis before the reaching the interface will cause the sensor response to increasing. By altering the reacting gas concentrations near the triple phase boundary, the gas response is changed when heterogeneous catalysis is away from the triple phase boundary [32]. There are two categories in the automotive radar sensor which is the short-range radar (SRR) and long-range radar (LRR). This radar sensor is the crucial part of the ACC because it has active brake assist. In another way to smooth the deceleration capability of the ACC, much higher braking forces for deceleration is provided by the active brake assist [33]. Ultrasound sensor is used in the automotive application. The distance measurement of an object in the path of an automotive, equipment or a person, either moving or stationary, is used in many applications such as blind man's walking stick, automotive control, robotic movement control, medical applications and so on [34]. With the aim of decreasing the number of injury and accident severity, optical sensors are used on on-road vehicle detection. This results in pre-crash sensing becoming an area of active research among automotive manufacturers [35].

III. METHODOLOGY

A. Research Method

The research method used in this article is called the secondary data analysis. To make the research different from the original works, the analysis utilised the existing data and gathered them for the future study.

There are several reasons that this method is chosen as the research method of this article. One of the reasons is due to the lack of appropriate facilities to experiment. The research conducted requires the use of specific sensors in automobiles which are expensive and difficult to be obtained with current resources. Besides, secondary data analysis does not require much financial support and the data can be easily obtained from the internet, so it is the most suitable method to be used. Most of the data obtained are from internet sources, but apart from that, books which are found in the local library is also used as a reference. For example, "Sensor in Automobile" written by John Turner.

The literature search was restricted to English -language articles published between the years (2000 to 2016). All studies in sensors used in automobile (cars) were included in this review. This review excluded sensors in another automobile such as train, ship and planes. A total of 30 studies on sensors used in an automobile are reviewed for this paper.

B. Reviews/Limitations
1) A review of new automotive sensors [6]
This paper concluded that the new automotive sensors cannot measure the very high temperature of over 1050°C. The sensors also are using the RTD-type sensors and thermistor-type sensor.

2) A Review of Current Sensor Technologies and Applications Within Automotive and Traffic Control Systems [7]

This paper mentioned about the high automotive manufacturing cost, safety alert requirement to driver and passenger, serious electronic system failure such as engine stops. There are works to continue to develop sensor fabrication methods and use of thick-film processing, and for the next decade, it is required to enhance the sensing and monitoring system on the vehicle.

3) Sensor Solutions for Automotive Industrial and Consumer Application [8]

This paper explained on making life easier, safer and more comfortable by application of sensor technologies. Full ISO 26262, which is a compliant process, is used to ensure the fulfilment of ASIL-rated safety requirements

4) Overview of Automotive Sensors [9]

This paper revealed that the sensor react to a certain amount of water and the importance to use a more sensitive sensor.

5) Application of a GMR Element to a Revolution Sensor [10]

This paper explained about the GMR sensitivity advantage reduced at room temperature. Therefore, the GMR is best operated at a cooler temperature.

6) Magnetic Sensor for Automotive Applications [11]

This paper exposed the limitation of the AMR-effect which is intrinsic. So, a switchable magnetic field generator is used inside the sensor element.

7) Angular Magnetic Field Sensor Based on Magnetic Tunnel Junctions Using a Current Loop Layout Configuration [12]

In this paper, an output signal will be produced when mismatching the resistance values in magnetic tunnel junctions (MTJ). The control of the magnetic properties of each magnetic tunnel junction (MTJ) arm is independent and needed in the Wheatstone bridge. The phase shift of 90° for two signals can be obtained. An original magnetic sensor architecture based on magnetic tunnel junctions (MTJs) with signal processing current loop circuit is used to replace the Wheatstone bridge.

8) Automobile Speed Measurement System Based on Microcontroller and Magnetostrictive Amorphous Wire Sensor [13]

This paper presents another method to measure the speed of a motor vehicle instead of speedometer reading which is attributed to differential lock system. Magnetostrictive amorphous wire (MAW) is used, and with this MAW sensor, it is possible to interfacing with microcontrollers. The speed that is measured can be stored in memory for future use.

9) Linear Temperature Microhotplate Gas Sensor Array for Automotive Cabin Air Quality Monitoring [14]

To differentiate the gas mixture in the cabin air quality, the evaluation of micromachined gas sensor array performance is needed. The miniaturised temperature gradient electronic nose (MTGEN) is needed to evaluate the performance. Micro-hotplate-based silicon gas sensor arrays are capable of detecting and identifying volatile gas compounds. Assembled

of semiconducting metal oxide, WO_3 in a TO-12 package to design the microhotplate-based silicon gas sensor. The array can act as a single die MTGEN

10) Automotive Suitability of Air Quality Gas Sensor [15]

The technical specification and automotive suitability with some qualification criteria is explained in this paper. The output signal of a gas sensor is corresponded to the concentration of the gas that prevalent to pollutant and the degree of contamination of the odour.

11) Polymeric Electronic Gas Sensor for Determining Alcohol Content in Automotive Fuels [16]

The oxygen content in the exhaust gas is measured by the lambda sense but not the ethanol content in the fuel. Replacing lambda sensor can be done with polymeric sensor.

12) Identifying Performance Gaps in Hydrogen Safety Sensor Technology for Automotive and Stationary Applications [17]

The actual performance specifications for commercially available sensors and existing performance targets for hydrogen safety sensors are different. The requirements of measuring the specified range are satisfied while the method of operation to compensate for the other is allowed by the combination of technology sensor.

13) Yield Enhancement of Piezoresistive Pressure Sensors for Automotive Applications [18]

The wide range of errors that they had exhibited is during the calibration and compensation. The number of sensors that calibrated in a batch is optimised, and calibration yield improves the advanced pre-checking

14) Pressure Sensor Glow Plug (PSG) for Diesel Engines [19]

This research work is required for high integration of the sensor element. It also needed connection technology with long-term stability, high accuracy and calibration capacity whereby piezo-resistive sensor is used.

15) A New Approach to Tyre Pressure Monitoring System [20]

A drop of tyre pressure causes the vehicle safety, tyre life, mileage and performance to reduce. The use of wireless sensor network technology based on the tyre pressure monitoring systems is used to monitor the tyre parameters

16) MEMS Sensors for Automotive Vehicle Stability Control Applications [20]

By merging functions and re-using the sensors information, new concepts need to be developed to optimise the functions of the vehicle. Multi-axis component is needed in integrating different sensing elements. Sensor synergy at a certain degree is needed to increase the level of integration to function.

17) Dynamic Detection of Airflow for Vehicle Intake System Based-on Hot-Film Anemometry Sensors [22]

The detection in the internal combustion engines by the airflow meter sensor needs to be developed. Hot-film flow meter is developed by using micro-electromechanical process technology. Airflow anemometry sensor produced by MEMS-based technology is demonstrated that help in the design of the future car.

18) MEMS Physical Sensor for Automotive Applications [23]

Stiff requirements such as high quality, reliability, performance and cost is required in this application. automotive MEMS sensors are highly demanded for safety and security.

19) Application of Pugh Selection Matrix for Fuel Level Sensing Technology Selection [24]

This paper stated that the fuel tank height of heavy commercial vehicles is more than 100 mm, thus a LVDT level sensors cannot be used. RF Capacitance type fuel level sensor is proposed as the best technology according to the Pugh Selection Method.

20) Fuel Gauge Sensing Technologies for Automotive Applications [25]

A traditional system such as the use of resistive float-type sensors is notoriously inaccurate. The use of embedded systems by smart fuel gauge systems such as microprocessor or microcontroller is used to provide a better accuracy.

21) Design and Development of Water-In-Fuel Detector [26]

Water comes into fuel causes contamination, and engine and fuel system damage and contributed to downtime and high maintenance costs. The water-in-fuel detector is used, but further development is required to detect water in other fuels. Other further work is the use of calibration of meter for fuel identification.

22) Liquid Level Sensor in Automotive Design [27]

Resistance sensors using a resistance wire is notoriously inaccurate. An ultrasonic sensor provided benefits for dynamic measurements, but they are more expensive and complex. A brand-new idea for the liquid level sensor is designed using the existing Whispering Gallery Mode (WGM) theory.

23) Development of a Magnetoelastic Torque Sensor for Formula 1 and CHAMP Car Racing Applications [28]

This paper focused on developing and implementing the racing torque sensor for increasing mass production automotive applications. The paradigm shift is to be implemented in racing applications that helps to accelerate torque sensor. Choice of shaft material, positional containment and the magnetic environment is taken into account

24) SOI rate gyro sensor for automotive control [29]

A new open beam structure of the silicon on insulator (SOI) that made by the micro-electro-mechanical system (MEMS) technology need to be introduced. Open beam structure (OBS) is used and provides excellent sensor features which are suitable for mass production in an automotive application

25) Humidity Sensors for Automotive, Appliances and Consumer Applications [30]

This paper argued that the humidity sensors must be in contact with the air which can affect the sensor. So, the sensors are used in a less contaminated to extend its lifespan.

26) Automatic Braking System with Sensor Fusion Concept [31]

Ultrasonic sensors exhibit a dead zone and accurate measurements. Capacitive sensing technology combined with ultrasonic sensors can improved the distance measurement system and provided the high accuracy measurements.

27) Application of Commercial Automotive Sensor Manufacturing Methods for NO_X/NH_3 Mixed Potential Sensors for On-board Emissions Control [32]

This paper identified the number of electrode materials and the electrolyte interface. It also address a set of minimised sensing needs and the patent of mixed potential sensors among the various issues. To show the potential of development of the sensor, a 3-electrode design in an ELS platform is used. Using the unique Los Alamos National Laboratory (LANL) design, NO_x/NH_3 mixed potential sensors which are stable, reproducible and high sensitivity can be implemented.

28) RF MEMS for automotive radar sensors [33]

This paper explained about the development of RF MEMS components to overcome the reliability issues. The MEM tuneable components had enabled various demonstrators and RF MEMS components for RF MEMS-based automotive radar and beam steering.

29) Distance Measurement of an Object or Obstacle by Ultrasound Sensors [34]

This paper pointed out that the ultrasound sensors cannot display how far is the obstacle. Thus, vision chips are used such as cameras that are operated under low light and in the non-visible spectrum.
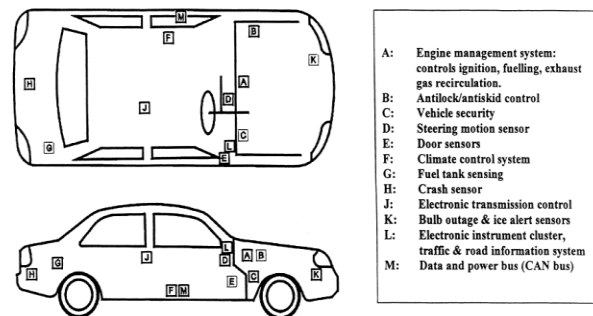
IV. RESULT AND ANALYSIS
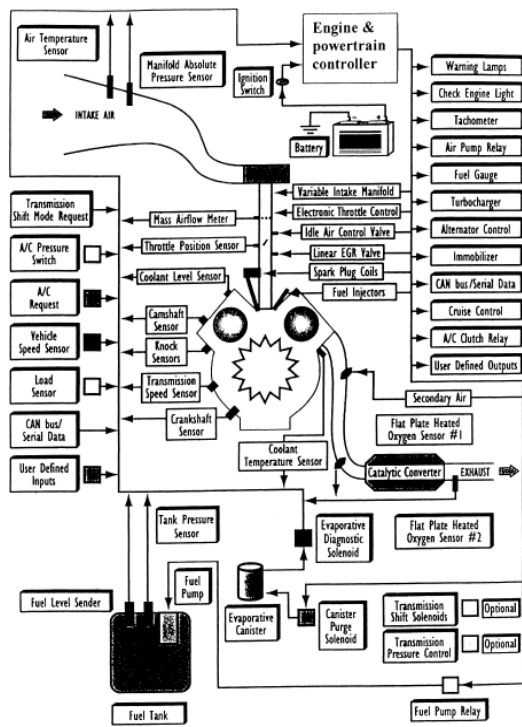

Figure 1: Automotive Measurement System [7]

Figure 2: Typical Powertrain Management System [7]

V. DISCUSSIONS

From the analysis table, we realise that every one of the sensors used in the automotive application has its limitation and could not perform optimally. Thus, a coping method should be taken in action to avoid unwanted problems.

There are many ways to cope with the limitation. Using the most appropriate sensor will reduce the influences of limitations to a minimum. LVDT level sensors are the most effective sensor for measuring liquid height up to 100 mm. However, as the fuel tank height of heavy commercial vehicles is more than 100 mm, the LVDT level sensors cannot be used. RF Capacitance type fuel level sensor is used to cope with the problem [24]. Based on the magnetic tunnel junctions, Wheatstone bridge is used in the angular magnetic field sensor, because Wheatstone bridge can control the magnetic properties of each MTJ arm independently [12]. From the Los Alamos National Laboratory (LANL) design, the application of commercial manufactured automotive sensor for NOx/NH3 mixed potential sensors for on-board emissions control, reproducible, high sensitivity and stable NOx/NH3 mixed potential sensors are used [32].

On the other hand, digital sensors should be used compared to analogue sensors. This is because digital sensors produce more accurate information than analogue sensors. For example, traditional systems which use the resistive float-type sensors are notoriously inaccurate while the embedded systems used by smart fuel gauge systems such as microprocessors or microcontrollers provide higher accuracy [25]. Magnetostrictive Amorphous Wire (MAW) is used on the vehicle instead of the speedometer and with this MAW sensor interfacing with the microcontrollers, and speed measurement may display via LCD, and the speed that is measured can store in the memory form for the future use in Automobile Speed Measurement System [13].

In some cases where the most appropriate sensor is used, errors still occur because of the dead zone of the sensors. As we all know, there is no perfect sensor technology. Even if we have chosen the most appropriate sensor, it still has its limitations. In this case, we can combine several sensors to cope with the dead zone of the sensor used. In the automatic braking system, the ultrasonic sensor is used. However, when ultrasonic sensors exhibit the dead zone, it will cause the measurements to be inaccurate. Therefore, to improve the distance measurement system, which gives high accuracy measurements, the capacitive sensing technology and ultrasonic sensors are combined [31]. The actual performance specifications for commercial sensors that are available and existing performance targets for hydrogen safety sensor vary . Thus, in hydrogen safety sensor technology, the combination of technology sensor is used for the automotive to compensate for each method of operation, so that the requirements for measuring the specified range is satisfied because the lower detection limit is not always given [17].

VI. CONCLUSION

The survey of literature has revealed that every sensor technology used in the automotive application have their limitation regarding function and are unable to perform optimally without the perfect match. This has proven that there are no best sensor technologies in the automotive application; only the most appropriate sensor technologies are used. Thus, every sensor has its advantages and disadvantages. Therefore, the appropriate sensor should be used in our automotive applications in order for the sensors to function optimally to avoid unwanted problems. This article has introduced present sensor technologies with automotive applications including their limitations and solutions.

REFERENCES

[1] W. Fleming . *"Overview of automotive sensors "* . Dec. 2001 ; Vol. 1, No. 4 ; pp. 296–308

[2] Strategy analytics sees automotive sensors market at US$17 billion by 2013 May 24, 2007. [Online]. Available: http://autoelectronics.com/news/automotive_sensors_market_0524/index.html

[3] William J. Fleming . *New Automotive Sensors* . Nov.2008 ; Vol.8, No. 11 : pp. 1900-1921

[4] Kruegar, S., R. Muller-Fiedler , S. Finkbieiner, and T.Hans Peter. *Microsystems for the automotive industry*. MST News 2005 ; S1/05 : pp. 8-10

[5] John Turner , PH. D . Automotive Sensors . New York : Momentum Press. 2009.

[6] William J. Fleming,. *New Automotive Sensors—A Review* . IEEE SENSORS JOURNAL , November 2008 ; Vol. 8 , No. 11 : pp. 1900 – 1919

[7] J D Turner and L Austin . *A Review of Current Sensor Technologies and Applications within Automotive and Traffic Control Systems* . 2000 ; Vol. 214 , No. 6 : pp. 589-614

[8] Infineon Analysis . *Sensor Solutions for Automotive , Industrial and Consumer Applications* . 2015 : pp. 1 − 51

[9] William J. Fleming .*Overview of Automotive Sensors* . IEEE SENSORS JOURNAL DECEMBER 2001 ; Vol. 1, No. 4 : pp. 296-306

[10] Tatsuya Fukami and Masayuki Ikeuti . *Application of a GMR Element to a Revolution Sensor* . June 2001 : pp. 5 − 7

[11] C.P.O Treutler . Magnetic sensor for automotive applications. *Sensors and Actuators A 91* . June 2011; Vol. 91 , Issue 1-2 : pp. 2-6

[12] G. Malinowski, M. Hehn, F. Montaigne, A. Schuhl, C. Duret, R. Nantua, G. Chaumontet. Angular magnetic field sensor based on magnetic tunnel junctions using a current loop layout configuration. *Sensors and Actuators A 144*. June 2008 ; Vol. 144 , Issue 2 : pp. 263-266

[13] Mercy. N. Kiio , John. N. Nderu , Stanley. I. Kamau . *Automobile Speed Measurement System Based on Microcontroller and Magnetostrictive Amorphous Wire Sensor* . October 2014 ; Vol.3 No.8 : pp. 21-28

[14] L. Francioso, A. Forleo, A.M. Taurino, P.Siciliano, L. Lorenxelli, V. Guarnieri, A. Adami, G. Agnusdei. Linear temperature microhotplate gas sensor array for automotive cabin air quality monitoring. *Sensors and Actuators B 134*. 2008; Vol 134 , Issue 2 : pp. 660-665.

[15] Thomas Tille. Automotive suitability of air quality gas sensor. *Sensors and Actuators B 170*. 2012; Vol 170 : pp. 40-44.

[16] Adriano R.V. Benvenho, RosamariaW.C. Li, Jonas Gruber∗ . *Polymeric electronic gas sensor for determining alcohol content in automotive fuels* . February 2009 ; Vol. 136 , Issue 1 : pp. 173-176

[17] L. Boon-Brett, J. Bousek, G. Black, P.Moretto, P. Castello, T. Hübert, U. Banach. *Identifying performance gaps in hydrogen safety sensor technology for automotive and stationary applications* . 2010 ; Vol. 35 , Issue 1 : P pp. age 373-384

[18] Marko Pavlin a, Franc Novak b .*Yield Enhancement of Piezoresistive Pressure Sensors for Automotive Applications* . Jan 2008 ; Vol 141, Issue 1 : pp. 34-42

[19] Hans Houben, Arno Marto, Frank Pechhold, Michael Haußner and Marc Borgers . *Pressure Sensor Glow Plug (PSG) for Diesel Engines* . MTZ worldwide 11/2004 ; Volume 65 : pp. 1-7

[20] Asha Mathai , Dr. P. Vanaja Ranjan . *A New Approach to Tyre Pressure Monitoring* System . February 2015 ; Vol.4 , Issue 2 : page 866 – 872

[21] M. Reze, M. Osajda. MEMS sensors for automotive vehicle stability control applications. *Mems for Automotive and Aerospace Applications.* 2013: pp. 29-53.

[22] Rong-Hua Ma , Tsung-Sheng Sheu . *Dynamic Detection on Airflow for Vehicle Intake System Based-on- Hot-Film Anemometry Sensors* . 2011 ; Vol. 1 : pp. 1-6

[23] David J. Monk , Ph.D. . *MEMS Physical Sensors For Automotive Applications* . 2002 ; Vol. 6 ; pp. 43-60

[24] Madke Pranita B., Dr. Jaybhaye M.D . *Application of Pugh Selection Matrix for Fuel Level Sensing Technology Selection* . 11-12 Feb. 2016 ; Vol.5 : pp. 368-370

[25] Vinay Divakar . *Fuel Gauge Sensing Technologies for Automotive Applications* . January 2014 ; Volume 3 , Issue 1 : pp. 40-42

[26] Remy Uche , Ph.D , Aninwezi Augustine . *Design And Development of Water-In-Fuel Detector* . 2012 ; Vol.3 , No.10 : pp. 1-10

[27] Mehmet Emre Erdem, Dogan Gunes . *Liquid Level Sensor in Automotive Design* . SENSORCOMM 2011 : The Fifth International Conference on Sensor Technologies and Applications : pp. 166 – 171

[28] Sami Bitar and John S. Probst , Ivan J. Garshelis . *Development of a Magnetoelastic Torque Sensor for Formula 1 and CHAMP Car Racing Applications* . March 6-9 , 2000 ; Vol. 1 ; pp. 1-7

[29] Y. Nonomura, M. Fujiyoshi, Y. Omura, N. Fujitsuka, K. Mizuno, K. Tsukada. SOI rate gyro sensor for automotive control. *Sensors and Actuators A: Physical* . 2006 ; Vol.132 , Issue 8 : pp. 42-46.

[30] Bruno Patissier . *Humidity sensors for automotive, appliances and consumer applications* . October 1999 ; Vol. 59 , Issues 2-3 : Pages 231-234

[31] Dhanya K. R. And R. Jeyanthi . *Automatic Braking System With Sensor Fusion Concept* . I J E E E S, June 2012 ; Vol. 4 No.1 : pp. 23-27

[32] Praveen K. Sekhar, Eric. L. Brosha, Rangachary Mukundan, Wenxia Li, Mark a. Nelson, Ponnusamy Palanisamy, Fernando H. Garzon. Application of commercial automotive sensor manufacturing methods for NO_X/NH_3 mixed potential sensors for on-board emissions control. *Sensors and Actuators B 144*. 2010 : pp. 112-119.

[33] J. Oberhammer, N. Somjit, U. Shah, Z. Baghchehsaraei . RF MEMS for automotive radar sensors. *Mems for Automotive and Aerospace Applications, Elsevier.* 2013 : pp. 106-136.

[34] A. K. Shrivastava, A. Verma, and S. P. Singh . *Distance Measurement of an Object or Obstacle by Ultrasound Sensors* . February 2010 ; Vol. 2, No. 1 : 1793-8201

[35] Zehang Sun , George Bebis and Ronald Miller . *On-Road Vehicle Detection Using Optical Sensors: A Review* . 2004 : 1-6.