SENSORS IN AUTOMOBILE AND ASSOCIATED MECHANISMS: A REVIEW

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Abstract: In this paper we have completed an extensive survey on sensors and associated systems used in automobile applications. This article describes the various types of sensors used, their characteristics and utility for unique functions in an automobile. Additionally, we intend to create a comprehensive catalog of the multitude of sensors available in the market to help the consumer make an educated choice while customizing their application. The primary selection criteria for every sensor based on their compatibility with the surroundings is also addressed in detail. Furthermore, this paper aims to emphasize the importance of appropriate sensor selection to help achieve enhanced performance in the automobile sector.

Index Terms – ABS, ACU, Automobile, CAS Compatibility, IoT, Safety, Sensors

I. INTRODUCTION

Nowadays the automobiles have undergone revolutionary changes when compared to their predecessors, the integration of electronic components within vehicles have been pivotal in bringing about this revolution. In today's date, a wide array of electronic sensors that are used to aid as well as monitor various parameters of a vehicle. This is done so that the user gets proper information of the various aspects of his vehicle so that optimum performance can be ensured and the maintenance required for the vehicle can be implemented right away without any delays. To speak about the areas of application of sensors within a vehicle, we can observe them right from the tires of the vehicle to the engine of the same. This wide range of applications suggests that the sensors chosen should be of proper quality and the user should understand what purpose these sensors stand to serve. The sensors, if employed on their own, will be nothing but instruments which collect data, the important aspect is to answer the question of 'What can be done with this data?'. As an answer to the question, an overview of some of the most important applications of sensors inside an automobile is elaborated upon. These applications fall under the category of necessities within a modern vehicle. The major applications spoken about here are the Anti-Lock Braking System(ABS), The Tire Pressure Monitoring System(TPMS), the Collision Avoidance System, the Parking System and Airbag Deployment. These aspects are the selling points of cars today and are few of the most influential aspects that a consumer considers while choosing a vehicle. The sensor data is extracted and interpreted by a microcontroller employed within any system and depending on the set-points specified within the microcontroller program, a control action is taken and the parameters are regulated. This control action is important in safety applications of the vehicle. The aforementioned systems are elaborated further with respect to their mechanisms of operation, compatibility and cost.

II. LITERATURE REVIEW

Yanxia Zhang, Hayley Hung published a paper on '**Using topic models to mine everyday object usage routines through connected IOT Sensors**'- arXiv: 1807.04343v1. **[1]** This paper deals with the recording of sensor data involved in an IoT system & its subsequent organization into a pattern referred to as topic model. By allocating specific identities to various objects namely, chair, dining table, remotes, et al. That are a part of a home automation IoT system, sensory data can be recorded and then used to develop a mesh of routine behaviors. This would assist a specific group of people: third level adults (65 and above) in various daily activities. We plan on using the data models and behavioral sensor patterns mentioned in this paper to help us figure out a method of selection for different sensors in any IoT system.

Madakam, S, Ramaswamy, R. and Tripathi, S. (2015) published a paper on '**Internet of Things (IoT): A Literature Review'** in Journal of Computer and Communications, 3, 164-173. **[2]** By studying this paper, we understood the basic structure of an IoT system especially the different layers involved. Various technologies are used while implementing an IoT system and each technology requires different devices with unique specifications. By reviewing the contents of this paper pertaining to the diverse technologies in IoT, we will apply this understanding towards understanding sensor specifications and compatibility for many other IoT systems.

Tarikul Islam, Member, IEEE, S. C. Mukhopadhyay, Fellow, IEEE and N. K. Suryadevara, Senior Member, IEEE published a paper on '**Smart Sensors and Internet of Things'. [3]** This paper is a course overview on the newly added subject of IOT and sensors to the curriculum of the aforementioned university. It discusses the scope of IOT as a field of study and speaks of the role of sensors in it. It describes various methods of sensor fabrication, their characteristics and application. For example, it speaks of the static and dynamic characteristics of a sensor and describes certain classes such as fractional order sensors, surface acoustic wave sensors. It also speaks about the relationship between WSN's (wireless sensory networks) and the IOT (internet of things).

Qin Yang, Sang published a paper on '**Optimal UAV Path Planning: Sensing Data Acquisition Over IoT Sensor Networks Using Multi-Objective Bio-Inspired Algorithms.' [4]** This paper is pertaining to the optimization of path determination for an unmanned aerial vehicle. This paper employs IOT as an organ of this path determination system which uses a combination of two algorithms viz. Genetic Algorithm(GA) and Ant Colony Optimization(ACO). The target area of the UAV is divided into grids which comprises of unit cells. They are of two types: SIG (Sensor Information Gathering) cells and flying cells. The IOT network of sensors provides the data for the algorithm to perform mathematical calculations for the path to be optimized.

V.K. Sehgal, S. Mehrotra, H. Marwah published a paper on **'Car Security using Internet of Things': 978-1-4673-8587-9/16 ©2016 IEEE. [5]** Through the above paper we understood the application of IoT for the purpose of car security. We will extract the information pertaining to the sensors used and the sensory shield arrangement designed in the system to serve the purpose of car security. Furthermore, the paper details the connection of different interfaces in the system including features like skype call, text message & GPS tracking depending on the user response to deploy any of the above specified services in any automobile to help the user avoid theft of their vehicle. We also obtain information regarding specific sensors viz. VSS - vehicle speed sensor & GPS Sensors which form the base of any automobile security system.

III. TYPES AND DESCRIPTION OF SENSOR

Today, a large number of sensors are used in automobiles for specific applications. In this paper, we will elaborate upon the following types of sensors namely, their description viz. characteristics, functions and cost of installation in any automobile application:

1. Proximity Sensors
2. Motion Detectors- gyroscope, steering angle sensors
3. Temperature sensors
4. Wheel-speed (ABS) sensors
5. Tire pressure Monitoring Sensors (TPMS)
6. Safety Systems and sensors

We will discuss some basic specifications of each category of sensors and further look at their functionality as implemented in an automobile system.

1)Proximity sensors: These are used to detect the presence of an object over a certain range that can be measured by the sensor. This range varies for different types of sensors. They are primarily used in portable or mobile devices such as cellphones, automobiles, roller coasters, conveyor systems, et al. A primary characteristic of any proximity sensor is the maximum distance it can detect, namely the 'nominal range'. The processes using which we can alter this parameter are called 'thermo-sensation'.

A multitude of IOT systems involve mobile devices which need to perform some kind of motion. A home automation system may need this sensor for simple switching applications where user could wave their hand and turn if a particular appliance. In automobile systems linked to IOT, proximity sensors play a cardinal role in detecting obstacles and helping the vehicle maneuver through a path. These sensors are used ubiquitously in the IOT ecosystem at diverse stages of implementation.

Depending on the application such as parking systems in a car or safety systems, the proximity sensors can further be chosen from the following categories:

- Ultrasonic Sensor
- Hall Effect Sensor
- Radar
- SONAR
- Fiber Optic Sensor

-One of the popular variants of the above type is the MB8450 USB-CarSonar-WR sensor manufactured by MaxBotix Inc. with a range of 500-5000 mm. Some of the features include centimeter resolution, short to long distance detection with its user-friendly USB interface design. The working principle of the above sensor is based on ultrasound operation that aids in locating obstacles.

Fig.1: Proximity Sensor - Type- Ultrasonic

Some other sensors that are widely used for proximity detection include: Blind spot sensor – SP904 (AS201801) based on principle of ultrasonic application.

2)Motion Detectors: Systems like the airbag deployment mechanism often utilize the motion detectors like gyroscopes and accelerometers. To understand the use of these sensors, it is important to have a fundamental understanding of the airbag deployment system. The airbag deployment system is one of the most contemporary innovations designed to ensure the passengers' safety. It consists of an airbag module which inflates and deflates very rapidly in the incident of a collision. These airbags consist of a cushion, a fabric bag, inflation module and an impact sensor. The airbag absorbs the excessive energy between the vehicle and the passenger during an accident. The airbags are passive safety devices and are now designed as a part of the Supplemental Restraint System of a car. The Airbag Control Unit (ACU) is the central controller which monitors all the diverse sensors that constitute the airbag deployment system and is responsible for determining the detailed characteristics of a crash including the angle of impact, severity of force and other related parameters. The entire system consists of four sensors- accelerometer, wheel speed sensor, brake pressure sensor and motion occupancy sensor.

The accelerometer is responsible for detecting the impact of the collision in terms of the speed at which the car has crashed and thereby signals the need to deploy an airbag. This sensor uses a spring and differential capacitor arrangement. When a force is applied on the spring, deformation occurs in turn modifying the capacitive bridge arrangement formed by the differential capacitors. The aforementioned change is then conveyed to the inflator in the form of a signal. As soon as the inflator receives a signal indicating an accident has occurred, a chemical charge is set off which ensures that a burst of nitrogen gas fills up the airbags eventually bursting out of the panels they are situated in providing a cushion to the passenger. The entire process is rapid and occurs within 50 milliseconds.

Fig.2 - Motion Detection Sensor - Type- Tracking Sensor

Gyroscopes are also used by the ACU (Airbag Control Unit). The status of the gyroscope or feedback provided helps the system identify the location of airbag deployment. For an instance, if a vehicle has flipped over, the front airbags may not necessarily be deployed.

The brake pressure sensors are advanced versions of fluid pressure sensors and help in identifying the engine oil pressure which is bound to increase in case of accidents and thus help in recognizing the need to deploy the airbags.

3) **Temperature Sensors:** Temperature sensing and controlling plays a pivotal role in engine performance and efficiency as well as in maintaining a controlled environment in the vehicle. Automobiles incorporate temperature sensors to ensure various parameters like engine, coolant or exhaust temperature remain in check. Sensors also regulate the battery temperature of electric vehicles for the purpose of safety. The advent of more efficient heat engines or IC engines is possible due to proper monitoring and control of the vehicular temperature. Temperature sensors are configured according to specific applications. Resistance Temperature Detector(RTD), thermocouples and infrared sensors are commonly used. Thermocouples are installed at places where high amount of heat is generated, for example in an Engine. Whereas RTDs or infrared sensors are primarily used for regulating lower temperatures. Sensor systems operate in a particular range and should be compatible with the main data logging system of the vehicle. Some of these temperature sensors are discussed below.

- Point air-duct Sensor: Temperature range: -40 to +90 degrees Celsius. It has a response time of less than 5 seconds. It has fast and reliable mounting.
- Outside Temperature Sensor: Temperature range: -40 to +85 degrees Celsius. It has a response time of less than 30 seconds.
- Battery Temperature Sensor: Temperature range: +40 to +85 degrees Celsius.
- Battery Coolant Sensor: Temperature range: -40 to +100 degrees Celsius.
- Transmission Oil Sensor: Temperature range: -40 to +150 degrees Celsius. It has a response time of less than 9 seconds.
- Liquid Temperature Sensors: Bosch Liquid Temperature Sensors accurately monitor the vital fluids in your vehicle ensuring long and healthy life. The sensor provides information to the Engine Control Unit to keep your engine running strong, safe, and efficient. They can bear extreme temperatures from -40 to 260 degrees Fahrenheit. They have a robust design with high resistance to engine vibrations.

- Air Temperature Sensors: Air Temperature Sensors measure the temperature of the incoming air to the engine. This information is provided to the Engine Control Module (ECU) to determine the correct amount of fuel needed for optimum performance and economy. They can bear temperatures between -40 to +260 degrees Fahrenheit. They have a sturdy, vibration-proof design along with high durability against operating materials.
- Screw Type Pipe Sensor: Temperature range: -40 to +150 degrees Celsius. The reaction time is 298 seconds.
- Screw Mount Sensor: Temperature range: -40 to +130 degrees Celsius. The reaction time is 75 seconds.
- Teflon tube Sensor: Temperature range: -40 to +250 degrees Celsius. The reaction time is 7 seconds.
- Slim Case Sensor: Temperature range: -20 to +80 degrees Celsius. The reaction time is 25 seconds. **[6]**


Fig.3.1


Fig.3.2


Fig.3.3

Fig. 3.1, 3.2, 3.3 - Temperature Sensors - Point duct, Battery Coolant, Transmission Oil Sensors

4) **Wheel speed (ABS) Sensors**: An Anti-Lock Braking System (ABS) is a mechanism used in newer automobiles to help stop the car in a way that avoids accidents or minimizes the risk of damage in case of accidents.

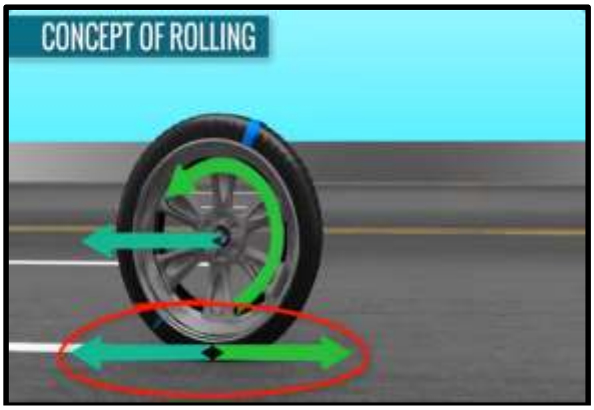
The wheel speed sensor plays the role of a Tachometer as it measures the rotational speed of the vehicle and then sends these values to the control module of the car. For any vehicle the speed of rotation of all the wheels at which the device moves or rotates is different. The ABS system is primarily designed to ensure that the brakes of the car do not lock due to the aforementioned occurrence.

Based on the readings fed to it, the ECU makes a decision regarding the release of pressure on a particular wheel which may be locking. In order to understand the compatibility and selection criteria for wheel speed sensors, a basic knowledge of the ABS system is essential. The working of the system is explained below.

Principle behind ABS: When a car moving in a particular direction needs to be stopped, we apply the brakes which generates a frictional force thus causing a reduction in the speed of the car. However, in this basic braking mechanism the wheels of the car are found to be rotating at distinct speeds. When the brakes are applied to a moving automobile, the difference in speeds of every wheel results in the locking of one of the wheels. Consequently, the vehicle tends to move in a random direction and may skid over the surface.

A rudimentary condition in braking systems is that the translational velocity of the wheel should be equal and opposite to the rotational velocity for the vehicle to reach a standstill. In case of automobiles without ABS, the wheels enter a locked state where they have a rotational velocity in a diagonal direction but the translational velocity remains in the initial direction thus forcing the car to move forward and skid over the distance.

The ABS mechanism on detecting the locked wheel, releases the brake pad allowing the wheel to spin intermittently thereby ensuring that the motion of the automobile is in synchronization with the brakes applied by the driver. The ABS maintains the frictional coefficient to its maximum value to enable stopping at a minimum distance. Furthermore, the release and increase of pressure on the wheels also helps control the torque of the car which aids in negating the twirling motion of the vehicle on applying the brakes.



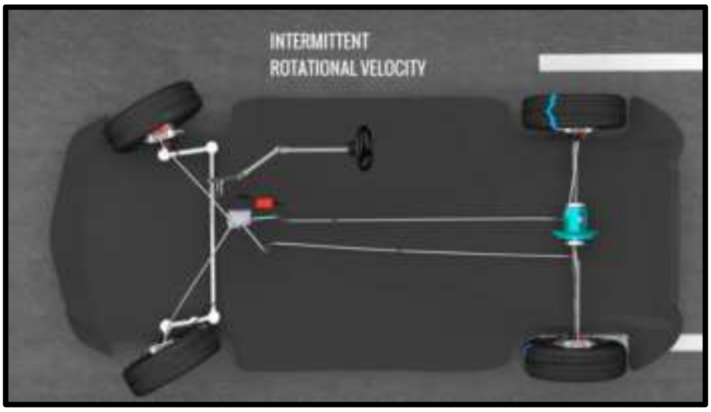


Fig.4.1- ABS Mechanism - Motion of Wheel

Fig.4.2 - ABS Mechanism - Relative Wheel Position

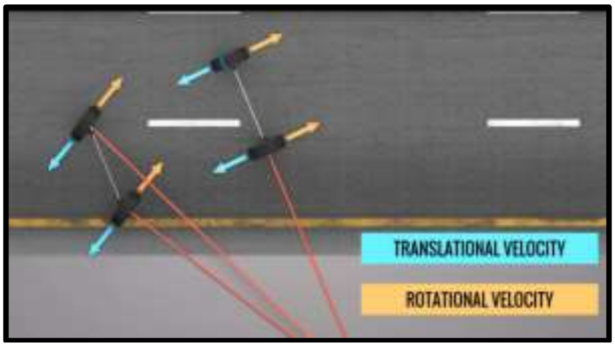


Fig.4.3

Fig.4.4

Fig.4.3, 4.4 - ABS Mechanism- Direction of Velocities

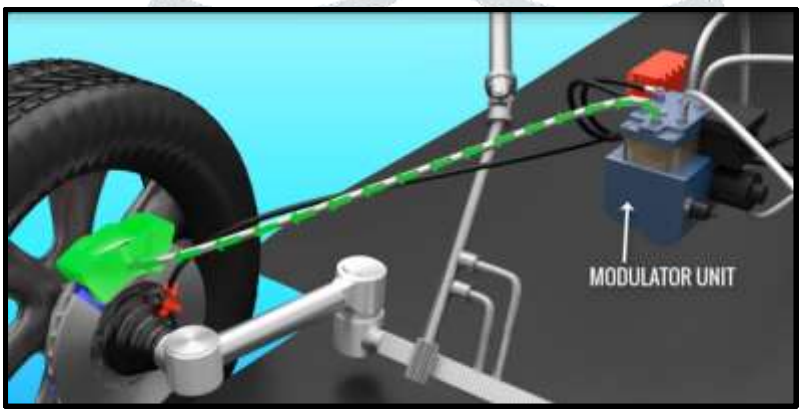


Fig.4.5 - ABS Mechanism- Control Unit (Modulator) - Braking & Release

TYPES OF ABS SENSORS IN MARKET:

The ABS sensors available in the market differ for every automobile. Generally, each company has its own range of wheel speed (ABS) sensors that are used for executing the ABS mechanism. Further, each sensor may fit all the models of a given company identically and thus may be used universally in a batch of vehicles designed by the same enterprise over a short span of time. The different categories have been mentioned in the table. [V]

Fig.4.6 - Wheel Speed Sensor- Generic SS20000

5)**Tire Pressure Monitoring System (TPMS) sensors:**

TPMS or Tire Pressure Monitoring System is an electronic setup which informs the user about the pressure built up in the tires of the vehicle. It also indicates whether the pressure inside the tires is above or below the optimum limit so as to prompt the user to build up further pressure inside or relieve it. This is done via an electronic sensor built in the vehicle. TPM devices are of 2 types: Indirect Tire Pressure Monitoring Systems and Direct Tire Pressure Monitoring Systems.

INDIRECT TPMS**:** This system does not have pressure sensors installed in the tires. It works in coherence with the ABS system. The wheel speed monitoring sensors, which are a part of ABS, provide data to the TPMS system. When a tire loses pressure, its diameter is slightly reduced and its relative speed with respect to the other tires is lowered and it is this lowering of relative speed which informs the system of the low tire. Federal Law requires the system to alert the user if the pressure falls below 25% of the optimum inflation pressure.

DIRECT TPMS: This system is most commonly used in today's automobiles. Direct TPMS is preferred because it provides information about the specific low tire and enables the user to pinpoint the tire. This system employs pressure sensors in each tire. These sensors relay the information to a central receiver which transmits this data to the ECU (Electronic Control Unit) of the vehicle. The pressure information is transmitted using radio frequency technology. The transmission takes place in the ultra-high frequency radio in one of the unlicensed ISM bands with the frequency for Europe being set as 434MHz and the rest of the world operating at a frequency of 315MHz.Power Transmission for this system is about 250µW and the battery life spans from 5 to 10 years. When the systems approach the end of its life, it informs the user prior to the failure of the system through the check light provided.

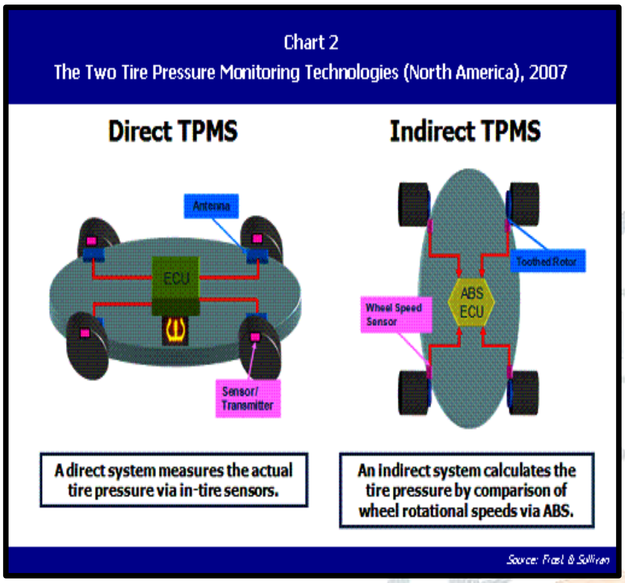


Fig.5.1- TPMS - Mechanism

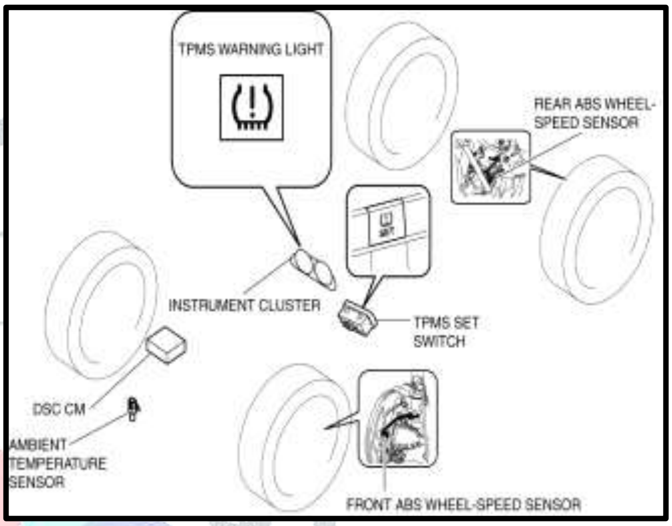


Fig.5.2 - TPMS - Component Function and Examination

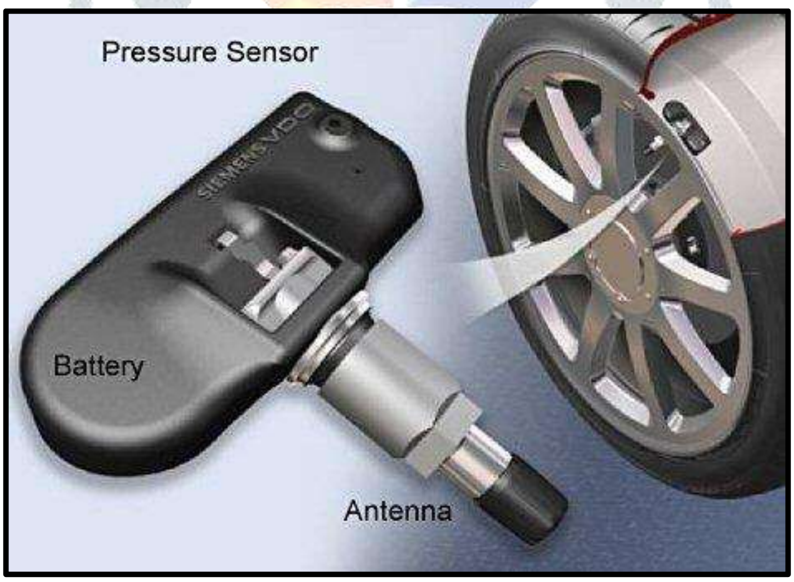


Fig.5.3. - TPMS Sensor

6) **Safety Systems and Sensors:**

Collision Avoidance System (CAS) is one of the most crucial elements within a car's safety systems. It is also known as pre-crash system or forward collision warning system. This system has two aspects through which it ensures the safety. Since it caters to the forward direction of collision avoidance, it usually acquires data through the usage of radar, LIDAR or Image processing. In the method which uses Image processing, a camera is situated behind the rear view mirror of the car, so that it does not obscure the vision of the driver. The images collected are processed to match the information extracted with the desired safety parameters. If a trend indicating possible danger is observed, then the system alerts the driver. If the threat observed is classified as an imminent threat, then the system assumes autonomy and takes control actions (braking or steering) without input from the driver, thus avoiding collision. This system can be employed to work coherently with adaptive cruise control within cars so that the sensors used can be common for both the systems. Depending on the principle used to detect objects in front, various sensors are used. The main categories of sensors used are Ultrasound, Millimeter wavelength radar, Laser, GPS RF detection sensors etc.

Fig.6 - Safety Sensor- Laser based sensor used for collision avoidance

IV. DATA SAMPLES AND ANALYSIS

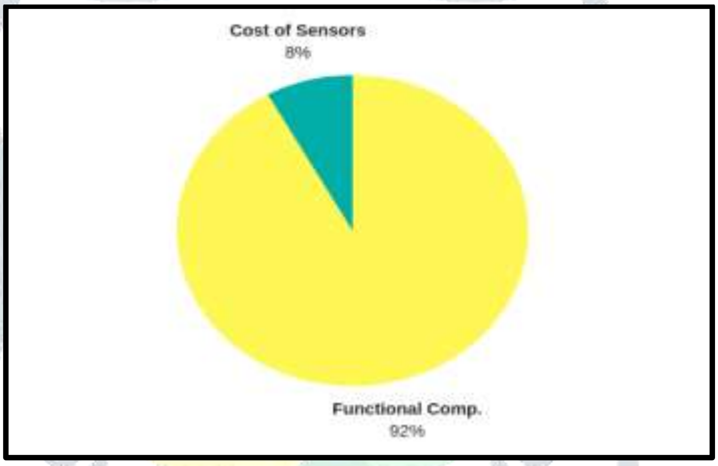


Fig.7.1 - Cost Bifurcation in Automobile

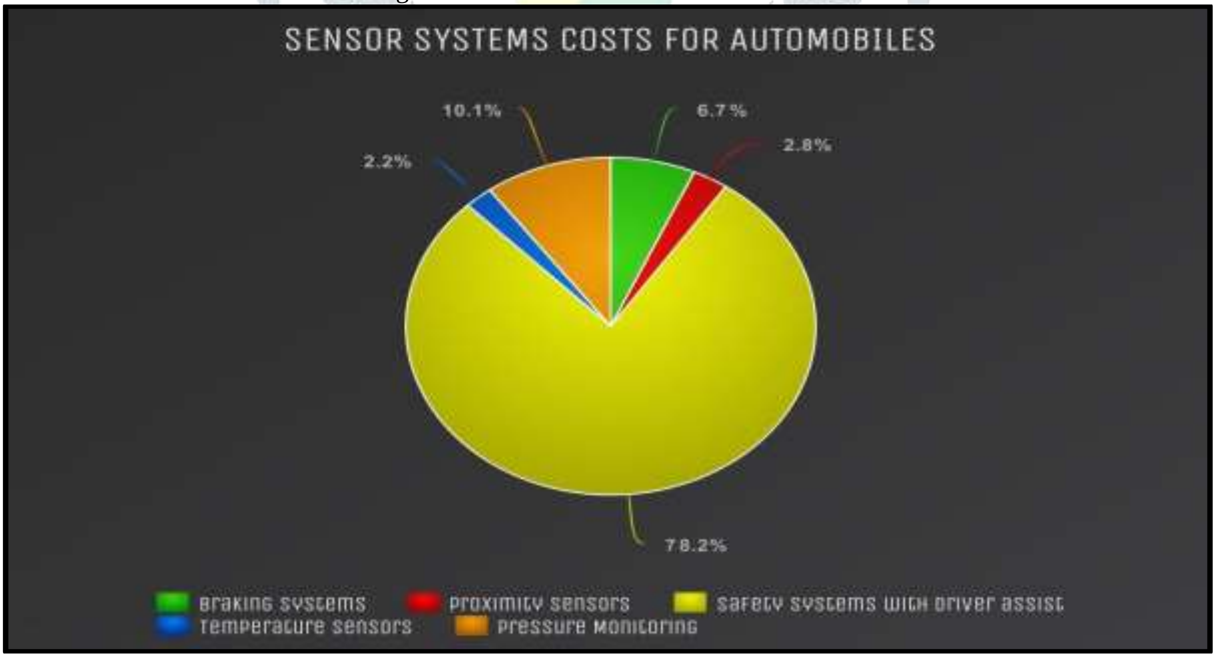


Fig.7.2 - Division of Expense for Sensors

The above pie-charts depict the distribution of costs for sensors in an automobile system.

- Figure 7.1 is based on data found through research conducted around the world in areas like North America, Asia and Europe where the average expenses of sensors in various systems constitutes almost 7-8 % of the total cost of the vehicle.

- Figure 7.2 details the bifurcation of costs according to various types of sensors used in a car. The pictorial depiction is based on data found through surveys of cars used in North America, Asia and Europe.

Accurate sensor selection can help a consumer or manufacturer select or design an automobile efficiently. The above representations provide evidence for the same as a small fraction of the car's cost may be used for sensors and the majority of the subsequent cost can be spent on safety systems which are the quintessential features of any automobile.

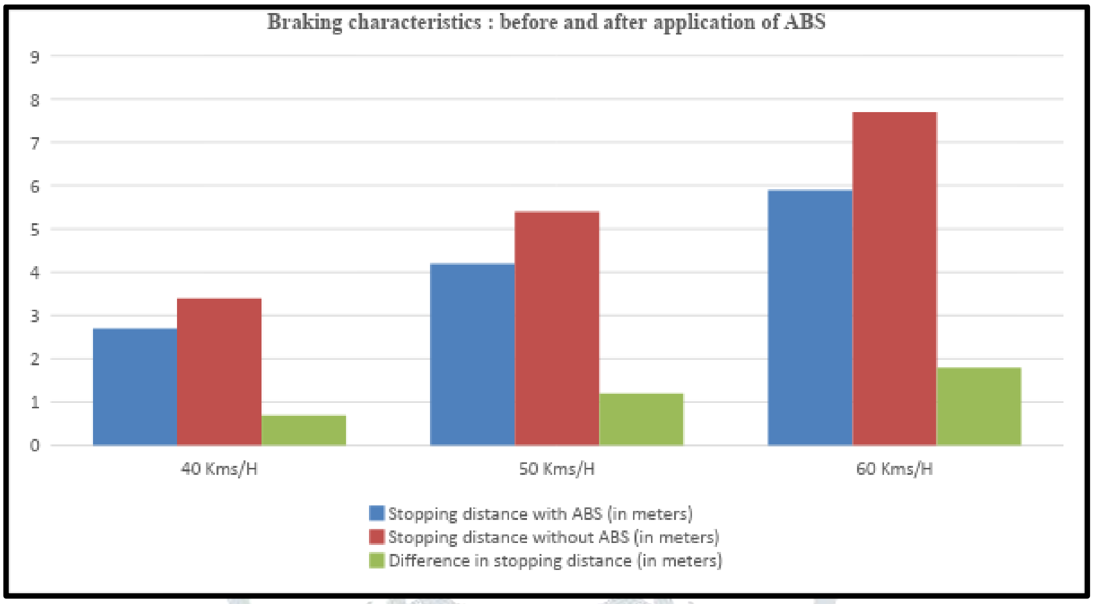


Fig.7.3 - Graphical Representation of Braking Characteristics of Automobile - with & without ABS

The above graph is a representation of the stopping distance for an automobile at different speeds. The graph indicates that as the speed of the vehicle increases, the difference in the stopping distance with and without ABS becomes more prominent and thereby leads to the conclusion that ABS is essential for ensuring a universal reduction in accidents in automobiles

V. TABULAR REPRESENTATION AND DISCUSSION

SR NO.	CATEGORY OF SENSOR	TYPE	MANUFACTURER	COST
1	Proximity	Ultrasonic	- MB8450 CarSonar WR MaxBotix Inc.	- $80.95
		Radar	- KKMoon Radar Sensor Module with buzzer and LED	-$41.04
		Image	- FenSens Parking Sensor	-$149 (Retail Price – 99+50)
2	Motion	Tracking	- TK20SGSE GPS Tracking Sensor - EMX101 Car Sensor	-$105.74 -$71.04
		Accelerometer/Gyroscope/Impact Sensor	- TATA – 287154209908: Side Impact Sensor - 9L8Z-14B004-A – Ford Impact sensor	-$26.00 -$40.08

		Airbag Control Unit	- Ford Mustang (specific design) - Honda (Universal sensor module)- Autotronics	-$119 -$40
3	Temperature	- Point Air Duct Sensor - Battery Coolant Sensor - Transmission Oil Sensor - Semitic Sensor (NTC Thermistor Type)	- Siemens 536-811 - MOPAR Battery Temperature Sensor - 56041053 Sensor BA 08037155 - AC Delco D1818A GM - Temperature Probe B3950 10K NTC sensor	-$27.16 -$37.19 -$38.78 -$1.99
4	Wheel Speed – ABS sensors	-	08 2008 'Ford' F150 RWD ABS Speed Sensor Replacement Rear Wheel Drive	-$22.95
			08 2008 'Toyota' Tundra ABS Speed Sensor Front Right Standard	-$128.43
			01 2001 'Nissan' Maxima ABS Speed Sensor Rear Left Pex NLA 2/16	-$79.43
			02 2002 'Chevrolet' Silverado 1500 4WD ABS Speed Sensor Front Left – (compatible with all models from 2003-2014)	-$23.95
			02 2002 'Jaguar' X Type ABS Speed Sensor Front Bosch	-$37.98
			Generic 'Honda' Civic 57455SNA003	-$26.76
5	Tire Pressure Monitoring System (TPMS) Sensor	-Direct TPMS	Mercedes-Benz Tire Pressure Sensor 000-905-72-00	-$119.75
		-Indirect TPMS		
6	Safety Sensors	Image Recognition	Brand motion Advanced Driver Assistance System (ADAS) - 1000	-$529.99
		Laser Detection	LIDAR-Lite V3	-$127.95
		Radar	FMCW Radar Sensor	-$106.94

Table V: List of different Sensors and Costs

The above table gives an overview of some of the most widely used sensors in an automobile. Various subtypes of each sensor category are responsible for different functions in the associated systems. The main aim of this table is to present an authentic account of the costs of different sensors and their compatibility in various vehicles to ensure the consumer make an informed choice when designing their automobile applications. An illustration of this fact are the Wheel Speed Sensors used in ABS which have been customized by every company for their own cars to ensure a balanced distribution of expenses while manufacturing these vehicles.

VI. CONCLUSION

In this paper we have discussed various types of sensors used in automobiles. The data collected originated from a broad range of samples and publications in the areas where sensors are deployed and function as the pivotal parts of different systems. The test case of automobiles with respect to the sensors used is extensively studied and the sensors and their corresponding applications in the vehicle depending on their principle of operation are explained in detail. The effective performance of any automobile largely depends on the wide array of sensors employed in the system as well as their compatibility with the vehicle. Along with the compatibility of sensors, their cost is also a decisive parameter for sensor selection. We have given an overview of the various types of sensors depending on the mechanisms employed by the sensors for data collection, their intended area of application, their manufacturers and the cost involved to install them. Overall, the cardinal purpose of this review is to provide an educational insight to the uninformed consumer to assist them in customizing their respective applications.

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