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REVIEW OF SENSOR ACTUATED CONTROL OF AUTOMOBILES

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Abstract: In this era almost everything is being controlled by technology. Slowly all the mechanical components are being replaced by electronic ones. Take the example of locomotives, which were once driven by steam and coal, have been replaced by electric engines running with the help of electric motors. This revolution in technology has reached our daily lives, like the gas burner stoves now have an alternative in the form of induction cook tops. Engineers all over the world have also tried to bring this change to the automobile sector in the form of various reforms in various components of automobiles. In this paper we discuss various ways to electronically control functions of automobiles such as throttle, braking, steering and gear shifting by the use of sensors and electromagnetic actuators.

Keywords —Actuators, brake, feedback systems, paddle-shifters, steering, throttle

I. INTRODUCTION

This technological revolution is a result of various efforts to make the experience of using a vehicle much more polished. Even simple things like the control for window has been changed from a manual roll up type window to power windows. The normal steering has been replaced by power steering. Anti lock braking system has been added which prevent the locking of wheels. All these systems utilize various technologies. Now, one such technology which is already being used in air crafts is x-by wire system. This technology basically aims at replacing the mechanical components with more efficient and accurate electrical actuators and sensors. This system is mastered by a central unit known as Electrical control Unit (ECU). The system uses various feedback systems to help retain the 'feel' of riding a vehicle. This technology is being used in a very preliminary form and there is a lot of work yet to be done to make it a commercial system. Automobile makers are slowly utilizing this to control operations such as throttle and steering. This paper focuses on the types of this technology and the future scope.

II. SENSOR ACTUATED CONTROL

2.1 Throttle by Wire

The automobile industries in the near past largely relied on mechanical components for carrying out the various functions required.

In this section of the paper we will be focusing on the throttle mechanisms in vehicles , be it a car or bike. So, to start with any internal combustion engine requires air to be supplied for combustion along with the fuel. Air is freely available while provision of fuel is done by using fuel injectors or carburetors (these have become obsolete in today's world). If the system is carburetted then the throttle valve is integrated with the carburetor. But in case of a FI (Fuel Injected) engine, the throttle valve is a separate unit.

2.1.1 Traditional throttle system :

The opening and closing of throttle valve is usually done by the use of a cable known as throttle cable. This cable is linked with the accelerator pedal. The degree of opening of the valve essentially depends upon the amount of pressure applied on the pedal. Applying pressure on the accelerator pedal increases the tension in throttle cable and it is pulled thus resulting in the opening of the throttle valve for air intake.

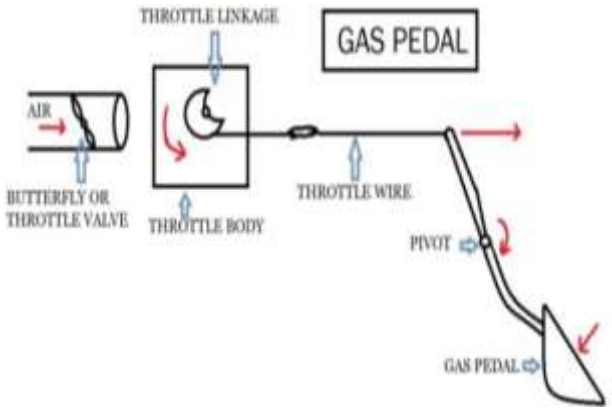

Fig 1: A Block Diagram Explaining The Conventional Throttle System

In the Fig 1, we see that the functioning of throttle system for fuel combustion completely relies on mechanical links. We know that mechanical links, though considered rigid by us, always have some losses which lead to lower efficiency.

2.1.2 Throttle by Wire System:

To reduce the above losses and to increase the performance of engine, a system called throttle by wire is used. Throttle by wire *or* accelerate by wire was the first type of drive by wire system to be used in vehicles. It is widely used in vehicles

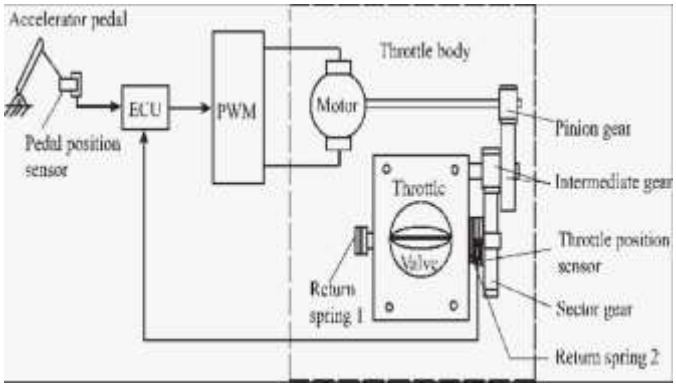

Fig 2: Block Diagram Explaining Throttle By Wire System

Components used in the system are -

i. Throttle position sensor
ii. Throttle actuator motor
iii. Potentiometer
iv. Electric Control Unit (ECU)

As shown in the Fig 2, this system utilizes a wide range of electronic sensors, all controlled by the ECU (Electronic Control Unit). The pedal uses these sensors which measure how much the accelerator has been pressed.

A throttle body usually contains two springs - one for throttle plate return and the other is called limp home spring which is used as a safety measure just in case the power supply to motor is lost. This will allow the vehicle to run at a limited speed of about 25-30 mph.

The accelerator pedal in this system is connected to a potentiometer. A potentiometer is an actuator used to convert linear displacements into signals, based on change in resistance, which can be understood by the ECU.

When position of the accelerator pedal is varied, it serves as an input to the potentiometer which in turn sends them to the ECU. The ECU, based on these inputs, sends a signal to run the actuator which controls the opening and closing of the throttle valve. The actuator used is a DC servo motor. The amount of opening to be provided is decided by the programming of the ECU.

The ECU program properly calibrates the degree of opening of throttle valve and position of accelerator pedal. The DC (Direct Current) servo motor takes input in the form of duty cycles. Less the duty cycle, lower the running time and vice versa.

Along with the potentiometer arrangement, a Throttle Position Sensor (TPS) is also used. The TPS sends position signals of the throttle valve to the ECU like a feedback system which helps in better performance of the engine.

Actually, two TPSs are used in the system- TPS_1 and TPS_2. TPS_1 acts as the primary sensor of position of throttle valve. It operates in a reverse sense. It has 5 volt reference voltage (high output) at rest position and it lowers as the plate opens. TPS_2 is used for cross checking the operation of TPS_1 . Also, in case TPS_1 fails, the second sensor does the job, but in the traditional manner (low output when valve is closed).

This complete system works together to produce excellent results and performs throttling with greater accuracy.

2.1.4 Advantages of throttle by wire system

The use of this system provides several advantages over the conventional throttle system -

- The binding problems in mechanical linkages is eliminated as a result of which the throttle doesn't stick.
- It allows electronic control of throttle that helps to reduce the emissions due to accurate operation.
- It is a modular system and can be modified to install various other systems such as cruise control.
- Allows greater control over torque which is integrated by the ECU with features like traction control, cruise control and stability control.

2.2 Gear Shift by Wire

All vehicles require a transmission system as an interface between the engine and the differential of the vehicle. Transmission system consists of clutch assemble and the gear box.

Various mechanisms are implemented for gear shifting. depending upon the mode of operation gear shifting can be classified as automatic, semi-automatic and manual gear shifting.

Manual gear shifting involves a series of mechanical links connecting the gearbox and the clutch assembly. While the automatic and semi-automatic transmissions uses hydro-static/electromagnetic actuators and sensor. use of actuators eliminate the bulky mechanical links between the gear lever and the gearbox

2.2.1 Details

Proper gear shifting results in a smooth drive. Manual gear shifting requires a average time of 4-5 seconds while automatic gear shifting is done in 100 ms.

Shift by wire uses a encoder to process the input signal and time the gear shifting actuators to achieve the perfect synchronization. This also eliminates the power losses and decreases the downtime.

Twin clutch is best suited for this type of system. It uses hollow shaft assembly and two prime actuators to drive even and odd gears separately. Twin clutch increases reliability. it also decreases the load on individual pressure plate.

2.2.3 Advantages of Gear Shift by Wire

i. Decreases shifting time
ii. Accurate synchronization can be achieved
iii. Decreases overall weight of system
iv. Twin clutch can be adopted
v. Decreases the risk of stalling

2.2.4 Limitations of Gear Shift by Wire

i. Higher loads require bigger actuators
ii. Replacing a component is difficult
iii. Safety concerns from pubic point of view

2.3 Steering by Wire

Electronic control systems find a vital place in modern automobile industry than in any other field. Last few years have brought to us huge revolutionary inventions in the field of electronic industry which congenially found a place in the automotive or automobile industry. To be precise it potentially could incarnate the whole system of IC engines, braking systems (Anti-lock Braking system is phenomenally functional everywhere) etc.

Electronic control has proved to render better, reliable performance in smidgen operational expenses.

Many years ago, electric power steering replaced the hydraulic pump from the mechanical power steering. This had some pros unlike the continuous operation of pump, leakage problems posed by hydraulic-pump fluid.

Conventionally, vehicles employ a rack-pinion or a worm-sector arrangement physically connected to the steering wheel.

On the contrary this physical connection is absolutely eliminated between the tires and the steering wheel. Factually this steering wheel can also be eliminated. This can be worked upon by incorporating the steering wheel into the dashboard with an external provision of left or right-handed drive lever.

A few production vehicles seem to have already incorporated the conventional steering on the front and by-wire steering on the rear so as to enhance low-speed handling and stability at high speeds. However, no one has yet employed fully steer-by-wire technology.

The steer-by-wire system seems to be conceptually released earlier by FHI (Tech-on 2005). Also, GM used Visteon steer-by-wire in Chevy sequel concept car (auto spectator 2006). This Visteon steer-by-wire comprises electro-mechanical actuators, torque and feedback sensors, power supplying units, electronic control structures/units etc. Introducing a 42V automotive electrical system will ensure reliable, affordable actuator implementation. Sensors required include sensors for sensing torque, steering angle, wheel speed, wheel angle etc. Actuators facilitate steering function, feedback transmission etc.

Some more advantages of steer-by-wire system are:

- Massive reduction in the sprung weight of the vehicle.
- Elimination of the steering column also eliminates the risk of it protruding into the cockpit in cases of frontal crashes.
- Liberty to have variable steering ratios as per the then road conditions, driver's skill and convenience etc.
- Variable relative steering angles can also provide better vehicle handling with utmost stability as the body-roll can be monitored to a larger extent.

2.3.1 Components Used in The Steering System:

The main components used in the steer by wire system are as follows -

i. Steering actuator:

Steering actuator is the actuator which controls the turning of wheels and hence it is required to be very powerful. This is because turning of wheels will take place on various surfaces having different geometries and friction coefficients. So an ideal solution for this can be a brush-less dc motor which are known for their high power and silent operation. However, as the space available is less the motor which can be fitted will be of a lower capacity than required. Thus, we will require a gear system to increase the available power.

Fig 3: Steering Actuator

ii. Feedback motor:

A feedback motor is required to deliver the feel of real time position of wheels. This allows the user to know by how much angle the wheels have been turned which would be impossible if the two actuators are insulated. Thus, feedback motor is an essential component. Now this motor will provide feedback in the form of torque and will be controlled by the ECU. So, for easy operation by the user the motor should not be too powerful.

iii. Angular sensors:

These sensors are used to measure the degree of rotation of steering wheel. They are very crucial in the control of car

and hence are required to be very accurate. The output of theses sensors is usually a square wave.

2.3.2 Feedback System in Drive by Wire

Feedback is a very essential component in human- machine system. Feedback serves a important role in decision making process Replacing mechanical parts eliminates real time feedback.

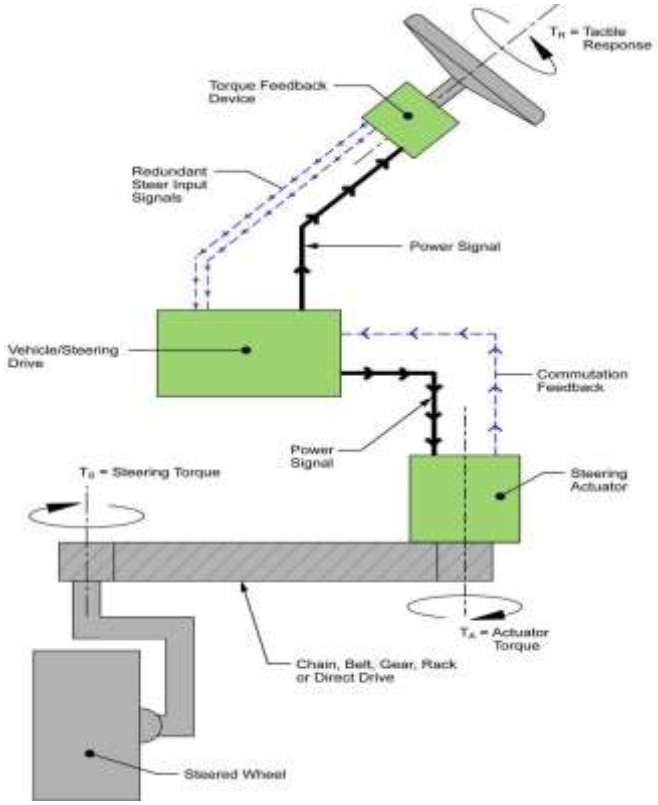

Fig 4: Block Diagram Explaining Steer By Wire System

A typical feedback system used in steer by wire control is shown in Fig 4. The feedback which is eliminated due to the removal of mechanical linkages is replaced by electromagnetic/hydraulic actuators. The steering wheel uses a torque emulator for cloning the steering-turning action. The torque is directly proportion to the mean angular displacement from the mean position.

Most of the systems uses electromagnetic stepper motor controlled by a closed loop comparator. This electronic system compares the current position of steering wheel and the position of steering assembly, and calculates the torque feedback accordingly. A sudden turning moment would require a larger force than normal turning force. This is done so to avoid the toppling of vehicles.

The feedback in vehicles can also be induced by using the frictional force caused due to a frictional disc which induces a negative feedback on a rotor. This way there is less wear and tear and the setup provide torque feedback over a wide range of inputs.

2.4 Brake by Wire

Braking is the most essential and important criteria on the view of safety in the automobile sector. Usual and only mechanical braking is not just enough to bring the desired entities into the favor of the customer point of view. Traditional mechanical and hydraulic breaking is not just enough to co-operate with the innovative technology of the present and future. For this inter-disciplinary approach should come into the picture to fulfill the criteria of the braking considering each and every aspect.

Braking by wire is the automotive technology which completely eradicates the traditional mechanical and hydraulic breaking components and replacing it by the sensors and actuators for braking control an automobile. But this technology is still under-development mode considering the efficiency, cost-effectiveness, and reliability factors.

Key points which make this brake by wire most auspicious and different are:

i. It reacts more quickly which results in shorter stopping distance as well as time.
ii. As there is no use of mechanical components it favors the user in noiseless operation and this eliminates vibrations to some extent.
iii. Less space requirement.
iv. Reduction of weight so its results to better fuel efficiency.
v. This allows the ECM to integrate with traction control, stability control cruise control etc.
vi. As mechanical components are not there it may facilities the need to introduce hybrid and fuel cell working engine to improve efficiency.

Automobile companies like Mercedes and Toyota have already tried on this topic to overcome conventional braking system but they were not able to co-up with the safety factor and regulatory issue, this thing was not able to use in the common commercial vehicles. More improvement is to be needed to fulfill the demands.

2.4.1 Analysis of Problem:

1. Risk Analysis and assessment

In brake by wire system, this is the utmost criterion that is to be fulfilled while implementing this system in working mode. We should be investigating the broad aspect of control, failure assistance and modes of the safety.

2. Brake system controller

A controller should be designed that can input from both, the brake pedal and vehicle control assistance. This should perform as best as the theoretical response time and damping. The performance of this system should be that much adequate so that it should definitely replace the existing convention braking system.

3. Actuator controller

Controller for the braking system should be synthesized because controller should be stable with good reference tracking and have fast response time so that the dynamic of the dynamics of the actuator controller is negligible compared with the dynamics of the automobile.

2.4.2 System Overview

Brake by wire is the system which uses both drive-line control system and brake pedal. In the process of this system, the torque value is calculated by brake controller and that value of torque is passed to and it gets processed in actuator controller, which controls the current through the actuator whose value is kept as a desired value.

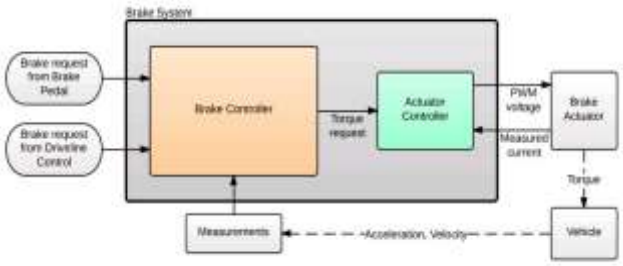

Fig 5: Block diagram of brake by wire system

Let's see the components of the brake by wire system as shown in the Fig 5:

i. Peripheral devices: This brake by wire system devices receives the input and sends output to the peripheral device in the vehicle.

a. Drive-line control:

This is an overlaying system which controls the drive-line. This will send a signal of brake request in the form of the desired rate of acceleration.

b. Brake pedal:

This will be the same as the existing market pedal for braking which will generate an analogue voltage between 0.5 to 4.5v depending upon pedal angle.

c. Brake actuator:

Brake actuator serves as a link between electrical and mechanical components of the brake system. The actuator work used in the constructional vehicle is a solenoid valve. When a voltage is applied to the solenoid current is passed through the solenoid winding. this current creates a force in the opposite direction which makes plunger to move to some distance.

d. Internal measurement unit

This will provide the measurement value of the retardation and acceleration to the controller. This will be done by the use of the accelerometer.

ii. Brake system: The brake system will process the brake request from the brake pedal and driveline control together with acceleration value from the internal measurement unit, the output from the system will be PWM signal and fed to the brake actuator. Brake system will be working according to the following sub-system.

- Actuator controller

Its main working is to feed the brake actuator with its desired value of current. The design aspect for this controller is fast response time and less complexity, this thing is based on the assumption that the electric part of the brake system is much faster than the mechanical. Its input is torque reference and output is PWM voltage.

- Brake controller

Brake controller will study and process brake request with all filtered data. This will give an output of a torque request which is sent to the actuator controller. The sub-system of the brake controller is following

a. Brake pedal controller

The main objective of the brake pedal controller is to map the actuation of the pedal to the desired value of braking torque, which is used to emulate a traditional mechanical pedal.

b. Retardation controller

The retardation controller will process the retardation signal from the drive-line control together with acceleration data. The controller will calculate the desired braking torque and maintain the required acceleration.

c. Anti-lock system

It will limit the input torque to the actuator controller so that the sleep doesn't exceed a nearest optimal angle. the system will input the requested torque, current slip if the wheel, and instantaneous velocity and its will be torque request.

The general working module of the brake by wire system

i. The car equipped with this system will have a small electric motor near the wheels which will generate braking pressure.

ii. This is governed by electronic control units connected to the brake pedal that receive input from the driver's actions and interpret that information into a series of electronic instructions

iii. These instructions are then communicated through a miniature, real-time network connecting the entire braking system.

iv. The system also has a series of sensors that monitor both the vehicle's operations and the driver's actions

and automatically adapt the braking performance to maintain safety.

v. When the driver applies pressure to the brake pedal, information is electronically passed through the system, the external situation is evaluated, and the brake motors apply the true value of pressure to the wheels. All of this happens in a fraction of second and without requiring action from any mechanical parts.

Now let's see the advantages, disadvantages, future scope and its application.

2.4.4 Advantages of Brake by Wire System

i. The main benefits of the brake by wire is the quick response time, shorter stopping distance and with increased safety.

ii. As there is no mechanical component present in the braking system so the system is totally silent and normally do not have the vibration felt through the brake pedal and normally associated with antilock brakes.

iii. It takes less physical space which is the most important factor in working of an overall system in an automobile

iv. As there is no brake fluid involved which results in corrosion of the mechanical component, brake by wire is considered less damaging to the environment.

v. The amount of heat generated is less in brake by wire system which doesn't lead to failure due to changes in temperature.

vi. Using brake by wire the capacity of the system like speed, loads carrying capacity can be increased,

2.4.5 Disadvantages of Brake by Wire System

i. As there is complexity in the working of the sensor and actuator which is based on controlling unit it can be malfunctioned easily by viruses or threats which may lead to the accidents.

ii. As the system uses software's to control the processing unit, they have the ability to fail regardless of how many times it has been tested.

E.g. The sensor could make an error I n calculation due to external factors that may cause the brake-caliper and pads to apply an incorrect amount of pressure.

iii. Various software-based components are used in this system so the initial cost of the automobile is more, so the customer will deny purchasing.

iv. Separate battery back-up system is needed.

v. This system has to definitely rely on back-up for the adverse condition.

2.5 Disadvantages of Drive by Wire Systems

The drive by wire has a lot of advantages. But like everything it comes with a set of disadvantages as well which cannot be ignored and have to be considered while planning anything. The disadvantages are discussed in detail in the following points -

i. The whole motive of Introducing a new technology is to improve the performance and efficiency of any system, in this case a vehicle. The performance is surely improved as the drive by wire system allows much more accurate control over the vehicle and its operations. This is possible because all the mechanical linkages used earlier are replaced with much compact electronic components. But this system will compel us to use actuators and motors for the control of valves and other components, thus increasing the overall power consumption by components. So, unless a more powerful engine or a larger battery is used, the net performance of the car can be affected. Also adding larger batteries means increase in weight which will eventually lead to lower power to weight ratio.

ii. The number of motors and actuators used are high. For example, the system demands a separate motor for producing the "road feel" experienced by the driver at the steering. This will lead to a significant increase in the overall cost.

iii. Another major disadvantage of this system is the lag experienced between the instruction and execution of the command. For example, the engine takes a certain amount of time to respond after the accelerator pedal is pressed.

iv. Technology goes hand in hand with the use of software. the ECU, which controls all the functions of actuators and motors. This also leaves a slight chance of the software being hacked by wireless or wired means which may lead to mishaps and failures.

v. Specific use of throttle controller has allowed manufacturers to de-tune their engines so that they pass the ever-growing norms over emissions.

vi. There is a fair chance that a sensor in the system malfunctions or the software crashes. This can be dangerous and it will also mean that the car will have to be repaired before it becomes functional again.

2.6 Future Scope

Owing to the higher demands for improving the efficiency in the automobile sectors, the Drive by wire technologies can be used to improve efficiency and performance by a huge amount.

The current scenario may favour the use of electric vehicles but these are small steps which can make a gasoline powered vehicle a step closer to them by replacing the mechanical components by electric ones.

The only parameter which will remain to be replaced is the prime moving source, that is, the engine with an electric motor. Though this statement is very crude, but realizing the potential that can be achieved by the use of this technology can only be realized by taking such steps which are fairly

economical unlike the electric batteries which are an expensive affair and need a significant amount of research to tag them as "economical".

Agreed that there are cars in India like the Mahindra E_20 which are fairly cheap, but the limitation of driving range and charging facilities hit the sales. Teslas on the other hand have excellent range but are fairly expensive.

So, this can be a step towards striking a balance between the two until enough research is done in the EV area.

So it will be safe to say that in the near future, all vehicles will start to use these drive by wire technologies.

The flaws in this system can be overcome by using suitable technologies. For example, the delay in throttle response can be eliminated by a throttle delay eliminator. These are devices which are placed between the accelerator pedal and ECU and they bypass the factory settings and give instant response.

These systems can be re imagines totally and we can adopt a completely new concept for controlling a car. Now, as the mechanical linkages won't exist, there will be enough freedom for the designers to place various controls more ergonomically accessible. The use of paddle shifters is one such example of convenient placing of controls, the shifters are easily accessible to the driver. He/she can shift the gears without losing their attention from the wheel, thereby even reducing the risk of false neutrals.

To ensure reliability during emergency situations, a time triggered protocol can be used, similar to a watchdog timer. It sends a clock signal to various components and waits for the feedback. If the feedback exceeds the safe limit, it will detect the failure and signal the user. All this will take place in a matter of milliseconds.

Another ergonomic design element which can be added is the use of some kind of piezoelectric sensor embedded into the steering wheel hand-grips which can be used for braking. The amount of braking will depend upon the pressure applied by the user on the steering wheel. This will also improve safety in emergency situations in which panic braking is required. Naturally the steering wheel will be the first thing the users will hold on to tightly in such cases and the chances of an accident can be lowered. This will also reduce the accidents due to accidental use of accelerator instead of brakes.

The absence of pedals in the cabin along with overall compactness will give larger free space in the cabin. This will play a crucial role for safety of driver during a crash as there will be more space and less obstructions.

All the above ideas project the wide array of possibilities which can be brought into existence by extensive research in this field, thus marking another major revolution in the automobile sector which will produce cleaner and more efficient automobiles.

2.7 Conclusion and Recommendations

There is a wide variety of sensors available in the market which have the potential required to transform the mechanical systems. This transformation to sensor actuated control is yet to be implemented due to the insecurities and low faith of common people in these systems. So, the advantages and robustness of these systems should be conveyed to the common people and they should be made aware of how this technology will pave the way towards future of automobiles.

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