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# Automatic Clutch Actuation Using Touch Sensor Based Gear Lever And Interconnected Brake

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## Abstract

*This paper focuses on the idea to eliminate the need for manual clutching by introducing a power drive which receives control signals from sensors mounted on the brake, tachometer and gear lever. A control unit determines the exact moment when the clutch is to be actuated based on the output from multiple sensors. The absence of manual clutching proves to be an ergonomic advantage to drivers. The compromise is not made on fuel efficiency and the gear shifts as frequently as required. The touch sensor mounted on the head of the gear lever relays a signal whenever the hand is placed over it, for shifting gears. A linkage between the brake and the clutch ensures that the clutch pedal is depressed when the brake pedal gets pressed, but with a small delay time. A signal from the tachometer of the vehicle also ensures that the clutch actuates to disconnect the drive from the wheels whenever the speed of the engine drops below a certain minimum value. This ensures that the engine does not cease when the vehicle is brought to a halt, with the engine running. Similarly, multiple occurrences of these events are taken into consideration and the control action is determined for such situations. The actuator connected to the clutch would replace the pressing of clutch pedal manually, and deliver precisely the correct amount of force in the direction at the required time to simulate clutching.*



## 1. Introduction

According to present day technology, the conventional four-wheeler car may either use a manual transmission or an automatic transmission. However, a car that uses a combination of both these mechanisms would be termed as semi-automatic transmission. The power that is produced in the crankshaft of a multi-cylinder internal combustion engine is transmitted to the wheels after a stage of speed increase or speed reduction. However, at times, the drive from the engine needs to be temporarily disengaged from the wheels so that gear meshing may be smooth and also that the two sides of the drive may independently rotate. For this purpose, a clutch plate along with a pressure plate is used. When the gear ratio is to be changed, the gear lever has to be adjusted, but prior to that, the clutch pedal is pressed. The clutch pedal is connected to the clutch plate through mechanical or hydraulic linkages.

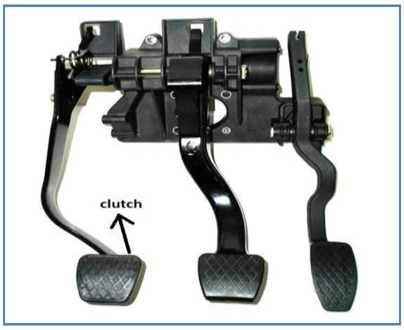


**Figure 1. Clutch, brake and throttle pedal**

A clutch forms an integral part of the power-train in an automobile. The clutching action becomes necessary as the engine rotates at a fairly constant speed whereas the final drive speed is variable and subject to change depending upon instantaneous conditions. The necessity for a clutch is eliminated in the case of automatic transmission which uses a torque converter and a fluid coupling. However, the fuel economy is bound to get reduced. Even in semi-automatic transmissions, the mileage gets reduced as the control system does not frequently shift gears, as in manual transmission. The manual gear shift is thus found best suited for Indian traffic conditions. However, clutch needs to be constantly engaged and disengaged, which is a difficulty from an ergonomic point of view, especially during long drives. Thus, the objective would be to actuate the clutch using minimal power when required, thus reducing human effort and at the same time delivering approximately the same fuel efficiency of that of a manual transmission vehicle.

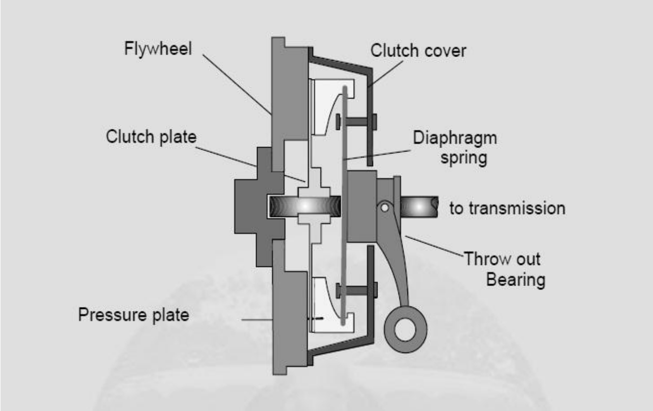


**Figure 2. Clutch plate**

## 2. Mode of Actuation

The clutch pedal is present in the space where the driver rests his legs. It is present to the extreme end of a row along with the throttle pedal and the brake pedal. The conventional driving position for the driver is to rest his left leg over the clutch pedal and to shift his right leg between the accelerator and the brake. Sometimes, the driver may even place his left leg aside. When the situation arises, the leg has to be moved to push the clutch. This can become uncomfortable during fluctuating driving conditions, especially in traffic. Thus, from the perspective or ergonomics, the clutch actuation could be automated which would result in lesser manual effort and improved driving efficiency. The actuation of clutch needs a force that has to be provided from a powered drive. The following types of forces may be applied:

- Push force
- Pull force.

Though both of these types would produce the same end effect, the spatial constraint should be taken into account. The push force exertion criterion would require an actuator to be placed in the gap beneath the steering column. This would be extremely uncomfortable for the driver to rest his legs and thus the pull force mechanism would be preferred.
The powered drive may be one of the following:

- Hydraulic or pneumatic
- Electrical

The placement of a hydraulic or a pneumatic actuator would require a compressor and a FRL unit (in the case of pneumatics), which would add to the weight of the system. Further, it would not comply with the spatial constraint of the system. To add to the limitations, the maintenance cost of pneumatic and hydraulic systems is higher than that of an electrical system. Rapid movements cannot be achieved with precision with such hydraulic and pneumatic systems. Thus, the mode of actuation is chosen as an electrical drive. Since, the motor is the best electrical drive to suit the purpose; we place a motor beneath the clutch pedal and link it to the bottom side of the pedal through a metal twisted wire cable. Further, a feedback mechanism indicating the position of the motor would be helpful in control actions and decision making. Thus, the motor to be used in this application is a servo motor. A servo motor is a motor fitted with an encoder or a resolver, which would denote the position or the velocity of the motor at every instant. A stepper motor may also be used for the same purpose, but stepper motor cannot be run at high speeds and the torque capacity is also limited. Thus a servo drive is best suited for this application, which would receive control signals from the special ECU for the automatic clutch, which will be discussed later. The motor however draws power from the battery for its operation.

The motor would be given three types of signals:

- Full retraction
- Partial retraction
- Restoration

Full retraction of the clutch would result in the complete disengaging of the drive from the gearbox. This would be essential during moments of rapid braking and gear lever touch sensing.

Partial retraction would move the clutch pedal halfway through its travel distance. This would provide a reduction in the drive transmission. This is essential during times of braking when complete disengaging is not necessary up to a certain extent. This condition is however short lived and the position of the clutch pedal would be shifted to one of the two extremes immediately.

Restoration of the clutch pedal to the initial position is however a crucial component to be considered. The restoration should be gradual so that friction is prevented and the engine does not stall at lower speeds. The restoration speed has to be controlled by the ECU as well.



## 3. Determination of Necessary Conditions

The clutch pedal is depressed during the following situations:

Manual transmissions depend on the driver’s instinct to shift gears. A driver first presses the clutch pedal so that the clutch is disengaged and no drive is transmitted from the engine to the gearbox, and moves the gear lever to the desired gear. Disengagement of the pressure plate from the friction plate is performed by the clutch fork, when the clutch pedal is pressed. The optimum position to shift gears is when maximum rpm is reached at a particular gear. At this position, the driver presses the clutch to change gears. The maximum force for pressing the clutch is calculated to be 150 N.

While braking at high speeds, the rpm drops suddenly as the engine slows down rapidly. This induces in the engine a tendency to stall as soon as its rpm falls below the idling rpm. An rpm sensor which is an angular potentiometer installed sends an instruction to the controller to make the motor depress the clutch pedal, so that the clutch shaft is disconnected from the gearbox output shaft when the rpm falls. This in turn prevents the engine from stalling.

During idling, if the clutch shaft is connected to the gear output shaft, increased load acts on the engine which leads to wastage of power. If the clutch is disengaged, some energy could be recovered. The system has been developed such that the angular potentiometer makes the motor press the clutch during idling too, as the controller has been programmed to instruct the motor to depress the clutch at idling speeds.

## 4. Design of Mechanism

The design procedure for the mechanism would involve a study of already existing mechanisms in the clutch assembly. They are:

- The pedal is a lever pivoted at a point. The large displacement and small force is converted to small displacement and large force by fulcrum principle.
- The force from the fulcrum is used to move a master cylinder which in turn moves a slave cylinder which provides necessary axial force to actuate the clutch plate or fork.

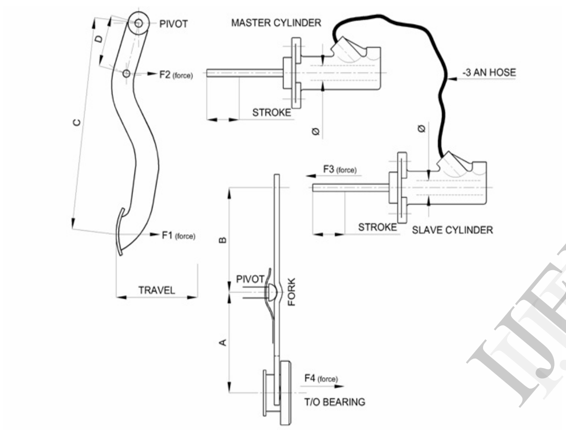


**Figure 3. Clutching effort transmission**

A series of calculations was done based on popular models and the force necessary to actuate the clutch fork was found out to be 180 kg-force or ~1800 N.

**Table 1. Specifications**

| FORCE F4 | RECOMMENDED T/O BEARING STROKE | ORIGINAL FORK | | MIN. FORK STROKE |
|---|---|---|---|---|
| | | A | B | |
| 180 Kg | 11.0228 | 110 | 145 | 14.53 |

The forces to actuate each of the other links in the mechanism were worked out in reverse to calculate the exact force that would be required to move the clutch pedal. This force had to be supplied by the automating mechanism for the system to work. The clutch pedal force was found out to be 15 kg-force or ~150 N.

**Table 2. Force calculations**

| | PEDAL TRAVEL | PEDAL FORCE | MASTER STROKE | SLAVE STROKE |
|---|---|---|---|---|
| mm | 143 | 15.08 Kg | 24.80 | 21.60 |
| Inch | 5.64 | | 0.98 | 0.85 |
| | FORCES | | | |
| | F4 | F3 | F2 | F1 |
| Kg | 180 | 100 | 87 | 15 |

The leverage for the clutch pedal lever was obtained as 5.78 by assuming the distances from the pivotal point based on ergonomic considerations and spatial constraints.

The area ratio of the hydraulic cylinders was found to be 0.87 according to the system present in a standard GM clutch.

Since the area reduced by 0.87 times while transmission, the displacement would increase by 1.15 times. This in turn implies that there will not be much changes to the force transferred since the ratio is closer to 1. The hydraulic cylinder system is merely for power transmission through larger distance.

**Table 3. Hydraulic cylinders ratio**

| PEDAL RATIO | | | CYLINDERS RATIO |
|---|---|---|---|
| C | D | RATIO | |
| 260 | 45 | 5.78 | 0.87 |



**Table 4. Cylinder dimensions**

| MASTER | | | SLAVE | | |
|---|---|---|---|---|---|
| NOMINAL | DIAMETER INCH | DIAMETER MM | NOMINAL | DIAMETER INCH | DIAMETER MM |
| 7/10" | 0.7 | 17.78 | 3/4" | 0.75 | 19.050 |
| 5/8" | 0.625 | SURFACE | | 19.05 | SURFACE |
| | | 248.2867 | | | 285.0230 |

The mechanism to actuate the clutch involves an AC servo motor placed beneath the clutch pedal offset by a small distance to enable clutch pedal free play.

A wire rope consisting of twisted wires connects the clutch pedal bottom to the pulley attached to the motor output shaft. An AC servo motor is chosen as it can be directly energized by the alternator of the IC engine. The position of the motor is such that it is in accordance with the spatial constraints of already existing popular vehicles.

A model of the system was designed in CATIA V5 describing the position of the motor and the clutch pedal system connected by a wire rope.

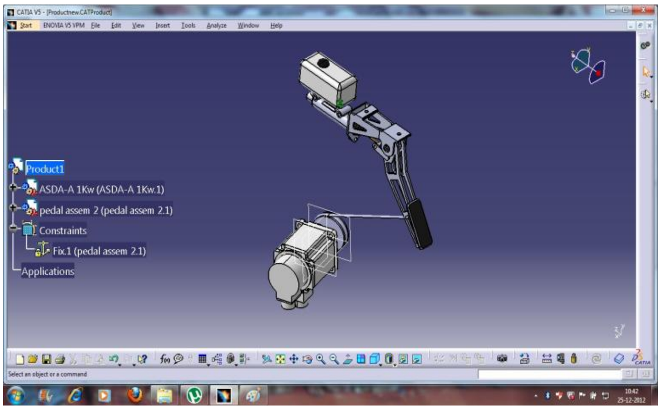


**Figure 4. CATIA Model of system**

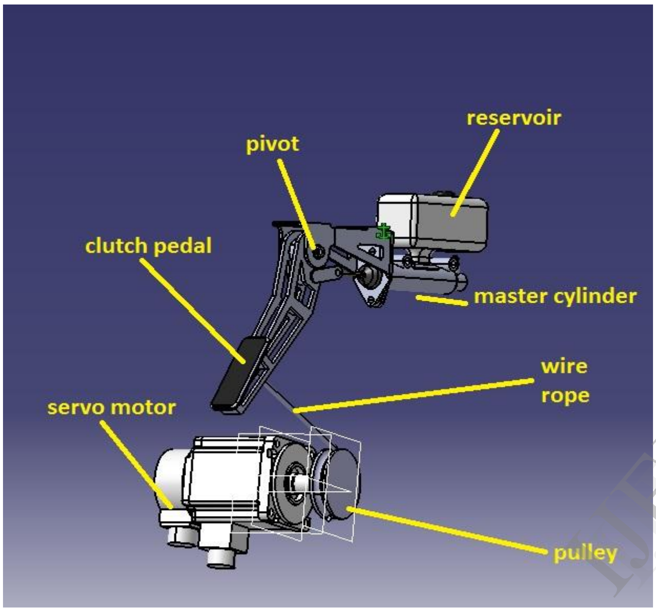


**Figure 5. Labelled diagram of system**

## 5. Selection of Motor

The force that is applied to the clutch pedal has been calculated to be ~15 kgf.

A pulley of diameter 8 cm was selected, based on constraints of space and availability, to be mounted onto the motor shaft.The velocity with which the clutch pedal is depressed is approximated to be 0.3 m/s.

The speed of the motor was calculated to be,

$$N = \frac{60v}{\pi D} = \frac{60 \times 0.3}{\pi \times 0.08} = 71.6 \sim 75 \text{ rpm}$$

The clutch pedal release is to be three times as slow as the speed of its depression i.e. 0.1 m/s which translates into a motor reverse speed of 25 rpm.

The torque of the motor was calculated to be,

$$\begin{aligned} T &= \text{Clutch Depression Force} \times \text{Pulley Radius} \\ &= 15 \times 9.81 \times 0.04 \\ &= 6 \text{ Nm} \end{aligned}$$

The power of the motor was calculated to be,

$$P = \frac{2\pi NT}{60} = \frac{2\pi \times 75 \times 6}{60}$$
$$\sim 45 \text{ W}$$

Adopting a factor of safety of 2, a 90 W motor could be chosen for actuating the clutch pedal. Based on popular standards and catalogs, we chose a 100W motor for the same.

An analysis was performed, in NX Nastran 8.1, to determine whether a standard automotive clutch pedal, modeled in Aluminum 6061, will be able to withstand the stresses induced by the wire rope attached to it. The wire rope is that of a pulley attached to a 100 W motor that produces a maximum of 12.7 Nm of torque, and 31 kgf of force. Adopting an approximate FOS of 2, 600 N of force is applied to the bottom of the clutch pedal, and the results are observed. The analysis assumes that the clutch pedal has gone through its entire range of travel, and therefore its pivot becomes fixed.

A maximum of 94.7 MPa of stress was induced, which was well within the yield stress of 275.790 MPa of aluminium 6061. Also, a maximum displacement of only 0.85 mm was observed, which was negligible. Thus it was concluded that the external drive would not cause significant stress over the clutch pedal.



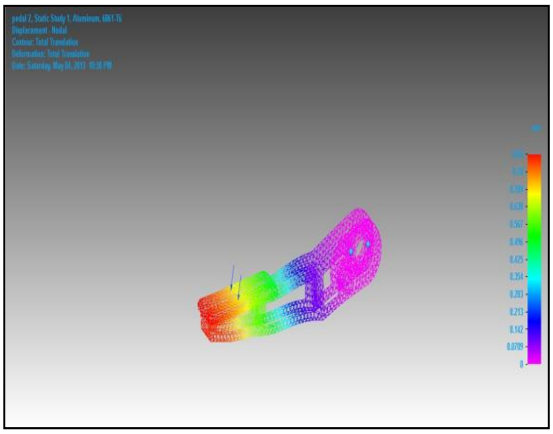

**Figure 6. Stress analysis-1**

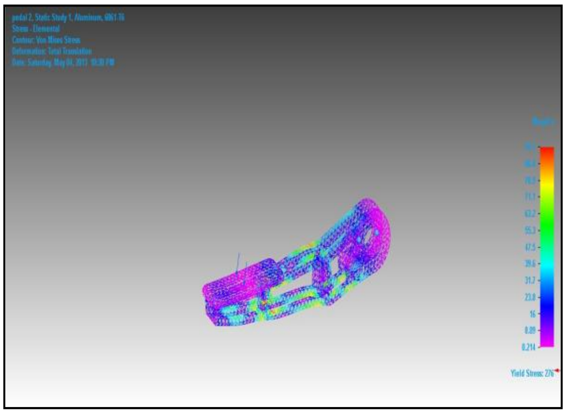

**Figure 7. Stress analysis-2**

## 6. Electronic Control Unit

The mode of actuation of the AC servo motor for engaging or disengaging the clutch is decided by the electronic control unit.

The electronic control unit shortly called as the ECU is a separate microcontroller unit specially intended for this application.

The actuation of ac servo motor through the ECU occurs based on the following conditions.

1) Whenever the status of the touch sensor mounted on the gear is 'ON' and also when it is 'OFF'.
2) Whenever the rpm of the wheels falls below 1000 rpm.

### 6.1. AC Servo Motors

The servomotors used in industry today are usually operated in closed-loop mode. To understand how the servo motor is used in the system, it is first necessary to review the entire system.

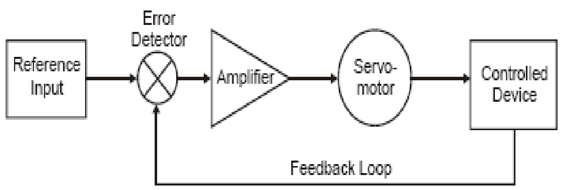


**Figure 8. Closed loop feedback**

A reference input (velocity input) is sent to the servo amplifier, which controls the speed of the servomotor. Directly mounted to the machine, or to the servomotor, is a feedback device, either an encoder or resolver. This device changes mechanical motion into electrical signals and is used as a *feedback loop*. This feedback loop is then sent to the error detector, which compares the actual operation with that of the reference input. If there is an error, that error is fed directly to the amplifier, which makes the necessary corrections. In many servo systems, both velocity and position are monitored. The velocity loop control may take its command from the velocity loop feedback device, a resolver or tachometer mounted directly to the motor. The speed of the AC servo motor is controlled by pulse width modulation technique.

An example of PWM in an AC motor drive: the phase-to-phase voltage (blue) is modulated as a series of pulses that results in a sine-like flux density waveform (red) in the magnetic circuit of the motor. The smoothness of the resultant waveform can be controlled by the width and number of modulated impulses (per given cycle).

### 6.2. Interfacing of the AC Servo Motors to the ECU

The speed control of the AC servo motors is carried out through ECU by pulse width modulation technique. So the interfacing of AC servos to the ECU- Micro controller involves proper selection of ADC units and amplifiers for each stage.

### 6.3. Touch Sensor Unit

The touch sensor is basically a touch pad mounted on top of the gear head. The touch pad is interfaced to the ECU and based on the status of the touch sensor (i.e) whether it is ON or OFF the clutch gets engaged or disengaged by through the AC servo motor. The AC motor will be forward or reverse actuated based on the time duration the touch sensor is ON.

When the driver touches the gear head for applying the gear, the touch sensor is switched ON. The ECU will be programmed to actuate the AC servo motor in a speed, sufficient for the actual engagement of the clutch pedal.

When the driver takes his hand off the gear head, the clutch pedal has to be disengaged. But the disengagement of the clutch pedal depends upon the status of the gear at that moment. So the ECU is programmed in such a way that the speed of disengagement is adjusted by pulse width modulation.

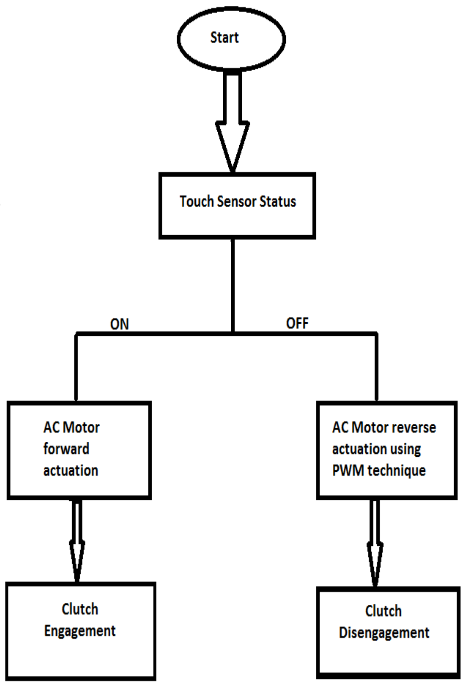


**Figure 9. Touch sensor Flow chart**

### 6.4. RPM Sensor Unit

The engagement and disengagement of the clutch becomes a necessity, when the rpm of the wheels in the car falls below 1000. In this condition the clutch has to be engaged compulsorily. So for this purpose, the rpm of the wheels are to be sensed. The status of the rpm is read from the tachometer which is present already, using an angular potentiometer, and based on it, the ECU is programmed for the forward or reverse actuation of the AC servo motor.


**Figure 10. Gear lever knob**

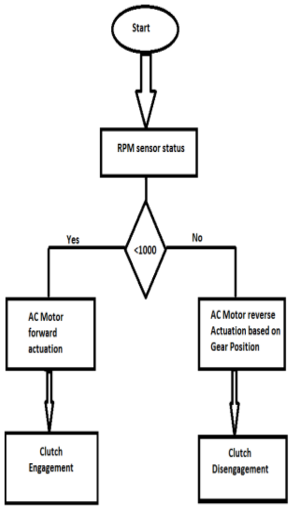


**Figure 11. RPM sensor flow chart**

## 7. Application in Existing Vehicles

The arguments for implementation of the proposed system in existing vehicles are predicated on the identification of a need for balancing the convenience of automatic transmission equipped vehicles with the savings in fuel consumption that manual transmission vehicles allow for.

Automatic transmissions shift gears solely by locating the optimum-shift points supplied by a tractive effort – speed curve. They do not take dynamic conditions such as the type of terrain driven on, into account. Manual transmissions depend on the intuition of the driver to shift gears, but driver fatigue due to repeated depression and release of the clutch pedal, in addition to the accelerator and brake pedals, is a common concern.

Thus a need arises for relieving the driver of additional effort required to depress the clutch pedal, without compromising on fuel efficiency. An additional case for implementation can be made in the form of an argument that adequate room to house the servo motor chosen is available in the space where the clutch pedal is located. The motor can be mounted in such a way that it does not interfere with the free movement of the driver's feet.

The implementation is rendered completely feasible by the fact that no hurdles would be faced in installing the touch sensor in the gear lever, as the gear knob in a typical manual transmission vehicle is hollow. Thus the implementation of the system proposed in manual transmission vehicles would enable the reduction of driver fatigue without breaching in on fuel efficiency.

## 8. Conclusion

The idea discussed in the paper is an innovative method to actuate the clutch reducing human effort. Although meant for cars which are to be designed in the future, the design of the mechanism has been made flexible so that it can be implemented in present day cars by making minor modifications. The result would be improved driving comfort, at the same time retaining original fuel efficiency. The idea gives the opportunity to develop a retro-fit model system to an existing vehicle, which demonstrates its ease of implementation.

A sub-system which can be attached and detached would be more serviceable and also customizable. The failure of this system is also combated since the clutch pedal is still reachable to the human leg, which serves as a manual over ride mechanism. Further, it will discourage bad driving practices such as keeping one hand over the gear lever knob while driving, due to the placement of touch sensor. Thus, this system can be effectively implemented to improve present day manual transmission automobiles.



## 9. Acknowledgment

The authors of this paper would like to thank the Students' Research Council of PSG College of Technology, Coimbatore for their motivation and support.

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