Modeling and Design Optimization of an Cost Effective Alternative Rain Sensing Wiper System

Amol Khatkhate, Mina Bairagi, Ram Kumar Maurya,
Husain Jasdanwalla, Nitin Dhamal and Varsha Shah

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Mathematical modeling and Design Optimization of an Alternative Cost Effective Rain Sensing Wiper System

Khatkhate Amol M[1*], Bairagi Mina[1], Maurya Ramkumar[1], Jasdanwalla Husain[1], [2]Dhamal Nitin and Shah Varsha[1]

[1]Rizvi College of Engineering, Off Carter Road, Bandra (W), Mumbai – 400050. INDIA
[2]PhD Student, Veermata Jijabai Technological Institute (VJTI), Matunga, Mumbai., INDIA.
amolmk@eng.rizvi.edu.in

Abstract. The conventional wiper system in an automobile is operated by the Lucas motor (12V heavy duty) and is connected to the micro-controller of the vehicle. In places like Mumbai, where there is heavy and persistent rainfall, such systems can malfunction due to water logging in the vehicles. In this paper, we present the mathematical modelling and design optimization of an electrochemical based rain sensing wiper system which works with minimal electronics and is independent in operation of the micro-controller of the vehicle. The main component of the system is an electrochemical cell having an accordion joint salt bridge made of straw which is modelled as a mass-spring-damper system and which produces a deflection of 3.2 μm under the impulse force of a single raindrop. When the circuit is completed due to deflection of the salt bridge, it generates sufficient current which is fed as input to the set of transistors in Darlington configuration making the wiper to run at the rated speed and also performs other functions like opening/closing of windows and doors. A solar charged 12V DC battery can be used to supply the necessary power to the wiper. The modeling and optimization in design with comparison with the conventional Lucas motor based wiper system is presented in this paper.

Keywords: rain sensing; electrochemical; accordion salt bridge; wiper.

1 Introduction

During to heavy rains lot of vehicles lose their electronic capability due to water logging which can result in loss of life of individuals. A rain sensing wiper and alert system that works on a principle other than electronics and independent of the micro controller of the vehicle would be a boon in such a situation. The voltage can be made to close the windows or open the door locks/windows during heavy rain allowing passengers to escape from the vehicles. Situations such as sudden rain can cause the driver to panic resulting in him pressing some wrong button in-order to start the wiper. A low cost automatic rain sensing wiper will be very useful in such a scenario.

Section 2 discusses the design of the electrochemical rain sensor (ERS) and the various parameters associated with its sensitivity. It also explains in detail the working of the ERS. The useful life of the ERS and comparison with the existing sensors in literature has been explained in detail in Section 2.4 and 2.5. The literature review [1-4] and working principle of various existing automatic rain sensing wiper technologies are discussed in detail in Table 2 in Section 2.5 of the paper. Section 3 discusses the application of Electrochemical Rain Sensor to the wiper system. Section 4 presents the detailed mathematical model for the conventional Lucas wiper motor and for the newly proposed DC geared motor with the rack and pinion arrangement. Section 5 presents the results of the simulation of the ERS based wiper system and shows the comparison with the conventional Lucas wiper motor arrangement for various parameters. Section 6 presents the MATLAB program code in detail. Section 7 discusses the salient features, conclusions and future work.

**Corresponding email and phone* : amolmk@eng.rizvi.edu.in / 91-8007977166

2 Design of the in-situ Electrochemical Rain Sensor (ERS)

The in-situ electrochemical sensor as seen in Figure 2 below is made using the conventional technique. Two electrodes of Cu and Zn are placed in their respective electrolytes. In-order to complete the circuit, a salt bridge is made using the following procedure.

2.1 Procedure for making Accordion Joint Salt Bridge

The salt bridge acts as a connector between the electrolytic solutions and thereby completes the circuit. Basically the salt bridge is in the galvanic cell to regulate the charges in solution and keep them neutral. Without this, there is no flow of electrons, and therefore no electrical output. It avoids voltage drop. The standard procedure of making a salt bridge is enlisted below:

1. Prepare about 150 ml of distilled water in 400 ml beaker and bring to boil.
2. Take 3 g agar-agar powder and stir the mixture as the suspension boils
3. Remove the beaker from the heat and stir in 15 g KCL until the salt dissolves.
4. Pour the warm mixture in the bent straw salt bridge until it is completely filled. Once agar is set, store in plastic bag for preventing drying out.
5. Seal one end with cotton plug and ensure that no air bubbles are present in the salt bridge prepared.

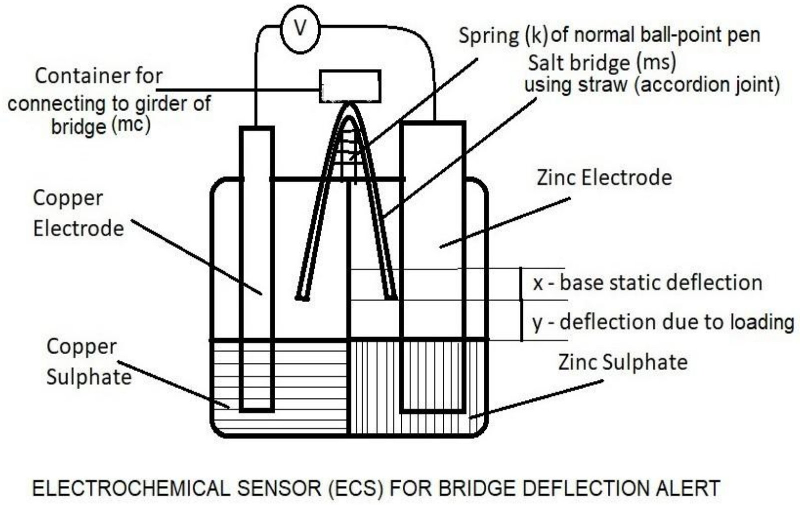

Figure 1 – Electrochemical Rain Sensor (ERS)

2.2 Working of Electrochemical Rain Sensor (ERS)

The electrochemical alert sensor is modeled as a mass-spring-damper system as shown in Figure 1 above. The parameters used in the design of the electrochemical sensor are given in Table 1 below. The static deflection due to the container, salt bridge and spring is 51.4 μm. In-order to test the sensitivity of the sensor, raindrops were considered as a forcing input.[6]

Diameter of raindrop – 3 mm, Terminal velocity – 8 m/s, Time taken to come to rest – 80 ms

Force generated due to impulse = mv/t = $(1000 \times \pi \times (0.003)^3 \times 8)/(6 \times 0.08) = 1.41$ mN

Every raindrop generates an impulse force of 1.41 mN resulting in a deflection of 3.2 μm of the assembly (container + salt bridge + spring) which slowly reaches to static deflection in about 1.2 s. This was in consideration with the value of damping of air, $\zeta_{air} = 0.01$ while in practice air has almost negligible damping and will continuously produce a sinusoidal oscillation of amplitude 3.2 μm.

Table 1. Parameters for the Electrochemical Rain Sensor

Parameter	Value	Unit	Availability
Mass of container (m_c)	1.47	gm	General purpose container to give medicine to children and adults (10 ml)
Mass of salt bridge (m_s)	3.5	gm	Normal straw with center bend (accordion joint)
Mass of spring (m_k)	0.17	gm	Used in normal ball-point pen
Stiffness of spring (k)	950	N/m	NA

The steady state response to raindrop force can be seen in Figure 2 below. The cell will continue to generate current while it is raining and will stop when the rainwater in the container drains out. The deflection 'y' can be adjusted to allow for suitable amount of rain water being collected in the container thus adjusting the sensitivity of the ERS. Sample calculation of the sensitivity of the cell is explained in the next section.

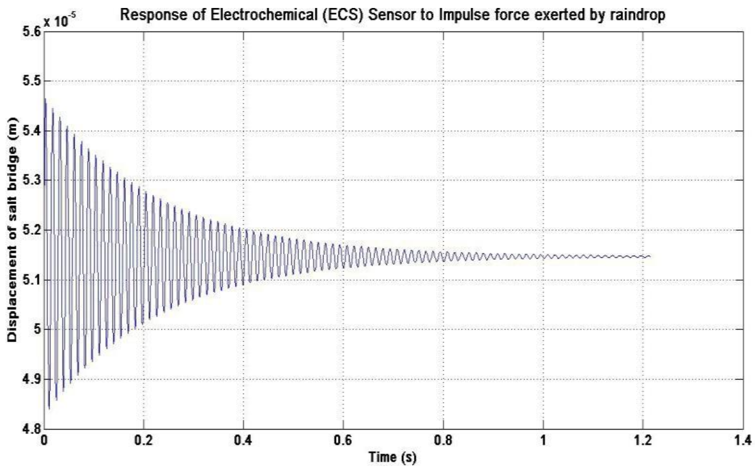

Figure 2 – Response of Electrochemical Rain Sensor (ERS)

2.3 Sample Calculation of Sensitivity of Electrochemical Rain Sensor (ERS)

Volume of 1 raindrop = $\pi D^3/6$ m^3
Allowable deflection/threshold = y_{allow}
Steady state oscillation due to single raindrop = 3.2 μm
Steady state response due to N raindrops = 3.2N μm
Total deflection due to 'N' raindrops = N x $1000g\pi D^3/6$ μm (Static deflection) + 3.2N μm(oscillatory assuming all in-phase)
Assume the time between successive raindrops be 1 second; then
y_{allow} = N x $1000g\pi D^3/6k$ μm + 3.2N μm
For D = 3 mm; k = 950 N/m
y_{allow} = 0.148N + 3.2N

So, for a threshold value equal to a thickness of an A4 paper, yallow = 50 μm which gives N = 15 with a response time of 14 seconds assuming a spacing of 1 s between raindrops

$N = ROUND(y_{allow}/3.348)$
Sensitivity of ERS, S = 3.2/Volume of 1 raindrop (ml) = 3.2/0.0141 = 227 µm/ml
Time to response = N-1 seconds

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2.4 Useful Life Of The Electrochemical Rain Sensor (ERS)

The sensor produced in the manner as described above is very light in weight and sensitive to small disturbances. Also, due to the field environment, the sensor may lose its capability of sensing. Due to changes in ambient temperature, the salt bridge characteristics may change and thereby make the sensor malfunction. Hence, in-order to understand the exact behavior of the sensor, we conducted a test for determining the average lifespan of the sensor when it is continuously in the conducting state. The experiment was conducted with an accordion salt bridge over a period of 18 days

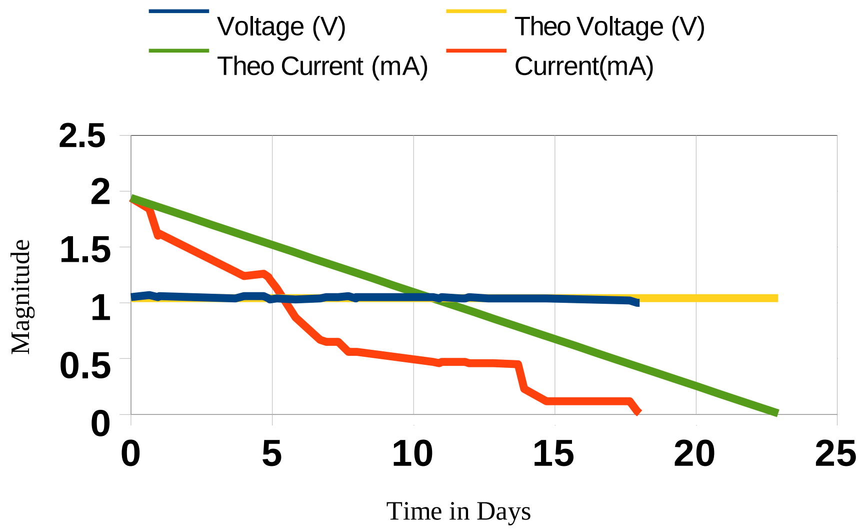

Figure 3 – Performance of ERS (Cu-Zn Voltaic cell with accordion salt bridge in 0.1 M 100 ml solutions)[§]

using 0.1 M solution of each of the electrolytes $CuSO_4$ and $ZnSO_4$. The voltages and current were measured at different time intervals. The measured voltages and current were used to compute the actual power of the sensor(cell). The theoretical time for the cell life was computed as given below:

Cell life in days = (No of cells x Molarity x Volume (liters) x No of electrons/mole x 96485)/(60 x 60 x 24 x (Final current + Initial current)/2))

The theoretical current is taken to be average of initial and final current value. The theoretical cell (sensor) life turned out to be 22.9 days. The actual experiment worked for 18 days (432 hours). The performance of the ERS is as seen in Figure 4 below. The actual curve of the current indicates that the ERS will discharge as a battery in an exponential manner. The voltage provided by the ERS is almost constant at 1.04 V which is less than the expected value of 1.1 V due to polarization effects. The current starts at a value of 2 mA and exponentially decays to zero.

Observations:

1. The volume of electrolytes reduced to 50% after 18 days and $CuSO_4$ became almost colorless indicating consumption of all ions.
2. Accordion salt bridge made of **plastic** does not allow for proper gelation of the agar-agar KCL solution and hence further work in this area needs to be carried out. Advantage of this method is the consumption of plastic and creating a plastic-free environment

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§The data for the Cu-Zn cell can be shared upon request and proper authorization from Rizvi College of Engineering (RCOE)

2.5 Comparison Of The Electrochemical Rain Sensor (ERS) With Other Sensors

The following table explains the comparison of the ERS with various other sensors and has been published in literature[7]

Table 2

	DIFFERENT TYPES OF RAIN SENSORS				
	Plate based sensor[2]	**Piezo-electric sensor[1]**	**Probe based sensor[4]**	**Optical based rain sensor[3]**	**Electro-chemical rain sensor[7]**
Operating principle	Micro controller based	Micro controller based	External circuits connected to micro controller	Micro-controller based	Independent of micro controller
Working	Small drops of water change the resistance	Water between plates decrease resistance	Contact of water with probe completes rain circuit	Change in reflection due to rain water	Rainwater energy is converted into displacement of electrochemical switch
False rain detection rate	Very high	Less than 5 %	Less than 2 %	Less than 2 %	Less than 2 %
Voltage required	12 – 5 V DC	12 – 5 V DC	2 – 6 V DC	12 – 5 V DC	1 – 3 V per single cell
System response time	Not mentioned	500 ms after rain contact	On collection of 10 cu.cm	Very low	550 ms after rain contact
Sensor surface size	Very large	<= 4 cm x 4 cm	>=2.58 cm x 2.58 cm	Not applicable	1 cm x 1 cm
Placement of sensor	On the windshield	On the windshield	Inside the font hood	Inside the car cabin	Inside the front hood
Cost of replacement	Quite high	Quite high	Around Rs 1000	Around Rs 7000	Around Rs1500
Adaptivity	Changes the aesthetics of the vehicle	Embedded on windshield	Volume of rain collected is high	Seamless integration with vehicles	Adaptable to all vehicles

3 Application of the ERS to the Wiper System

The following sections discuss in detail the two types of arrangements for the operation of the wiper motor using

- Conventional Lucas Wiper motor arrangement [8]
- DC Geared Wiper motor with Rack-pinion mechanism [7,9]

3.1 Comparison Of The Lucas Wiper Motor and the ERS based wiper motor

The conventional wiper motor assembly is as shown in Figure 5 (a) below. The wiper motor assembly developed at Mechatronics Lab, RCOE using a DC geared motor and a rack-pinion mechanism is as shown in Figure 5 (b). The normal wiper motor operates at two speeds of 45 rpm and 60 rpm.

Figure 4

(a) Conventional Lucas wiper motor (b) Electrochemical based rain sensing wiper system

Table 3 – Parameters of the two configurations

Parameters	Conventional Lucas Wiper Motor [8]	DC Geared Motor with rack-pinion [7][9]
Weight of wiper arm	330 gms	330 gms
Length of wiper arm	450 mm	450 mm
Crank rod length	NA	25 mm
Connecting rod length	NA	50 mm
Diameter of pinion	NA	79 mm (Module 1.41, Teeth – 56, Pitch - 18)
Length of rack	NA	100 mm
Weight of motor	800 gms	180 gms
Stall torque of motor	180 kg-cm	80 kg-cm
Stall Current	14 A	7.5 A

The torque required at 65 rpm for a wiper rod of length 450 mm with a mass of 330 gms is as shown in Figure 6 below. The wiper is modeled as a rotational load along-with the rack and pinion which can suitably generate the required trajectory. Frictional force is considered to be 0.8 N [5].

3.2 Schematic of the proposed Electrochemical based Rain Sensing Wiper System

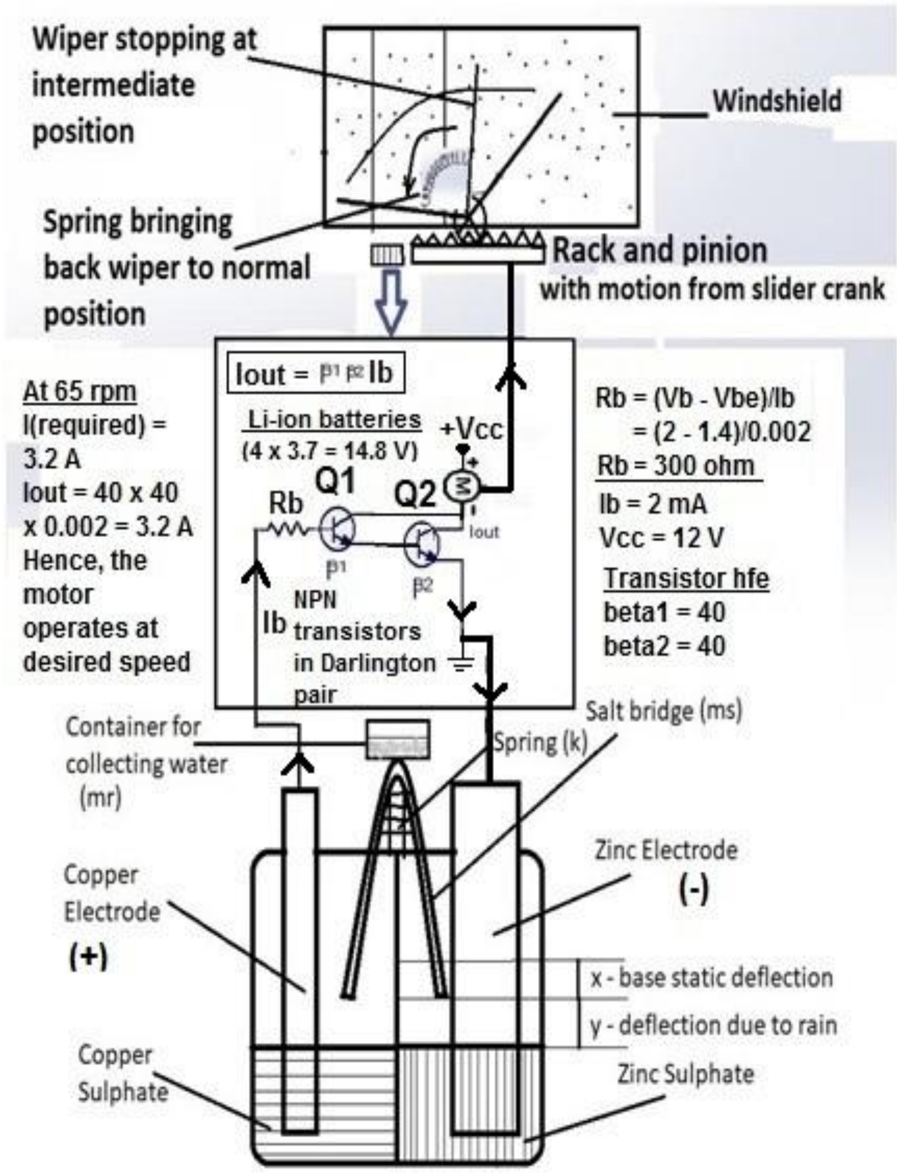


Figure 5 Schematic of the Electrochemical based rain sensing wiper system

The Figure 5 above shows the detailed connections for the implementation of the Electrochemical based rain sensing wiper system. As the impulse force due to the raindrops causes the salt bridge to connect with the electrolytes, the current is generated which is fed to the base of transistor with hFe = β_1. The base of the transistor is connected to the ERS which has to generate more than 1.4 V for both the transistors in pair configuration. This is achieved by a Cu-Al voltaic cell (cell voltage = 2 V) combination whose results will be similar to those mentioned for the ERS above.

The general purpose transistor BC547 has a hFe from 10-1000. For a BC547-A Series value of 40, the transistor can supply enough current (2 mA x 40 x 40 = 3.2 A) to run the wiper at the speeds of 45 and 65 rpm. The voltage at 45 rpm is 9 V which is got from a voltage regulator.

The transistors in Darlington pair, causes the current to be amplified by a factor of $I_{out} = \beta_1 * \beta_2 * I_{in}$. This huge magnified current can be used to drive other applications like door opening/closing and windows opening, etc at higher speeds of rainfall. The voltage supply $+V_{cc}$ is 14.8V (4 Li-Ion batteries) that is charged through a solar panel. The Darlington pair require a voltage of 0.9 V across the collector-emitter junction and hence the voltage applied across the motor is 14.8 -0.9 = 13.9 V which corresponds to a maximum speed of 70 rpm. The bases of both the transistors need to be in forward bias condition for which the voltage across the P-N junction must be greater than 0.7 V each. ie.1.4 V. Hence, the cell to be used is an Cu-Al cell which generates a steady voltage of 2 V instead of the Cu- Zn combination.

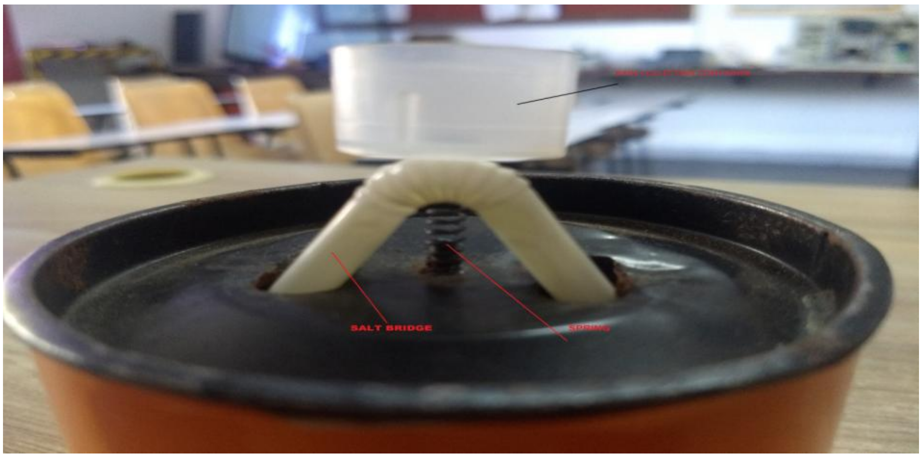


Figure 6 – Actual prototype of the Electrochemical Rain Sensor (ERS)

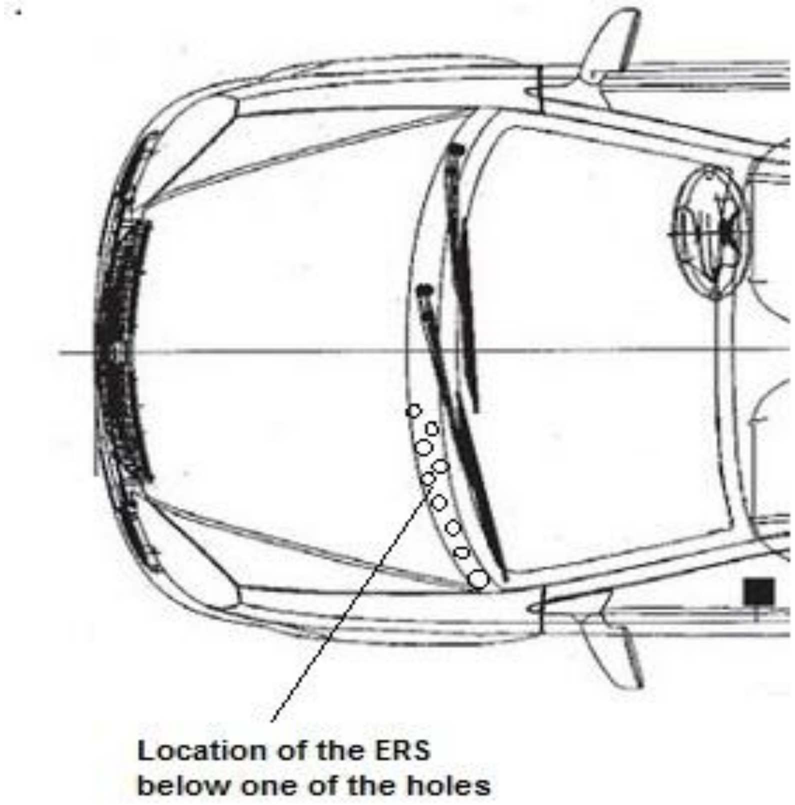
Table 4 : Comparison of the two configurations for wiper motor systems carried out in MATLAB2014a

Motor Configuration	**45 RPM**			**65 RPM**			**100 RPM**			**Cost Of System Per Vehicle**
	T_{avg} N-m	**I_{avg} (A)**	**I_{max} (A)**	**T_{avg} N-m**	**I_{avg} (A)**	**I_{max} (A)**	**T_{avg} N-m**	**I_{avg} (A)**	**I_{max} (A)**	
Conventional Lucas Wiper motor arrangement [8]	2.44	1.71	2.18	2.44	1.71	3.29	2.44	1.71	6.2	**4400/- (MIN)** (TVS SINGLE WIPER SYSTEM) [10]
DC Geared Wiper motor with Rack-pinion mechanism [7]	2	1.68	2.13	2	1.68	3.2	2	1.68	6	**1500/-** 1000 (DC GEARED MOTOR) + 200 (RACK AND PINION) + 100 (SLIDER CRANK) + 200 (ERS)[9]
% Change in parameter from conventional arrangement	**-18**	**-1.75**	**-2.75**	**-18**	**-1.75**	**-2.75**	**-18**	**-1.75**	**-3.23**	**66% reduction**

As seen in Table 4 above, the torque required by the DC geared motor arrangement is quite less as compared to the conventional Lucas motor for the 3-speed arrangement. The current required is almost the same in all the cases for both the wiper arrangements.

3.3 Sensor location on the vehicle

The windshield on a passenger vehicle typically ends in the portion of the car where there is a space for the rain water to trickle down after the wiper cleans the windshield. This area has small holes and can accommodate the sensor underneath.



The ERS kit can be very well accommodated without causing any change in the current manufacturing process and thereby provide the user the capability of automatic rain sensing for the vehicle.

A suitable "**ERS KIT – ELECTROCHEMICAL RAIN SENSING KIT**" will be designed using the following components as shown in the Table 5.

Table 5 : ERS Kit Components

Components	Manufacturing Cost
Rain Sensitive Cell	200
Accordion Joint Salt bridge (12 QTY)	70
Rack and Pinion	180
Slider crank	50
DC geared motor	1000
TOTAL	**1500**

4 Mathematical model of Wiper System

The mathematical models of both the systems are presented in this section

4A - Conventional Lucas Wiper Motor System

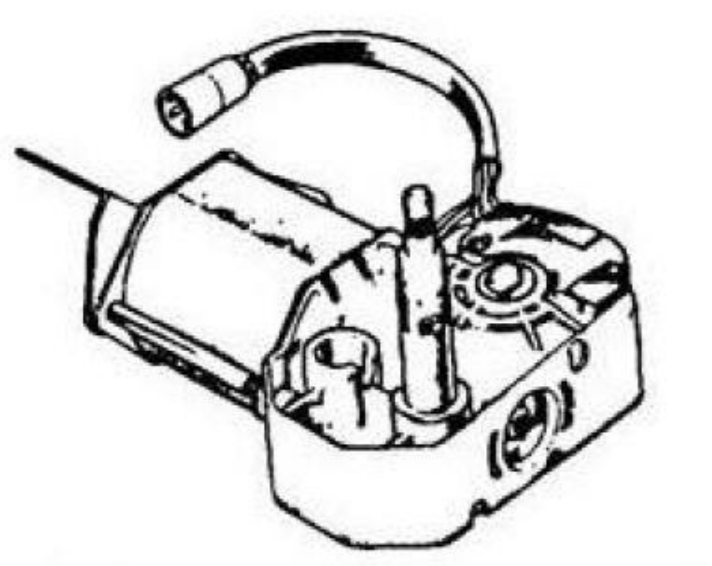


Figure 7 – Conventional Lucas Wiper Arrangement for Single wiper

The conventional Lucas motor consists of worm and worm wheel attached to a DC motor and operating a four bar mechanism to rotate the wiper. The equation of torque produced by the Lucas motor is shown below

$$\boxed{T = F\ \mu\ f_s\ f_l\ l\ (\omega_a/\omega_m)(R_h/R_c)(1/e)}$$

where:

T = torque to move one wiper arm (N-m)
F = force onto blade on screen (N) = (W + 0.8)cos($\beta + \lambda$) W = 90 gms weight
Frictional force, 0.8 N = maximum frictional force on blade [6] β = angle of travel by wiper (rad) = max 180 – 2λ
λ = relief angle on windscreen = 15 degree
μ = maximum dry coefficient of friction, which is 2.5 f_s = multiplier for joint friction, which is 1.15
f_l = tolerance factor, which is 1.12
l = wiper arm length, m = 0.24 m
ω_a = maximum angular velocity of arm, rad/s
ω_m = mean angular velocity of motor crank, rad/s e = efficiency of motor gear unit which is 0.8
R_h = motor winding resistance, hot-Ω = 1.05
R_c = motor winding resistance, cold-Ω = 1

Figure 8 – Various parts of the conventional wiper assembly

4B - DC Geared Motor Rack and Pinion Wiper System

Taking downward direction as positive
W + mg = N.................(1)

Taking right side positive
$-F_t + \mu N$ = -mddot(x)....................(2)

Moment about O taking clockwise positive
-T –WLcos($\beta + \lambda_0$)/2 + F_tR - μNR = Iddot(β) = (WL^2/3g)ddot(β).........................(3)

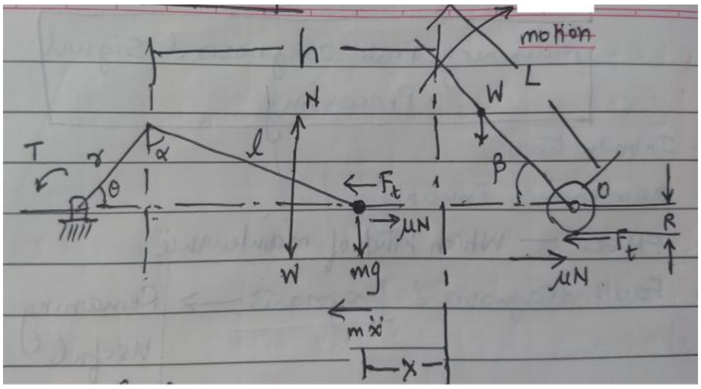


Figure 9 – Free Body Diagram of the ERS based wiper system

Also, for the pinion and rack arrangement,
β = -x/R
dot(β) = + dot(x)/R
ddot(β) = -ddot(x)/R

Substituting in the equation (3), we get

T = [(WL^2/3gR) + mR]ddot(x) - (WL/2)cos($\beta + \lambda_0$)......................................(4)

Consider the rack and pinion configuration as shown in Figure below.
In a pinion rotation of 180 - $2\lambda_0$ deg in a single direction, the rack covers distance equal to ONE travel length. The relief angle on the windshield is given by $\lambda_0 = (2\pi - 2(x_m/R))/4$.

Figure 10 – Proposed ERS based wiper system for automobile

5 Simulation Results and Discussion

The curves showing the displacement of rack, velocity of rack and acceleration of rack is given in the Figure 5 below

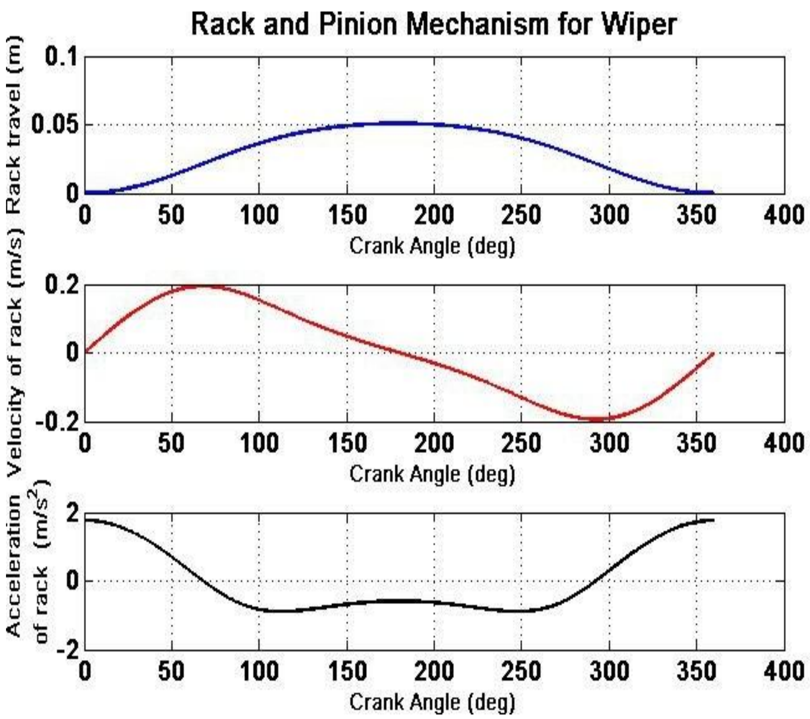


Figure 11 – Response of the slider crank mechanism actuating the rack

The performance of the DC geared wiper motor is compared with the conventional wiper motor and the results are shown in Figure below:

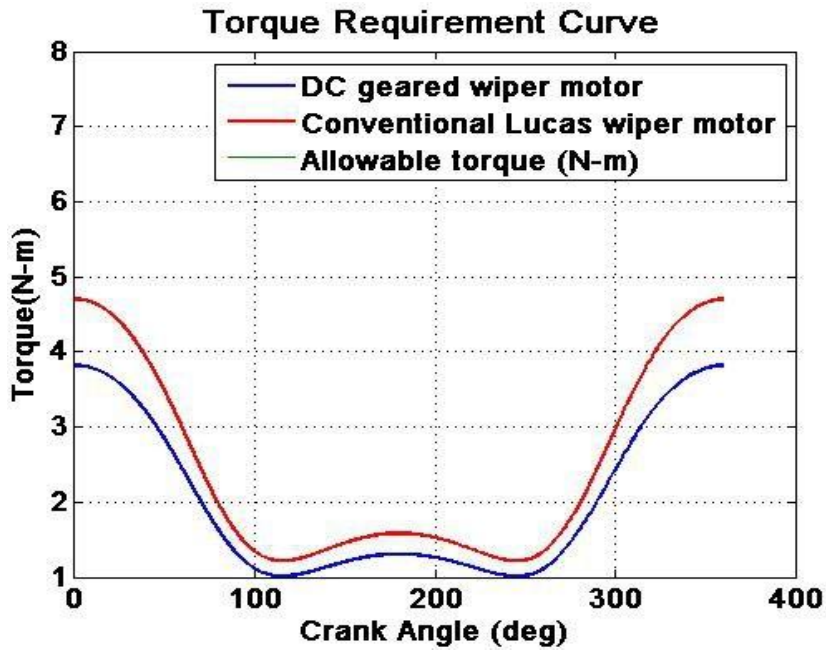


Figure 12 – Torque demand curve for the wiper systems

As seen in Figure 6, the torque required by the DC geared motor wiper is large at the starting point and then reduces as it approaches the mean position. As seen in Figure 7, the tangential force provided by the rack-pinion arrangement and the conventional wiper motor is shown. The force required is maximum at the extreme position and reduces towards the mean positions.

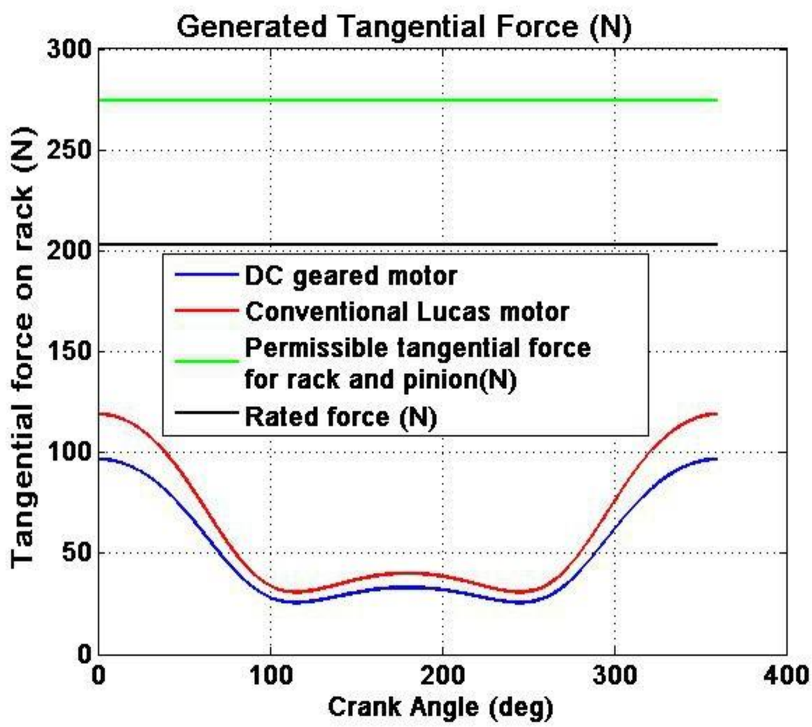


Figure 13 – Tangential force for Lucas wiper motor and DC geared motor at 65 rpm

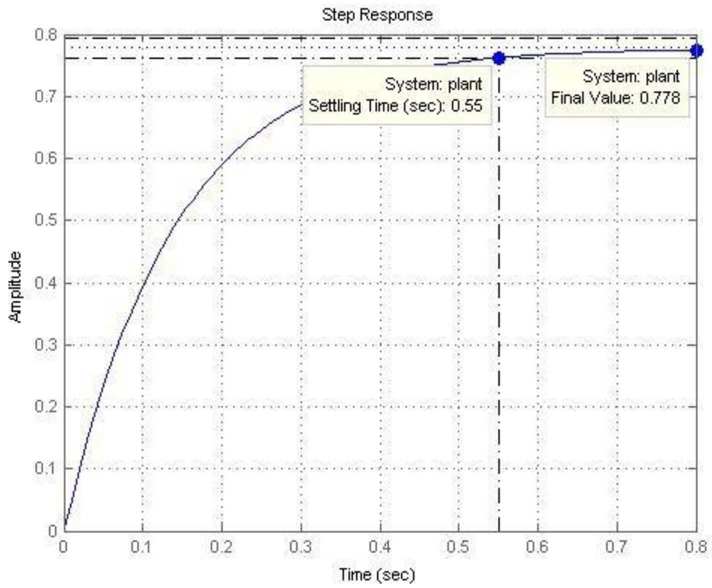


Figure 14 – Response time for rack and pinion mechanism

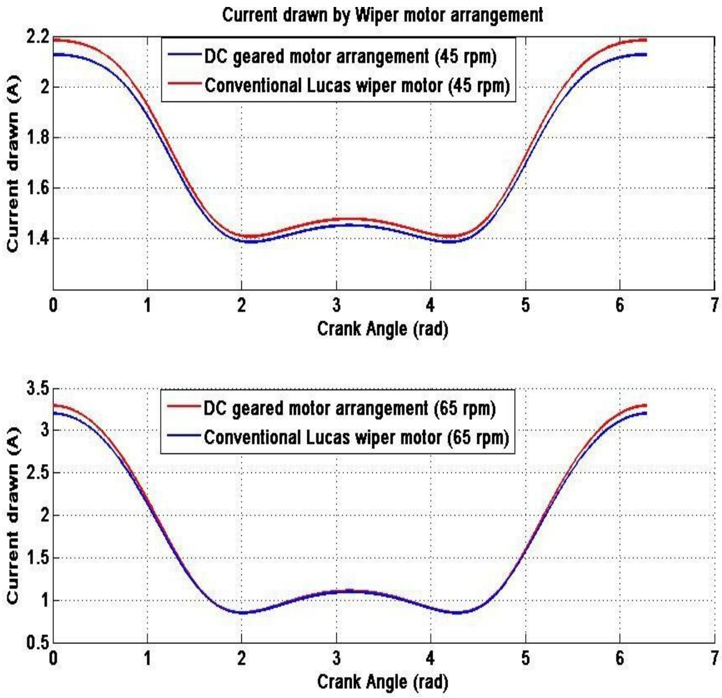


Figure 15 – Current drawn for Lucas wiper motor and DC geared motor at 65 rpm

6 Program Code

The following MATLAB code is used to simulate the two wiper systems:

```
clc;clear all;close
all;

n = 1; %no of cycles
theta = [0.1:0.1:360]*n*pi/180;
```

```
r = 0.0254;
l =  2*r;
h = l + r;
N = 65;
w = 2*pi*N/60;
% rack displacement, velocity and acceleration
x = [];
vel = [];
a = [];
b = [];
p = [];
q = [];
for k = 1:length(l)
for i = 1:length(theta)
    a(i) = r*cos(theta(i));
    b(i) = sqrt(l^2 - r^2*sin(theta(i))^2);
    x(i,k) = h - (a(i) + b(i));
    p(i) = r*w*sin(theta(i));
    q(i) = r^2*w*sin(2*theta(i))/(2*sqrt(l^2 -
r^2*sin(theta(i))^2));
    vel(i,k) = p(i) + q(i);
end
plot(theta*180/pi,x(:,k));
hold on
grid on
end
hold off
figure;
plot(theta*180/pi,vel,'r-');
grid on;

delta = [];
d2x = [];
for i = 1:length(theta)
    d2x(i) = r*w^2*cos(theta(i)) +
(4*r^2*w^2*cos(2*theta(i))*(l^2-r^2*(sin(theta(i))^2)) +
(r^2*w*sin(2*theta(i))).^2)/(4*(l^2-
(r*sin(theta(i)))^2)^1.5);
end
figure
plot(theta*180/pi,d2x);
grid on;

figure
subplot(3,1,1)
plot(theta*180/pi,x)
grid on
subplot(3,1,2)
plot(theta*180/pi,vel,'r')
grid on
subplot(3,1,3)
plot(theta*180/pi,d2x,'k')
grid on

%calculation of required torque for motor
m = 0.18;
W = 0.33*9.81;
L = 0.45;
R = 0.0395;
lambda = (2*pi - (2*max(abs(x(:,1)))/R))/4;
T_rated = 8*ones(1,length(theta));
```

```
fos = 2.5;
beta = -x(:,1)/R;
alpha = -W*L^2/(3*R*9.81) + m*R;
alpha_lucas = -W*L^2/(3*R*9.81);
for i = 1 : length(theta)
         T(i) = -fos*(alpha*(d2x(i))-(W +
0.8)*(L/2)*cos(beta(i,1) + lambda));% alpha*(d2x(i))+
weight of wiper + frictional force
end
T_lucas = [];
F = [];
neu = 2.5;
fs = 1.15;
fl = 1.12;
wmean = mean(w);
Rh = 1.05;
Rc = 1;
e = 0.8;

% Torque of a typical Lucas wiper motor
for i = 1:length(theta)
    F(1,i) = (alpha_lucas)*(d2x(i)) - (W +
0.8)*(L/2)*(cos(beta(i,1)+lambda));
    T_lucas(1,i) =
-F(1,i)*neu*fs*fl*(max(vel/R)/wmean)*(Rh/Rc)*(1/e);
end
figure
plot(theta*180/pi,T,theta*180/pi,T_lucas,'r',theta*180/pi
,T_rated)
grid on

% Tangential force transmitted by rack and pinion
Ft = [];
g = 9.81;
Ka = 1.5;
fn = 1.05;
Sb = 1.2;
Lkhb = 1.5;
E = 0.35;
mu = 0.1;
for i = 1 : length(theta)
    Ft(i) = T(i)/(R);
end
Fu_per = max(Ft)*Ka*Sb*fn*Lkhb*ones(1,length(theta));
figure
plot(theta*180/pi,Ft,theta*180/pi,T_lucas/R,'r',theta*180
/pi,Fu_per,'g',theta*180/pi,T_rated/R,'k');
grid on

%Transfer function between rack and pinion
s = tf('s');
c = mu*m*9.81/(max(vel)/sqrt(2));
tau = ((W*L^2*R/(3*9.81)) + m)/c;
plant = (1/c)/(tau*s + 1);
figure;
step(plant)
grid on

% Calculation of voltage generated by Cu cathode and Al
anode using Nernst equation
Vo = 0.34 -(-1.66);
```

```
R_const = 8.314;
F = 96485;
Temp_Cu = 25 + 273;
Temp_Al = 25 + 273;
Al = 0.1;
Cu = 1;
V_cell = Vo - (R_const*Temp_Al/(2*F))*log(Al) +
(R_const*Temp_Cu/(2*F))*log(Cu);

T_max = 8;
T_max_lucas = 18;
V_nom = 12;
I_noload = 0.8;
I_noload_lucas = 1.4;
I_st = 7.5;
I_st_lucas = 14;

Power = [];
I_act = [];
I_lucas = [];
R_act = [];
R_lucas = [];

V_act = (N/60)*V_nom;
T_allow = T_max - (60 - N)*T_max/60;
I_man = 7.5*ones(1,length(theta));

% calculation of current drawn by Conventional Lucas
motor and DC geared wiper motor
for i = 1:length(theta)
    Power(i) = T(i)*w;
    I_act(1,i) = T(i)*(I_st - I_noload)/T_max;
    P_lucas(i) = (T_lucas(i)*w);
    R_act(i) = V_act/ I_act(1,i);
     I_lucas(1,i) = T_lucas(i)*(I_st_lucas
- I_noload_lucas)/T_max_lucas;
    R_lucas(i) = V_act/ I_lucas(1,i);
end
plot(theta,I_act,'b',theta,I_lucas,'r')

% calculation of time for which cell can be used
Q = 4*5*0.1*2*96485;    %Coulombs = No of Cells x
Molarity x Volume of electrolyte x no of electrons/per
mole x 96485
I_avg = mean(I_act);
I_lucas_avg = mean(I_lucas);
discharge_time = Q/(I_avg);
discharge_time_lucas = Q/(I_lucas_avg);
hours = discharge_time/3600
hours_lucas = discharge_time_lucas/3600
```

7 Conclusions and Future Work

This section discusses the salient features of the Electrochemical Rain Sensor (ERS) based wiper system as compared with the existing conventional Lucas wiper system.

- Since, the electrochemical reaction is spontaneous, the actuation by this kind of a cell will result in very ***less response time***. (approx 700 ms – 550 ms by rack and pinion + 150 ms by the ERS as seen in Figure 6)
- The DC geared motor consumes almost ***18% less torque*** than the conventional Lucas motor and runs with very minimal parts.
- Also, ***80% weight reduction*** by replacement of Lucas motor with geared DC motor and the ***easy off the shelf availability of the rack and pinion*** setup are a lucrative point to choose this alternative.

- Compactness of this arrangement as seen in Figure 6 which has a dimension of 36 inches to a reduction of 6 inches which is ***1/6th the original size*** is a great advantage for the auto industry.
- The cost reduction estimated with the alternative wiper system is around ***66% per vehicle***.
- Experimental verification of the same is a part of ongoing work.

Furthermore, a suitable ARAI standard compatible product will be designed. The sensitivity of the product will be compared with the existing products in the market. Pilot project on an actual existing compact car will be carried out to prove the effectiveness of the technology. Also, suitable maintenance procedures and manuals will be designed so that the technology transfer to Car Service Centers can be easily carried out. The benefits of the technology can be seen if implemented by car companies on a large scale. Furthermore, following enhancements will be done in due course of time which will lead to value addition of the above rain sensing wiper:

- Automatic speed control of wiper based on rate of rainfall
- Automatic mist and fog removal
- Design of parking mechanism for wiper
- Design of vibration isolation system for cell and effect of temperature on the performance.

The introduction of this new type of system in current cars needs to also be checked in terms of its effect on the fuel economy especially the effect on reduction in usage of air-conditioning and the gains/losses that it has as compared to an existing rain wiper system.

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