CHAPTER 5 RESULTS AND DISCUSSION

This chapter illustrates different methodology results which are addressed in previous chapter for current and flexi force calibration model, mathematical modeling of power window system, its software in loop testing, Decision tree classifier algorithm for obstacle detection, hardware in loop testing and experimental setup analysis.

5. 1 Calibration

Sensor calibration is a strategy for enhancing sensor execution by expelling basic mistakes in the sensor response. Auxiliary errors are contrasts between sensors expected a response and their actual responses, which represents reliably at each instant of time estimation is taken. Considering these errors, which are repeatable can be computed among set configuration; such that accurate and exact reading utilizes the estimations made by the sensor can be compensated frequently and carefully to calculate any types of errors. The main objective of calibration is to provide upgraded execution by enhancing the general precision of the fundamental sensors. Calibration of the current sensor and flexi force sensor required for exact analysis in power window setup for obstacle detection.

5. 1. 1 Flexi Force Sensor

The flexi force sensor is used to identify the amount of valid force acting on the power window during upward movement. Calibration of the flexi force sensor is divided into two components one is signal conditioning unit and another one is calibration of static forces.

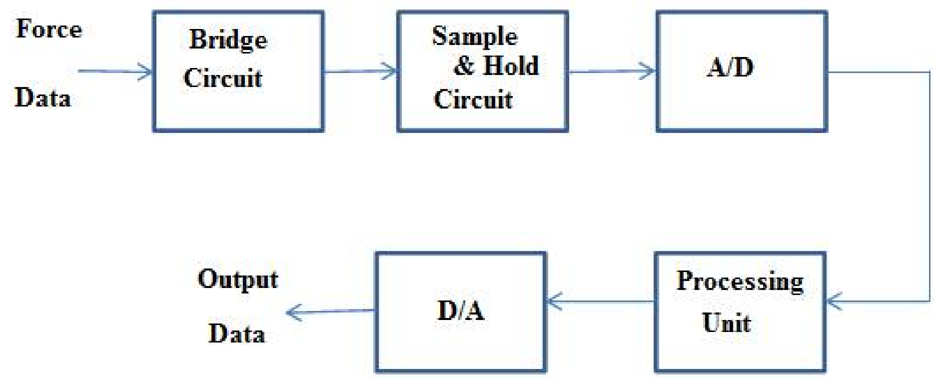

Figure 5-1 Flexi force sensor configuration

For flexi force sensor configration is repersented in Figure 5-1 and the signal conditioning circuit is illustrated in Figure 4-8. The operational amplifier IC and flexi force sensor are energized with DC +5 V. The mode of operation of the operational amplifier circuit is inverting mode and generates analog output on the basis of fixed reference resistance (R_F) and flexi force sensor resistance R_s. An analog to digital converter (ADC) which is part of the inbuilt feature of dSPACE Kit (ACE 1104) is used to convert output voltage into the corresponding digital signal. In the amplification circuit the possible output of the sensor is balanced with change in reference resistor (R_F) and drive voltage (V_T). Lower set of reference resistor and driving voltage applied to sensor makes the less sensitive sensor hence leads to poor selection of calculating dynamic force range.

5. 1. 1. 1 Calculation of Force

A pneumatic actuator is a fixed metal tube containing a cylinder; when you nourish pressurized air to the tube, it powers the cylinder inward or outward. With pneumatic actuator, a linear rod is connected to the system which force and accordingly external mechanism moves forward or backward as per input applied. Two principal factors influence the power the cylinder applies: the pressure of the air supply and the cylinder's area. The more prominent the power, and the more noteworthy the area, the more power the cylinder is prepared to generate.

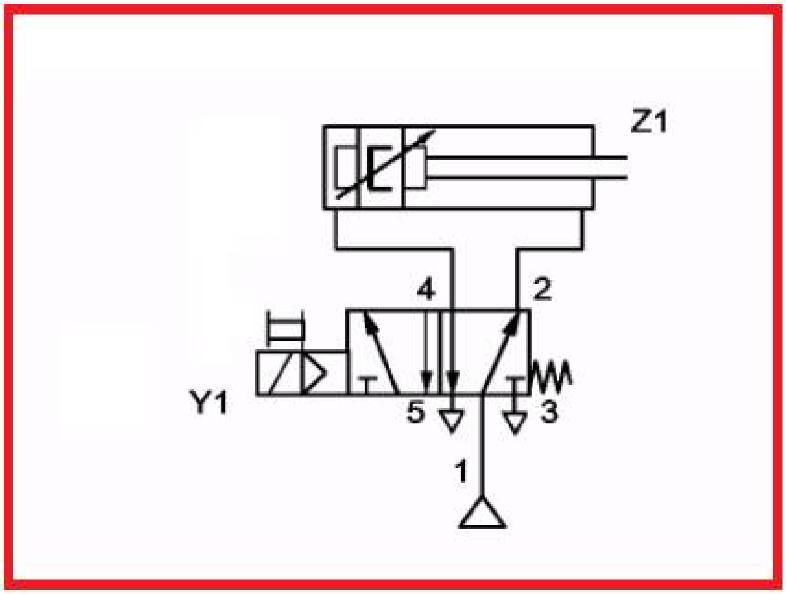

Figure 5-2 Pneumatic circuit for force generation

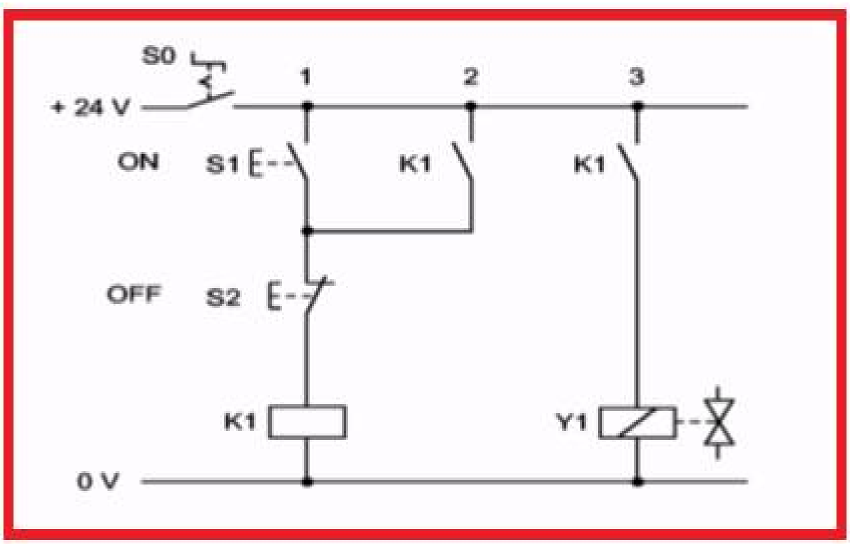

Figure 5-3 Pneumatic circuit control using relay based components

The force exerted by a double acting pneumatic cylinder shown in Figure 5-2 generates different force for obstacle detection whereas Figure 5-3 is the controlling circuit for a pneumatic system which can be expressed as

$F = p\,A$

$= p\,\pi\,d^2 / 4$

Where

F = *force exerted (N)*

p = *gauge pressure (N/m^2, Pa)*

A = *full bore area (m^2)*

d = *full bore piston diameter (m)*

At 1 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 1)}{4} = 50.24N$$

At 2 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 2)}{4} = 100.48N$$

At 3 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 3)}{4} = 150.72N$$

At 4 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 4)}{4} = 200.96N$$

At 5 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 5)}{4} = 251.2N$$

At 6 bar of pressure, the force generated by an actuator with a bore diameter of 80mm (8cm) is a type of double acting cylinder.

$$F = \frac{(\Pi \times D^2 \times P)}{4} = \frac{(3.14 \times 8^2 \times 6)}{4} = 301.4N$$

In the above configuration, when the force applied to the sensor is increasing the output voltage also increases proportionally i.e. Non inverting configuration of operational amplifiers. If measuring resistance R_M and flexi force resistance R_{FSR} are exchanged then output voltage decreases with increase in input force i.e inverting configuration of operational amplifiers. For limiting current the measuring resistance R_M selection must at the maximum level for the expected sensitivity range of input force.

To overcome impedance matching limitation operational amplifier based measurement signal condition voltage follower circuit used. Input force and output voltage characteristics curve are plotted considering VCC = +5V and GND = 0V. The characteristics curve of flexi force sensor which is a Force-sensing resistor (SEN-09375) is represented in Figure 5-4. With help of pneumatic circuit different forces are applied on the power window system and accordingly change in resistance as a response is capture from SEN-09375. With help of operational amplifier circuit shown in Figure 4-8 change in the resistance response is converted into a change in voltage response. Felxi force sensor SEN-09375 is a negative temperature coefficient device and accordingly, voltage value decreases when the force [101] of sensor is increased.

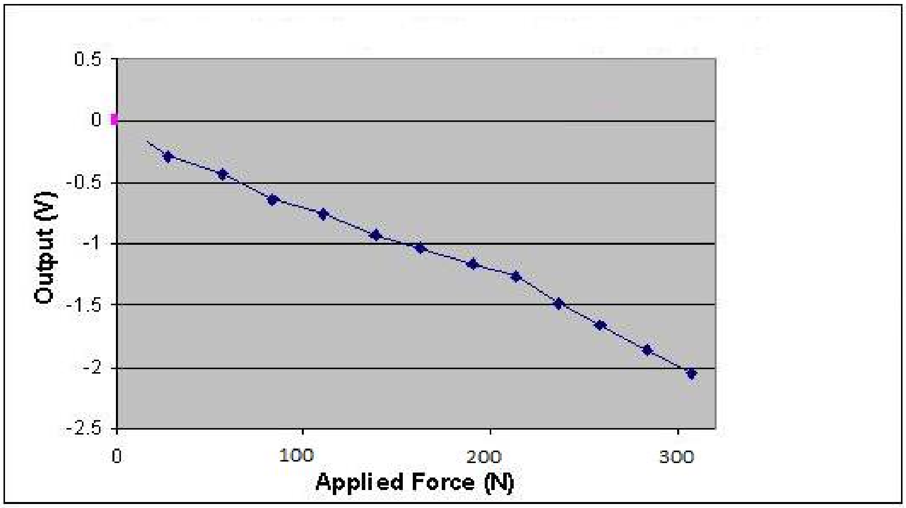

Figure 5-4 Force versus voltage characteristics curve

5. 1. 2 Current Sensor

In the research work, current sensor ACS 721 is used for current measurement in load circuit which is coupled in series with DC motor presented in Figure 5-5. The main features of ACS 721 are it works with 5V and its output sensitivity is lies between 66 to 185 mV/A.

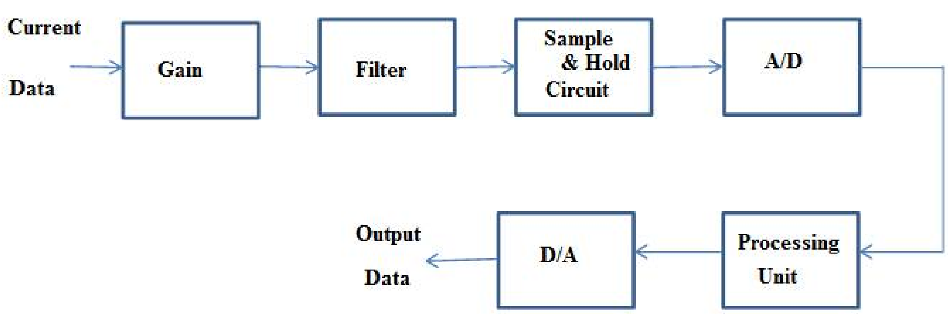

Figure 5-5 Detailed hardware configuration of the Current sensor

Torque, Power and current calculation for power window system which consists of the current sensor[102] ACS 721 and DC motor is shown in Figure 4-5 depend on the following equation:

$$Torque\ (N-m) = Force\ (N) \times Distance\ (c.m) \tag{5-1}$$

$$Power\ (Kw) = \frac{\{Torque\ (N-m) \times Speed\ (RPM)\}}{9.5488} \qquad (5\text{-}2)$$

$$Power\ (Kw) = Voltage\ (V) \times Current\ (A) \qquad (5\text{-}3)$$

5. 1. 2. 1 Observation Data (Current Vs Voltage)

In power window load circuit, current sensor position and configuration of the load circuit is an important activity. Once sensor installation and load circuit designing are completed, it's time to collect data i.e. current versus voltage value. For observation data different known loads i.e. different forces in required that span the range of force you expect to encounter. Table 5-1 represents different load acting on the plat model. With help of equation (4-1) to (4-6) and (5-1) to (5-3) torque and the current value is calculated and represented in Table 5-1.

Table 5-1 Observation table for current, force and torque measurement of power window systems

S.No	Force (N)	Torque (N-m)	Current (A)	Possible outcome
1	100	6	4.2	1
2	50	3	2.5	0
3	110	6.6	5	1
4	120	7.2	5	1
5	130	7.8	5.8	1
6	140	8.4	5.8	1
7	150	9	6.6	1
8	160	9.6	6.6	1
9	170	10.2	7.5	1
10	180	10.8	7.5	1
11	190	11.4	8.3	1
12	200	12	8.3	1
13	90	5.4	4.2	1
14	80	4.8	3.3	1
15	70	4.2	3.3	1
16	60	3.6	2.5	0
17	40	3	2.5	0
18	100	6	7.5	1
19	50	3	7.5	1

20	110	6.6	8.3	1
21	120	7.2	8.3	1
22	130	7.8	4.2	1
23	140	8.4	3.3	1
24	150	9	3.3	1
25	160	9.6	2.5	0
26	170	10.2	2.5	0
27	180	10.8	4.2	0
28	190	11.4	2.5	0
29	200	12	3	0
30	90	5.4	5	1
31	80	4.8	5.8	1
32	70	4.2	5.8	1
33	60	3.6	6.6	1
34	40	3	2.5	0
35	105	6	3	0
36	115	3	3	0
37	125	6.6	3	0
38	135	7.2	5	1
39	145	7.8	5	1
40	155	8.4	2.5	0
41	165	9	2.5	0
42	175	9.6	3	0
43	185	10.2	3	0
44	195	10.8	6	1
45	95	11.4	6	1
46	85	12	8	1
47	75	5.4	8	1
48	65	4.8	8	1

The characteristics curve of current sensor ACS 712 which is used for the calculation of stall torque of DC motor which is configured in series with power window motor. Circuit for sensing current i.e. ACS 712 is represented in Figure 4-7. With the change in torque demand by the power window system current varies in the load circuit and accordingly captured by the ACS 712. With help of torque[103] and the current relation of DC motor, change in load torque is converted into a change in current and represented in Figure 5-6. Different torque (Nm) versus current (A) value of calibration curve is captured in Figure 5-6. From calibration characteristics curve it is observed that when stall torque is very high to overcome this state current requirement by the DC motor [104] also rises to high value. In two cases stall torque is high one is glass frame has reached its maximum position i.e. power window glass frame in a closed state and another condition is if any obstacle rises in the upward movement of glass frame.

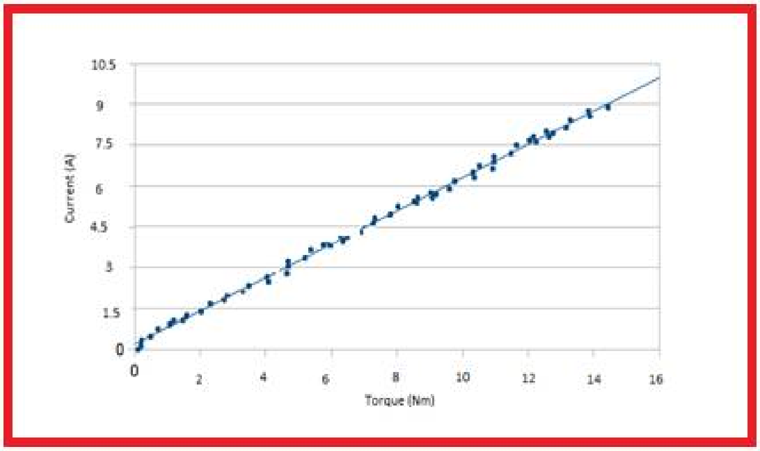

Figure 5-6 Relationship between Torque and current drawn during load is active for the current sensor

5. 2 Software In The Loop Testing

Software-in-the-loop testing also called as SIL testing, is utilized to depict a test approach where executable code, for example, algorithm (or even a whole controller process), normally composed for a specific mechatronic system, is tried inside a displaying situation that can help to demonstrate or test the product. Power window system development requires plant and controller models using Simulink which exhibits various parameters response for different class of vehicle require software in loop (SIL) testing. Plant model development requires electromechanical system i.e. DC motor, gear train and different switches shown in Figure 4-3.

5. 2. 1 Current Measurement

During mathematical modeling and simulation of automotive power window plant model exhibits following characteristics with respect to current flowing in the load circuit shown in Figure 5-7.

- Current in load circuit changes when power window is moving either an upward direction or downward direction.
- During upward direction maximum current flowing in the circuit is 6A during transient state and once steady state is acquired by the motor then current decreases to 2.2A.
- During downward movement maximum current flowing in the circuit is 5.2A during transient state and once steady state is acquired by the motor then current decreases to 1.8A.

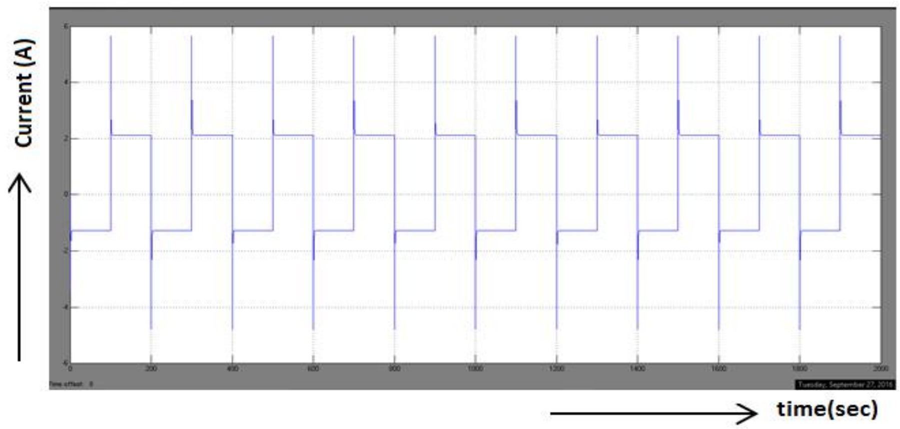

Figure 5-7 Current and time behaviour of the power window

5. 2. 2 Voltage Measurement

Mathematical modeling and simulation of automotive power window plant model exhibit voltage characteristics with respect to time is represented in Figure 5-8. From voltage characteristics curve it is observed that during upward and downward movement of power window plant model system voltage remains constant i.e. 12V. From Figure 5-8, it is represented as when motor direction changes with help of drive circuit voltage remain constant during a change in state.

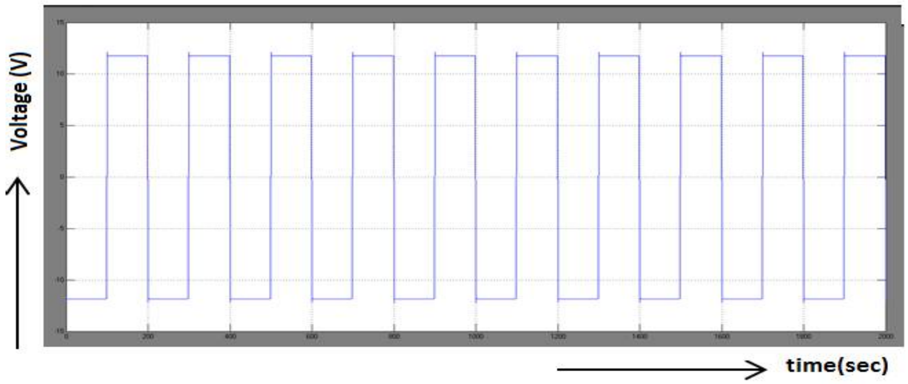

Figure 5-8 Voltage and time behaviour of the power window

5. 2. 3 Speed (RPM) Measurement

During mathematical modeling and simulation of automotive power window plant model exhibits following behavior with respect to RPM measurement i.e. the speed of the power window DC motor during upward and downward movement shown in Figure 5-9.

- Motor RPM changes when power window direction changes i.e. movement in upward direction and downward direction.
- During upward direction maximum RPM of the motor is 1500 RPM and during downward movement, maximum RPM of the motor is 2500 RPM. The difference in RPM of power window DC motor because of gravity factor in terms of the additional load acting on the motor during upward direction and downward direction.

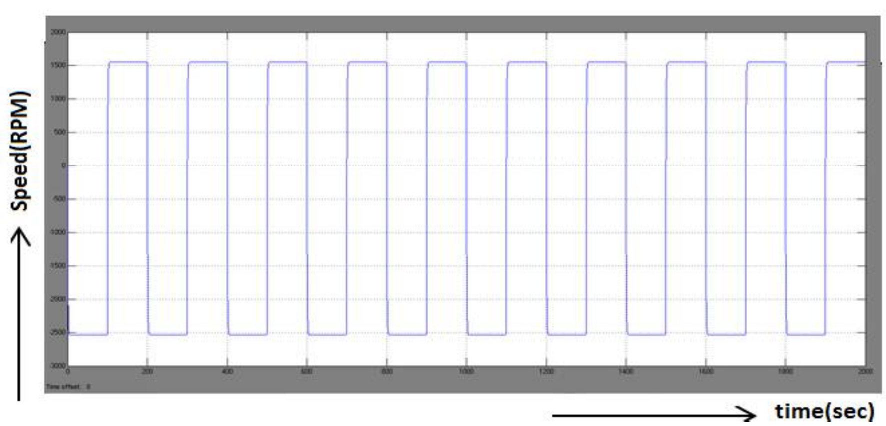

Figure 5-9 RPM of motor and time behaviour of the power window

5. 3 Decision Tree Algorithm

DTC algorithm utilizes a decision tree as a predictive model to go from observations around a machine to decisions about the machine objective. For the measurement system, data mining and machine learning DTC algorithm is one of the predictive demonstrating approach. The overall performance of the proposed DTC algorithm is tested and validated with smart power window system using different current sensor and force sensor which is configured with dSPACE ACE 1104 kit. The comparison of decision tree classifier results is done based on the accuracy in detecting current sensor using ACS 712 and force sensing resistor using SEN 09375. The results are validated with hardware in loop technique using dSPACE kit. Figure 5-10 illustrates test set result and Figure 5-11 illustrates training set result of decision tree classifier algorithm for power window system. From Figure 5-10, it was observed that out of 12 different test setup 93 percent is valid outcome whereas invalid outcome is only 7 percent. It is observed that our proposed DTC algorithm for creating decision tree is effective in identifying valid as well as a false decision about power window system.

5. 3. 1 Test Set Sample Result

From sample test set data, it was observed that out of 48 different test setup input, 93 percent response is valid and only 7 percent is an invalid response in power window system. Object detection algorithm evaluation of power window system is achieved to the extent of 93 percent.

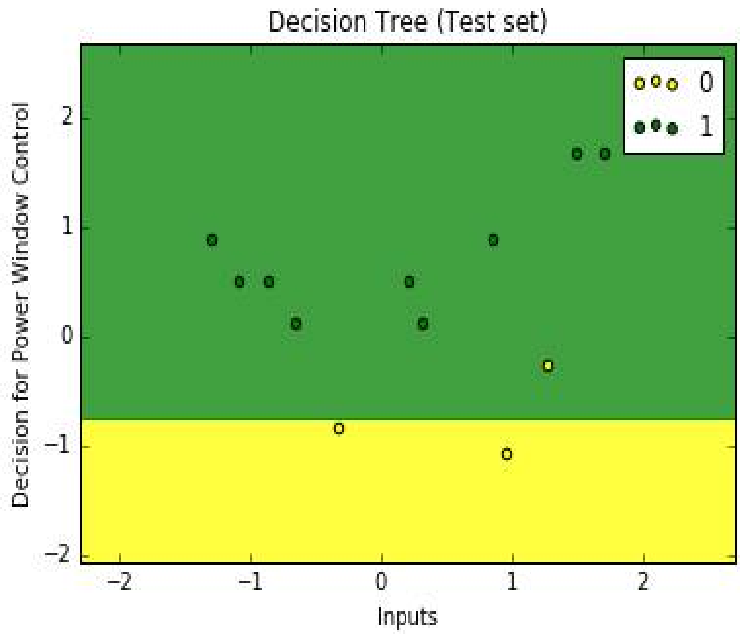

Figure 5-10 Illustrate Decision tree test set sample results

5. 3. 2 Training set Sample Result

During development of the decision tree algorithm which is further classified with the training set and test set. Decision tree algorithm happens with the formation of training set data and evaluation of system performance using the test set. Training set formation is achieved with help of torque acting on rotor shaft and current flowing in the load circuit which is represented in Table 5-1. Variation in stall torque and current flowing in the load circuit will decide during obstacle window will move upward direction or halt at that state itself with possible outcome as an output response. Observation table of current and torque value will decide appropriate action by power window. In DTC algorithm 75 percent of observation data is configured as a training set in this research.

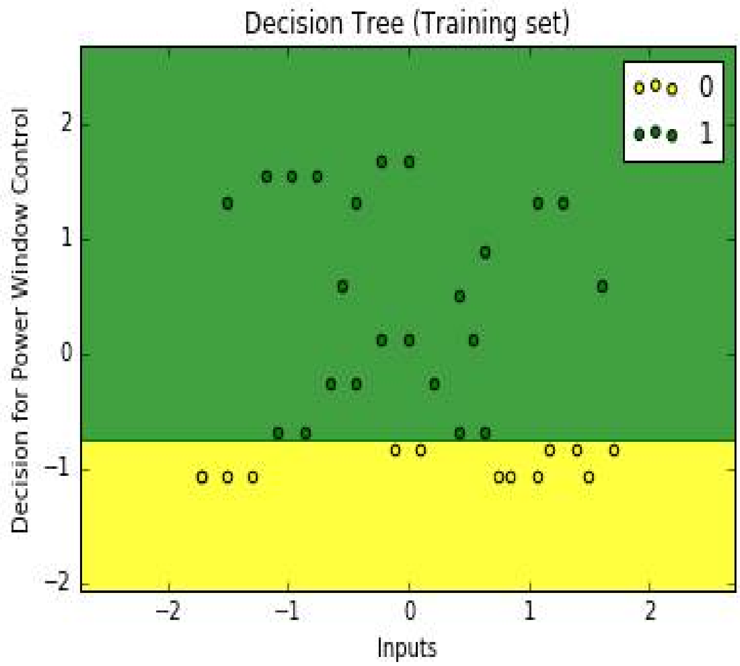

Figure 5-11 Illustrate Decision tree training set sample results

5. 4 Hardware in Loop

The power window system performance with DCT algorithm is evaluated through Hardware in loop testing through dSPACE ACE 1104 simulator. Different current and flexi force sensory data is listed in Table 5-1, the DTC algorithm with dSPACE system provides better decision capability of the power window system performance with less workload to the user either driver or passenger. Power window system controller is developed in MATLAB/Simulink software. After building error-free plant model in Simulink is converted into an .sdf file which uploads the file into the dSPACE ACE 1104 simulator. The experimental data acquisition is achieved through calling RTI library functions [105] provided by MATLAB and Simulink. The human-machine interface which is utilized for beginning and halting the program and which furthermore gives a way to understand the controller signals continuously. Figure 5-12 illustrates the voltage profile of power window system which consists of DC motor shows that the simulation result and HIL results match at all time except in the beginning and end of the cycle. Current Profile of Power window system with different load is shown in Figure 5-13.

5. 4. 1 Voltage Profile

Figure 5-12 displays the voltage profile of the simulation model and hardware in loop testing model which consists of PMDC motor and gear train electromechanical arrangement represents that, the simulation result and HIL results matches at all time except in the beginning and end of the cycle. In real time system beginning require an understanding of different electrical losses and mechanical losses (Frictional, damping etc.) which leads to a steady-state analysis. In one cycle simulation voltage and system hardware voltage remains same at all time and maintained a constant value of +12Vduring upward direction and -12V during downward direction.

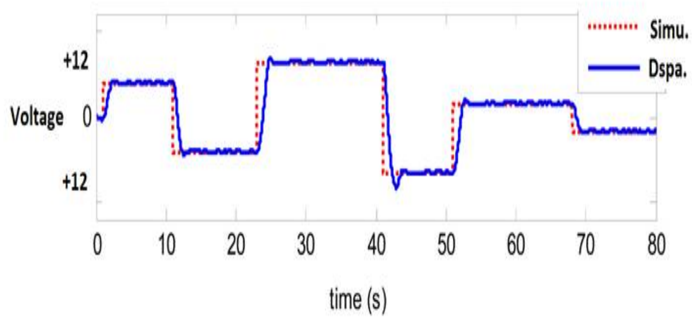

Figure 5-12 Illustrate Voltage Profile of Power window motor

5. 4. 2 Current Profile

Current profile is represented in Figure 5-13 which displays the instantaneous current profile of the simulation model and hardware in loop testing model which consists of PMDC motor and gear train electromechanical arrangement represents that, the simulation result and HIL results matches majority of the execution time when no additional load [106] is acting on the power window system. In real time system, different load and their response are captured lately compare with simulation model because the real-time system needs different electrical losses and mechanical losses (Frictional, damping etc.) which leads to a steady-state analysis. During upward movement maximum current is measured in the range of +15A and during downward movement maximum current is -10A but during normal operation, without load, it consumes 3-4A only.

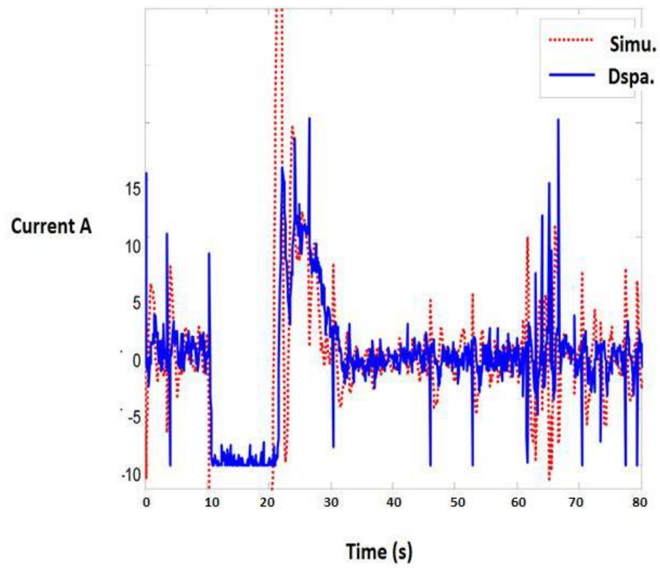

Figure 5-13 Illustrate Current Profile of Power window system with different load

5. 5 Experimental Setup

The experimental setup of automotive power window is shown in Figure 5-14. The setup consists of broadly divided into two areas one is simulation and control model and the second part is hardware component configuration. In the simulation, plant model of automotive power window system[107] is developed and it is tested during modeling itself on MATLAB/Simulink platform shown in Figure 4-3. In hardware model it is further divided into sensor and switch model, drive circuit, dSPACE simulator (ACE 1104) and Power window system illustrated in Figure 5-14.

For obstacle detection mechanism flexi force sensor and current sensor in load circuit are added. As per automotive power window guidelines obstacle detection mechanism[108, 109] works with a force less than 100N and it should be higher than 40N acting on the glass frame when the window is moving upward direction. From a mathematical fundamental, force (N) is proportional to mass (kg) and gravity (m/s^2).

$$F = mg$$

Where $m = Mass\_of\_system$ and $g = 9.81\frac{m}{s^2} = gravity$

By definition

$$Force = mg = 1N = 1kg\frac{m}{s^2}$$

$$40N = 40kg\frac{m}{s^2} = m \times 9.81 \times \frac{m}{s^2}$$

$$Mass = m = \frac{40}{9.81}Kg = 4.07Kg$$

Similarly, 100N force is applied to the system then 10.2 Kg of weight is required. So converting force into a mass of the system, the sensor must capture pinching weight from 4.07Kg to 10.2 Kg.

Figure 5-14 Experimental Setup of Power window

5. 5. 1 Results Comparison with Referred Works

The experimental data display the incremental improvement in comparison with referred research work. 2.88 Second time taken by the power window motor to move completely in upward direction at the same condition 2.62 seconds power window system requires to move from upward to downward direction. The assessment with the referred research [4] and [80] is presented in Table 5-2 and evaluation diagram is presented in Figure 5-15.

Table 5-2 Comparison of upward and downward time parameters

Parameters	Experimental Results	Ref. [4]	Ref.[80]
Time_ Upward	2.88 sec.	3.27 sec.	4.00 sec.
Time_ Downward	2.62 sec.	3.20 Sec.	4.00 sec.

The power window system is implemented on OPEL ASTRA model and upward time and downward time of power window glass frame are validated. Different travel time from lower position to higher position and vice versa is represented in Figure 5-15.

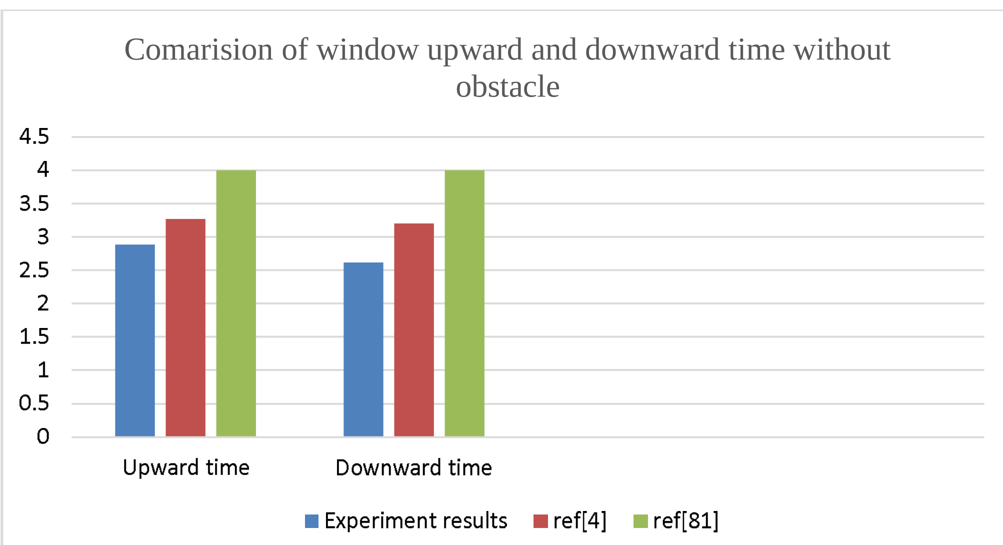

Figure 5-15 Comparison of upward and downward estimated time without obstacle

In the obstacle detection mechanism of automotive power window uses current sensor and flexi force sensor as obstacle detection mechanism which is simulated with Matlab/Simulink software and implemented with dSPACE ACE 1104 simulator kit. The main objective of obstacle detection mechanism is to identify presence or absence during upward movement of power window and prove appropriate action(10 centimeter below highest reference position) through control algorithm.[110].

The experimental setup exhibits following incremental improvement result in comparison with referred research and development work. During the obstacle identification condition the power window glass frame will start moving towards downward direction till 10 centimeter and time required to reach 10 centimeter is 1.3 seconds. However 2.62 seconds time taken to reach from extreme upward [111] position to extreme downward position. The incremental improvement in comparison with referred research work is illustrated in Table 5-3.

Table 5-3 Result comparison analysis

Parameters	Obstacle Detection/	Action Performed	Experimental result	Ref. [6]	Ref.[4]
Movement time (Upward)	Yes	10 Centimeter below to Maximum	1.3 S	3.27 S	4.00 S
Movement time (Downward)	No	Not Required	Not Required	3.20 S	4.00 S

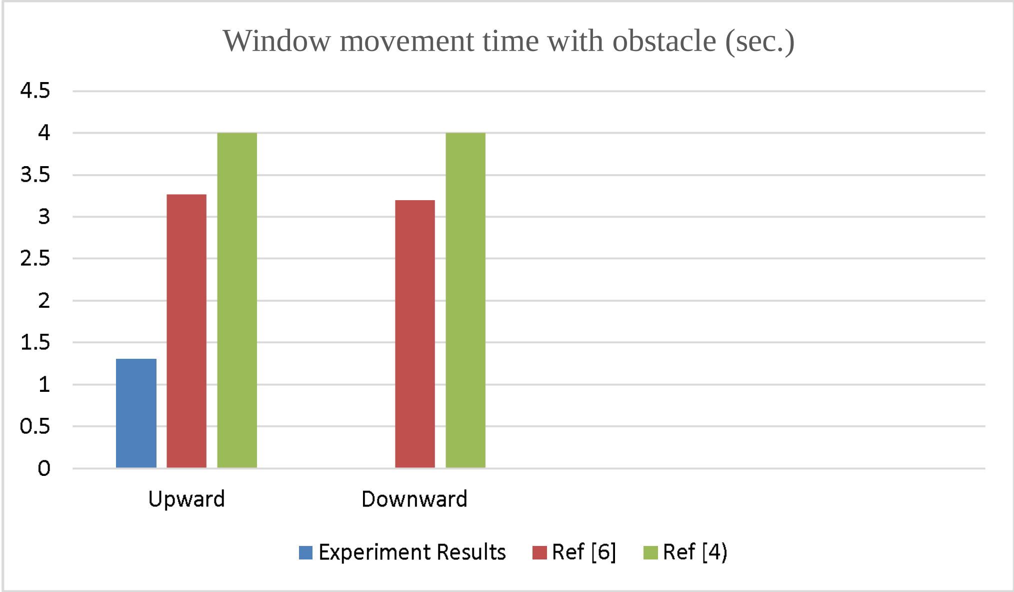

Figure 5-16 Comparison of downward estimated time with obstacle

The chapter concludes result and discussion of the automotive power window system. The above sub-section illustrates the result of current and flexi force calibration model, mathematical modeling of power window system, its software in loop testing, decision tree classifier algorithm for obstacle detection, hardware in loop testing and experimental setup analysis.