Modelling and Simulation of Object Detection in Automotive Power Window

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Abstract

The paper focuses on the system modelling of hardware based power window control system. In power window system, Direct Current (DC) motor served as the source of power to drive the power window frame and accordingly power window can be raised and lowered. In the paper, mathematical model of a DC motor controlled by an H bridge circuit and bridge is controlled through input switches which are available at driver and passenger door side. The main objective of power window control is to control the movement of glass door in upper and lower direction and this operation is controlled with the help of current sensor, fire sensor and position sensor in the replacement of manual control hand turned crank techniques for existing power windows. The driving component is DC motor that drives the power window using self-locking techniques for worm gear in the minimum ratio of 1:50 and output of worm gear goes to lead screw having pitch of 3mm to deliver linear movement to power window. The control unit of power window senses both high and low load obstructions. It is used to activate and deactivate the movement of the glass door in upward direction and downward direction with the help of DC motor, whenever, any hard and soft obstruction is detected. The automatic power window with intelligent control is designed and verified with several conditions that claim its movement in upward and downward direction. The simulation model is visualized in MATLAB/Simulink and performance is analysed with respect to current, voltage and speed measurement.

Keywords: DC Motor, Intelligent Window Control System., Mathematical Modelling, Power Window

1. Introduction

The power window system consists of motor that rotates in clockwise and counter clockwise direction and accordingly window is raised and lowered which is controlled by means of an array of switches. The window completes a drive circuit, when the switch is activated and sends the current to the motor to move the window up or down. Power window systems are used in automobiles and should meet the safety standards and security vehicular operation to prevent more fatal and injurious accidents like pet neck as well human body being trapped, that can lead to suffocation because of malfunction or usage error of the power window1,6. In some of the design of vehicle power window has the switch on a hand rest from where it can be triggered accidentally such as child can climb to place his or her head outside of the window. The driver controlled lockout system exists in some vehicles to overcome such problems. Such system protects the human and prevents rear seat passengers to meet accidents by the trigger mechanism of the switch6. The lifting mechanism is a device that
plays significant role in power window system. The process through which lifting windows in most cars happens due to a linkage to move the window glass in upward direction. The DC electric motor is associated with the worm gear having ratio of 1:50 and different other pinion gears to create a large gear reduction, after this it is connected with lead screw giving it appropriate torque to lift the power window. The main advantage of worm gears mechanism is that it has the self-locking advancement feature due to that it makes the angle of contact between the pinion gear and worm as shown in Figure 1. The control system is having driver up, driver down, passenger up, passenger down, temperature sensor and current sensor as input which are processed by the control system and power window dc motor is handling the load to adjust the mechanical movement in the automobiles

![Figure 1](image1.png)

Figure 1. The basic structure of power window control.

Power window electrical control system is of four types. They are classified as Relay driven DC motor, H-Bridge driven DC motor, Brush Less DC motor (BLDC) and Permanent Magnet Synchronous Motor (PMSM). The Advantages over different power window electrical control techniques are specified in Table 1.

![Table 1](image2.png)

Table 1. Advantages over different power window electrical control techniques

The paper is organized as follows: Section 1 represents introduction, section 2 presents system modelling with physical system design and MATLAB Simulink model to support the window section modelling and its automation. Section 3 presents the MATLAB simulation results and description to support the result outcome. In section 4, the conclusion is presented.

2. System Modelling

The model of the system is presented with the help of mathematical model.

2.1 Physical Modelling

A common actuator in power window control systems is the DC motor. It directly provides rotary motion and, coupled with worm gear and lead screw, can provide translational motion. The electric circuit of the armature and field are shown in the below Figure 2. The input to the physical model of power window system is the voltage applied to the motor's armature coil, while the output is the rotational movement of the shaft Revolutions Per Minute (RPM).

![Figure 2](image3.png)

Figure 2. Circuit of physical model of power window system.

In the dc motor, the magnetic flux is induced due to the inducing existing in the stator. The magnetic field generated by the coils is ‘B’. The rotor is rotated with respect to the stator. The supply given to the stator helps to rotate the rotor and can be vary with the increment in number of coils.

In the modelling it is assumed that single coil is used having inductance \( L_e \) and Resistance \( R_e \) because of dispersion in conductor. The voltage equation in the same circuit is given by equation 1.

\[
v_e(t) = L_e \frac{di}{dt} + R_e i_e
\]  

(1)

The Laplace domain representation of the equation 1 is given by equation 2.
\[ i_e(s) = \frac{k_s}{1 + \tau_s s} \quad (2) \]

Here, \( k_s = \frac{1}{R_s} \) is stator gain and \( \tau_s = \frac{L_s}{R_s} \) is stator time constant.

The stator is characterized with single coil having inductance \( L_a \) and resistance \( R_a \). When the back e.m.f of the motor is considered the equation of armature is given by equation 3.

\[ v_a(t) = L_a \frac{di}{dt} + R_a i_a + e \quad (3) \]

The Laplacian transform of the equation 3 is given by equation 4.

\[ \frac{i_a(s)}{v_a(s) - e(s)} = \frac{k_s}{1 + \tau_s s} \quad (4) \]

The Torque extracted by the motor is given as

\[ T_M = K_f f i_a \quad (5) \]

The EMF hold by the motor is given as

\[ e = K_f f \omega \quad (6) \]

The torque and back emf of armature winding is given

\[ T_M = KI_i i_a \quad (7) \]

\[ e = KI_\omega \omega \quad (8) \]

The motor experiences the torque when the voltage is supplied to the stator and on the rotor. The torque is applied on the mechanical structure of the system which depends on the viscous friction factor ‘F’ and rotor moment of inertia ‘J’. It has also been experienced that the load torque is analysed on the motor in each operational conditions of the motor. Equation 9 supports the same functionality.

\[ T_M - T_L = J \frac{d\omega}{dt} + F\omega \quad (9) \]

In the equation 9 \( T_L \) is load torque and \( T_M \) is motor torque The equation 9 in ‘s’ domain is presented by equation 10.

\[ \frac{\omega(s)}{T_M(s) - T_L(s)} = \frac{K_m}{1 + \tau_m s} \quad (10) \]

Here, \( K_m = \frac{1}{F} \) is the mechanical gain and \( \tau_m = \frac{J}{F} \) is the mechanical time constant.

### 2.2 Simulation Model

The simulation model presents the power window system based motor driven mechanism. The DC motor is driving the power window mechanism having self-locking worm gear with the ratio 1:50. The output of worm gear goes to lead screw having pitch of 3 mm to deliver linear movement to power window. The power window control mechanism and its model use the driving pulley i.e. DP, four supporting rollers RL1, RL2, RL3, and RL4, and two clamping glasses, GCL1 and GCL2. The clamping glasses are attached to the power windows which have the movement to lift the window in up direction. The clamping glasses GC1 and GC2 are also attached with the rope in such manner that both clamps GC1 and GC2 can move forward following the same velocity. It helps the window to keep window level in the straight. MATLAB Simulink platform provides the pulley driving simulation with the help of Rope Drum block. Moreover, in the same way the supporting rollers are modelled using the blocks relating to Belt Drive Pulley. The specification and description of power window controller using Simulink is listed in Table 2. The controller must determine the power window movement on the basis of different input values and specified system requirements. The up and down movement of the power window is done through controller and depends on driver up and down switch, passenger up and down switch, motor armature current and temperature sensor. The driver up and down switch and passenger up and down switch is digital switch whereas motor armature current and temperature sensor are analog sensors. According to these data controller determine whether the power window will move upward and downward accordingly.

| S.No | Parameters                     | Value            |
|------|--------------------------------|------------------|
| 1.   | Rotor moment of inertia        | 3.228E-6 kg.m²   |
| 2.   | Viscous friction constant of motor | 3.5077E-6 Nms |
| 3.   | Forcing constant (EMF)         | 0.0274 V/rad/sec |
| 4.   | Torque constant of DC Motor    | 0.0274 Nm/Amp    |
| 5.   | Value of resistance            | 4 ohm            |
| 6.   | Value of inductance            | 2.75E-6H         |
| 7.   | Rotor Damping                  | 1e-06            |
**2.3 Controller Design**

The section provides information to the switch based controller implemented in MATLAB Simulink. The controller structure is considered based on the control inputs shown in Figure 1. In controller, according to following inputs motor forward and reverse movement is achieved.

1\(^{st}\) Input: Driver power window switch pressed Upward.
2\(^{nd}\) Input: Driver power window switch pressed Downward.
3\(^{rd}\) Input: Passenger power window switch pressed Upward.
4\(^{th}\) Input: Passenger power window switch pressed Downward.
5\(^{th}\) Input: Temperature input.
6\(^{th}\) Input: Current sensor.

According to above inputs controller decides whether the power window will move in upward direction or downward direction or will not move.

**2.3.1 Obstacle Detection Design**

In this power window model, the system continuously monitors the load on the motor shaft to detect presence of obstacle. When the power window recognizes an obstacle, the applied load force on the power window shaft increases the load on the motor and consequently rises in armature current. With increase in armature current in power window motor with appropriate current sensor in series with DC motor detects obstacle in the power window path.

**3. Results and Discussions**

The impact of current, voltage and motor speed of the power window system simulation model is below with the help of Figure 5, 6 and 7 respectively.

**3.1 Current Measurement**

![Figure 4. Simulation of current versus time (t) of power window.](image)
3.2 Voltage Measurement

![Figure 5. Simulation of voltage versus time (t) of power window.]

3.3 Speed (RPM) Measurement

![Figure 6. Simulation of motor speed (RPM) of motor versus time (t) of power window.]

It is clear from the simulation model shown in Figure 4, that the window is moving upward and downward with object detection. In the simulation waveform the upward and downward currents are 5.7 Amp and -4.8 amp respectively. The simulation result in Figure 5 shows that the voltage is varying form -12 V to +12 V which is constant for the entire duration. The simulation result in Figure 6 shows that the motor speed 1550 RPM in upward motion and 2550 in downward motion. Current, voltage and RPM of the motor have significant impact. It is because of power window control algorithm incorporated with the physical model especially if the results are observed using conventional power window stop mechanism like Hall sensor method or angular velocity method. The performances of the current sensor based power window system have better performance. The power window DC motor current gradually rises to significant threshold value and the power window automatically went downward with an optimal distance, when power window touches the obstacle.

4. Conclusions

In the research article, the modelling and simulation of automotive power window system using MATLAB Simulink tool. In the power window systems model, electrical and mechanical system clubbed together and simulation model were developed and using torque coupled sub models to connect two different simulation models, those elements composed of a mix of electrical, electronic and mechanical system model. The simulation model presented in the research paper is a MATLAB/Simulink based system that enhances the safety and comfort with respect to power window. The automobile vehicles are enhancing day by day and Engine Control Unit (ECUs) is one the major part of automobile. The proposed automatic window will be great extent solution to the automobile industries to enhance its efficiency and faster response time armature current sensor and temperature sensors. The hardware implementation of the simulated model definitely will increase the safety of the system. Further the research can be carried out to implement the same system in harsh conditions including electromagnetic interference, different types of noises, and compatibility. In appropriate estimations of the DC motor, holding torque effect and frictional effect must be included in the simulation model.

5. Conflicts of Interests

The authors declare that no conflicts of interest are existing regarding the publication of this research paper.

6. References

1. Park JH, Choi GH, Yoon TS Park JB. A Sensorless Safety Power Window Control System in Automotive Application. International Conference on Control, Automation and Systems,COEX, Seoul, Korea. 2008. P.1457–61.
2. Liu Xiaoming, Shao Yahui, Wu Haowei, Zhong Yuanhong. Design of Car Window Anti-trapping Without Sensor. Micromotors Servo Technique. 2007;(4):48–9.
3. Luca Zaccarin. DC motors: Dynamic Model and Control Techniques. Lecture given – 2012.
4. Ehsani M, Rahman M,Toliyat H. Propulsion System Design of Electric and Hybrid Vehicles. IEEE Transactions on Industrial Electronics. 1997 Feb; 44(1).
5. Kumar R, Krogh BH. Heterogeneous Verification of Embedded Control Systems. Proceedings of the 2006 American Control Conference Minneapolis, Minnesota, USA. 2006 June 14-16. p. 4597–62.

6. Kumar R, Kumar A. Design and hardware development of power window control mechanism using microcontroller. International Conference on Signal Processing and Communication. IEEE Xplorer, pp(361–365)

7. Karris ST. Introduction to Simulink with Engineering Applications. Orchard Publications, united states publication 2006.

8. Tiwari T, Shah A, Nainwad CS. Design and development of high power window for linear accelerator at 2.856 GHz3rd IEEE International Vacuum Electronics Conference(IVEC). 2002. P.377–8.

9. Wang Yi, Qiu Yunfeng, Yin Jie. Application of automobile power window controller for peripheral interface controller. International Conference on Electronic Measurement and Instruments (ICEMI), IEEE; Aug 2011.2, p.363–7.

10. Prawoto Y, Yusof MA. Automotive power window Mechanism failure initiated by overload. Engineering Failure Analysis.2013 July; 179–88.