

## Design and Prototyping of Powered Sliding Door for Light Commercial Vehicles

Uğur Demir<sup>1\*</sup>

0000-0001-7557-3637

<sup>1</sup> *Mechatronics Engineering Department, Faculty of Technology, Marmara University, Istanbul, 34710, Turkey*

### Abstract

This study presents the powered sliding door (PSLD) design and prototype for light commercial vehicles. First of all, the literature and patent research are done. And the state of the art for sliding door mechanism types and electronic control methods are investigated. Then, the requirements, specifications and regulations of original equipment manufacturers (OEMs) are dealt with and design requirements and criteria are determined. The performance requirements of the electric motor for the sliding door main unit are calculated according to the design criteria and the vehicle door. The main unit is designed to actuate the sliding door as per the design criteria by defining the electric motor. The vehicle door must be unlocked before opening or closing the door. Unlocking actuator is developed for this process. Subsequently, the electronic control unit (DCU) is designed to control the components and actuators. In order to solve the problem frequently encountered in obstacle detection when the vehicle is on a slope, the current limits are updated according to the current information read from the electric motor and the vehicle slope information, and the obstacle detection is tried to be performed. Finally, testing and verification studies are performed according to the design requirements.

Keywords: Powered sliding door; automotive actuators; obstacle detection; product development process

### Research Article

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\* Corresponding author

Uğur Demir

[udemir@marmara.edu.tr](mailto:udemir@marmara.edu.tr)

Address: Mechatronics Engineering Department, Faculty of Technology, Marmara University, Istanbul, 34710, Turkey

Tel:+ 905344787370

### 1. Introduction

Due to user demands and ease of use, the most used door types are conventional (mechanisms that allow movement to the outside or inside by rotating around an angle with a hinge) and sliding doors. Today's technological developments create the need for electrically controlled sliding door systems especially in light and heavy commercial vehicles for service purposes [1]. A view of a sliding door for light commercial vehicles is shown in Figure 1.



Fig. 1. The powered sliding door of light commercial vehicles

Generally, a powered sliding door system includes the door, power drive system, lock mechanism, and a single motor that operates both the lock and the power drive mechanism. The power drive system is connected with the door and works to move the door in open and closed positions along with the slide. The lock

mechanism is located on the door and can move between locked and open positions. A single motor on the door is connected by the power drive system and the locking mechanism. The power drive system, thereby moving the sliding door along with the slide in open and closed positions. The motor ensures that the lock mechanism is in the locked position when the power drive system moves the sliding door to the closed position [2].

The literature and patent studies conducted in this context are summarized as follows.

Labonde and Menke designed a system that uses a stranded cable to keep the vehicle door closed, with the spring winding connected between the body and the drum, allowing the drum to rotate the cable around itself and move the door to the closed position [3]. Kleefeldt et al. designed an electric sliding door system with electronically controlled actuators [4]. Kleefeldt et al. studied the design of an electric sliding door with a belt system for a sliding door with a slide mechanism [5]. Menke developed a design for powered sliding doors by using a cable drive system [6]. Faubert et al. worked on an electronically controlled sliding door mechanism for manually operated sliding door systems [7]. Naganuma developed a system that detects malfunctions by designing a driver circuit and a controller to control the sliding door of a vehicle [8]. Oxley worked on a pinion gear and a belt mechanism that transfers power from the motor to the pinion gear so that a rock door can be opened

and closed [9]. Osmura et al. studied that the experimental and simulation results between the current and the ideal door create the same feeling by the proposed controller both feedforward and feedback according to the virtual movements of an ideal door, which creates a sense of comfort for automotive sliding doors [10]. Oberheide studied the electronic controller that starts the engine with the feedback signal generated by the sensors to overcome the back driving force of the motor and the belt friction force generated during the manual movement of the door [11]. Oxley has developed a cable drive transmission mechanism to transmit engine power that can be electronically controlled in a sliding door system [12]. Franc et al. worked on automatic sliding door control software on sensitive door movement, adaptive control, and detection of door hardware capacity (motor power) [13]. Oladunmoye et al. observed that the operating behavior of automatic sliding door systems using an infrared sensor [14]. Nishida et al. worked on an intelligent door system. This door system detects people nearby and opens and closes the door with the appropriate opening and closing time [15]. Chomo et al. designed and developed the low-cost automatic sliding door system with the appropriate sensor, electric motor and raw material [16]. Mutlu et al. worked on a generic automatic sliding door mechanism with a rope mechanism that can fit all vehicle types [17].

## 2. PSLD (Powered sliding door) Configurations

According to the literature and patent research on the electrical sliding door system, 3 types of power transmission are used in this type of system. The power transmission types are shown in Figure 2. These transmission types are rack-pinion gear systems, pulley-rope systems and pulley-belt systems. Besides, it has been observed that these systems are packaged in 2 types of the power transmission mechanism, hidden and open. The package types are shown in Figure 3.

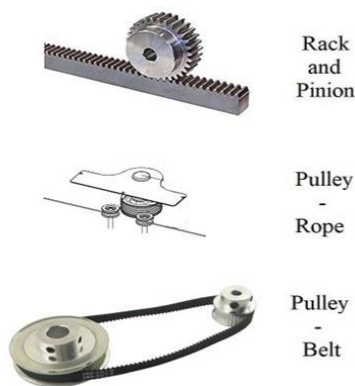


Fig. 2. The power transmission types of the powered sliding door

The companies (Veldo, Ikomat, Revar, Engin oto, etc.) that produce PSLD systems and solutions in our country produce in a quality that can only provide the opening and closing function, which is the most basic function of a sliding door. These companies offer an after-sales service rather than meeting the demands of the OEMs (Original Equipment Manufacturer). Similarly, traction

mechanism, gear reduction, motor power, control algorithms and the materials of the components that make up the system will be examined in benchmark studies planned to be made for the products of companies providing after-sales services.



Fig. 3. The package types of the powered sliding

The products of PSLD producers abroad (Kiekert, Vitte, Magna Closures etc.) were examined in terms of electronic control units, control algorithms, obstacle recognition systems and sensors. For the PSLD system in foreign competitors, it has been observed that products that meet the minimum and maximum limits are developed by taking customer specifications and the requirements in international standards into account. However, an obstacle recognition system with combined information from current and inclination sensors has not been encountered. In this study, an algorithm is developed to prevent getting stuck and accidents due to the missing calculations depending on the vehicle inclination.

## 3. Design Requirements and Constraints

The regulations and specifications used in some OEMs for the electric sliding door are summarized in Table 1. Where, requirements such as security functions, door mechanisms, general construction, audible signals, warning notifications, electromagnetic interference are included briefly.

Generally, the PSLD system can operate at 17% slope at temperatures between  $-40^{\circ}\text{C}$  and  $+82 / 85^{\circ}\text{C}$ , the electronic control unit can operate between 9.5 V and 16 V, an average lifetime should be of 45000 cycles of opening / closing or 7 years 500000 km, the operation should be 95% error-free, the sound noise generated during operation does not exceed 25 sones, the maximum force applied by PSLD mechanism in operation should be 300 N, the total product weight should not exceed 8 kg, the assembly tolerances  $\pm 0.2$  mm, an alarm should be with a sound of 69 dBA during door opening and closing, it should be ability to withstand corrosion with a coating of up to 36 months for metal parts, it should be ability to complete the salt test for at least 144 hours, the sealing requirements are limited to IP54, the power consumption must not exceed the 15 amps, it should operate 5 periods with +18 V supply above  $+85^{\circ}\text{C}$  and 1 period with +24 V when below  $+25^{\circ}\text{C}$ .

Table 1. OEMs verification requirements of PSLD.

Code	Requirement Title
ISO 26262	Automotive Safety Integrity Level
ECE R11	Uniform provisions concerning the approval of vehicles with regard to door latches and door retention components
ECE R21	Uniform provisions concerning the approval of vehicles with regard to their interior fittings
ECE R29	Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants of the cab of a commercial vehicle
ECE R107	Category M2 or M3 vehicles with regard to their general construction
ECE R10	Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility
ECE R28	Uniform provisions concerning the approval of audible warning devices and of motor vehicles with regard to their audible signals
ECE R118	Uniform technical prescriptions concerning the burning behavior and/or the capability to repel fuel or lubricant of materials used in the construction of certain categories of motor vehicles
ECE R52	Uniform provisions concerning the approval of M2 and M3 small capacity vehicles with regard to their general construction
EC 661/2009	Requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor
2001/85 EC Annex V	Guidelines for measuring the closing forces of power-operated doors
70/388/EEC	Audible warning devices for motor vehicles
70/387/EEC	Doors of motor vehicles and their trailers
74/60/EEC	Interior fittings of motor vehicles
2001/85/EC	Special provisions for vehicles used for the carriage of passengers comprising more than eight seats in addition to the driver's seat
2004-104/EC	Radio interference (electromagnetic compatibility) of vehicles

Table 2. Design requirements and criteria of PSLD.

Success Criteria	Desired Requirements
PSLD can open and close the door when the vehicle is on a slope	17% Slope
Providing the function of the PSLD above or below certain battery voltages	Correct operation capability between 9.5 V and 16 V and current consumption should not exceed 15 Amps
During the opening / closing of the PSLD, it does not make a noise above a certain value.	Must not exceed 25 Sones
Limiting the maximum force to be applied during the process and not exceeding the total product weight	Must not exceed 300 N and 8 kg
Maximum door speed	Must not exceed 0.25 m/sec

In this study, the design requirements and success criteria of the PSLD are summarized in Table 2.

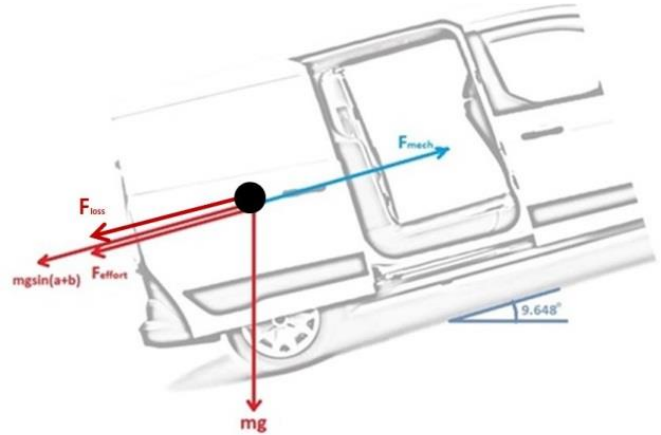


Fig.4. The forces acting on a sliding door

## 4. Design of PSLD

### 4.1 The Design of Main Drive Unit of PSLD

Basically, the forces acting on a sliding door are shown in Figure 4. These forces are the inclination of the vehicle ( $m.g.\sin(a+b)$ ), the friction force ( $F_{effort}$ ) and the mechanical losses ( $F_{loss}$ ). Eq.1 gives the formula for the force needed to move the sliding door.

$$m \cdot a_{door\_acceleration} = F_{mech} - mgsin(a + b) - F_{effort} - F_{loss} \quad (1)$$

In this study, the rack and pinion gear structure, which stands out with its ease of use, cost and safety features, was used. In this direction, when the formulas from Eq. 1. and vehicle properties are taken into consideration, the force requirement calculations are shown in Table 3.

Table 3. The required force calculations of the PSLD.

Door mass of the vehicle	50 kg
Slide slope	1 degree
Acceleration Range	From 0.3m/s <sup>2</sup> to 0.62m/s <sup>2</sup>
Maximum vehicle slope	17 %
The friction force	20 N
The mechanical loss	20 N
The inclination force	90 N
The minimum required force	40 N
The maximum required force	130 N

The KORMAS 12V (671 190 57) electric motor is used in this study, as it meets the automotive standards and is compatible with the desired operating voltages. The torque-current-power-speed characteristic of the electric motor used is shown in Figure 5.

According to the data of Table 2, Table 3 and Figure 5, the required diameter of pinion gear so as to transmit appropriate mechanical power is calculated in Table 4 which shows the door speed, motor power, motor speed, motor torque and radius of the pinion gear.



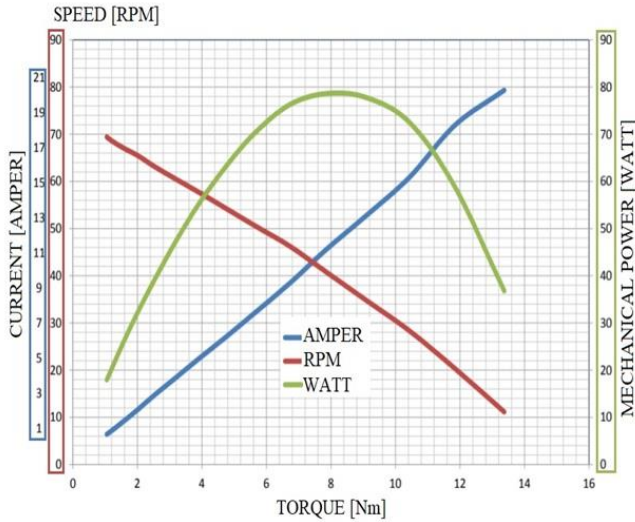


Fig.5. The torque-current-power-speed characteristics of the KORMAS 12V (671 190 57) electric motor

Table 4. The calculated pinion gear geometry of PSLD

Door speed	0,249 m/s
Motor power	32 Watt
Motor speed	36,7 RPM
Motor torque	8,26 Nm
Radius of pinion gear	0,065 m
Transmitted force	130 N

taken into account that the door can be opened from inside and outside in case of emergency, which is one of the special customer requests. In this context, the emergency exit handle rack and pinion gear system, an electromechanical actuator to open the door lock and an electronic control unit were considered. Figure 6 shows components of the PSLD. And Figure 7 and Figure 8 shows the assembly on the vehicle.

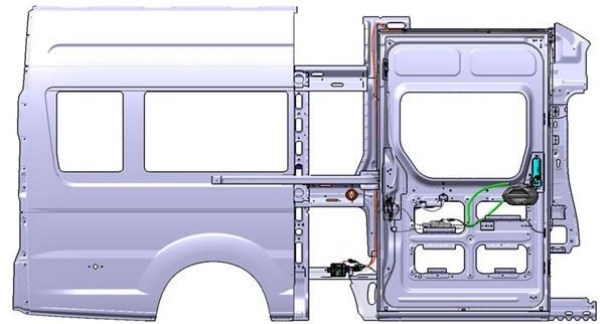


Fig.7. The outside view of assembly of designed PSLD

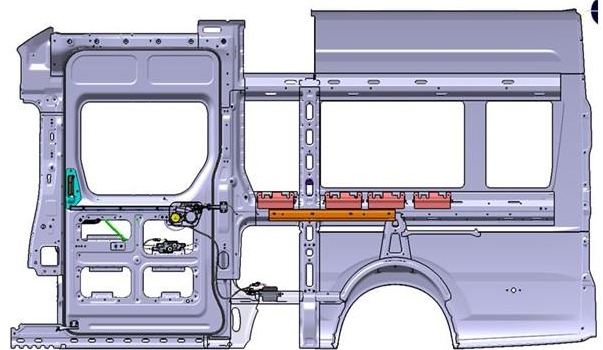


Fig.8. The inside view of assembly of designed PSLD

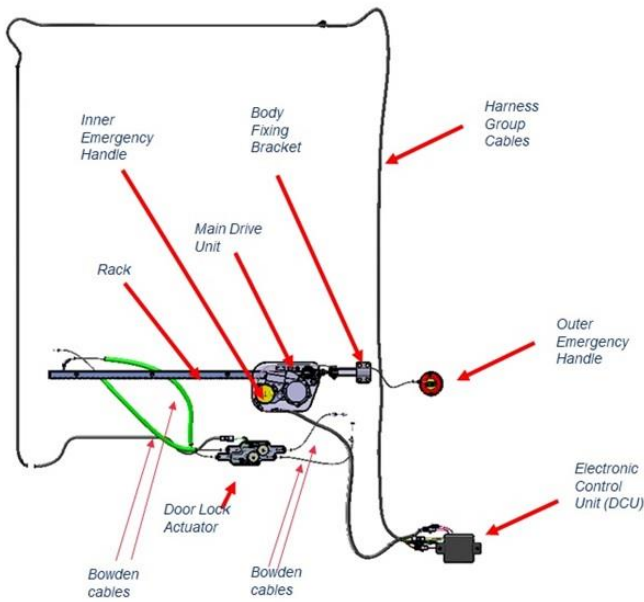


Fig.6. The designed components of the PSLD

The main drive unit shown in Figure 6 consists of the electric motor that enables the door to open and close, the crank handle that allows the rack and pinion system to release in case of emergency, a micro switch indicating that the rack and pinion gear system is engaged or disengaged, a position sensor that detects the information that the door is open, with a fixing bracket and a universal joint. Figure 9-11 show the detailed views of the main drive unit.

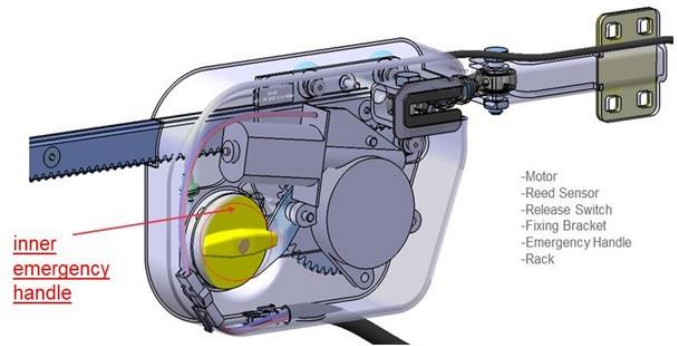


Fig.9. The view of main drive unit of designed PSLD

After the calculation of the pinion gear and the selection of the electric motor, a design study was carried out on the door. Here, it is also

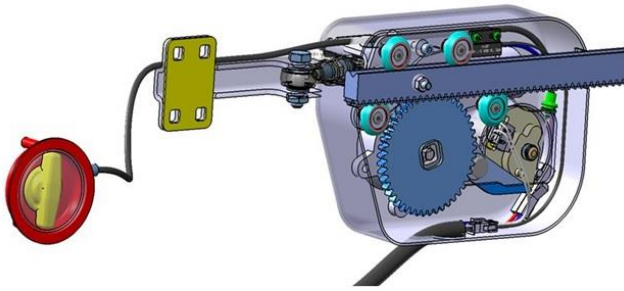


Fig.10. The detailed view 1 of main drive unit of designed PSLD

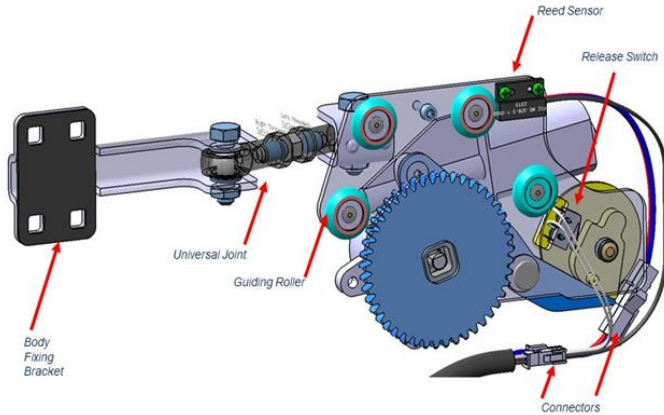


Fig.11. The detailed view 2 of main drive unit of designed PSLD

In order to meet the noise criterion, by using the guidance roller system, mechanical noise is prevented, and the results obtained in the previous tests are 4 Sones (Approx.. 48 dB) and it meets the success criteria.

#### 4.2 The Design of Door Lock Actuator Unit of PSLD

In this part, the door must be unlocked before the door opening operation starts. It needs an actuator which can provide this process. In addition, a design is developed to enable a parallel actuator and sliding door to operate in order to open by the inner door handle, in line with the customer's special request. Detailed visuals of this design are shown in Figure 12 and Figure 13.

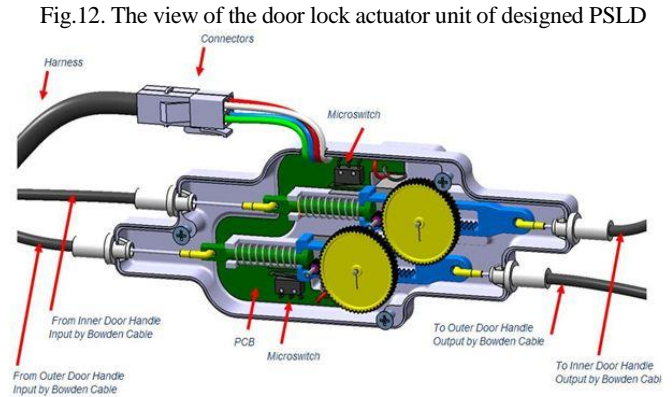
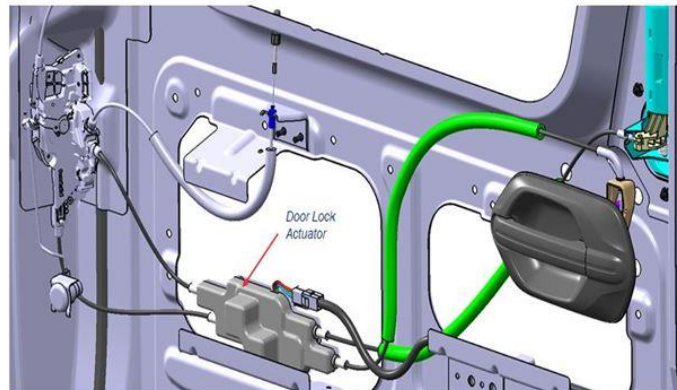


Fig.13. The detailed view of the door lock actuator unit of designed PSLD

As can be seen in Figure 13, the actuator consists of 2 electric motors with parallel mechanism, 2 gear system, 2 helical springs to take the first position of the system, 2 microswitches to read the status information of the lock, 2 bowden cables as inputs and outputs to move the lock.

The force required to open the door lock is 15 N. The system is designed according to the relevant requirements of JLR [18-20]. The electric motors used in the system are Mabuchi FC280SC. Typically the motor used in door actuators is preferred and compatible with automotive requirements.

#### 4.3 The Design of Electronic Control Unit of PSLD

DCU (Electronic Control Unit) creates and obtains signals to provide communication between the drive unit and door actuator. It also controls the current values of units in order to control transmitted forces and door speed etc. DCU has real time operating system. DCU controls the main drive motor by depending on battery voltage and motor current consumption so that DCU provides both safety actuation and exact time control. Figure 14 and Figure 15 show the detailed views of DCU.

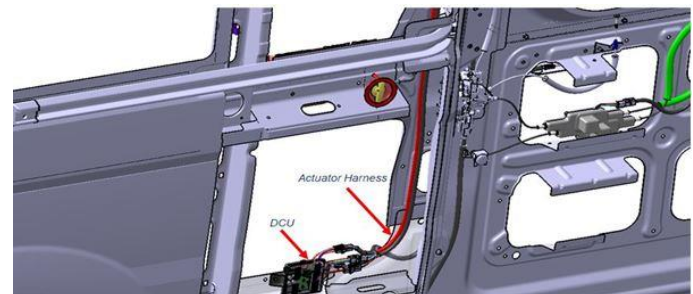
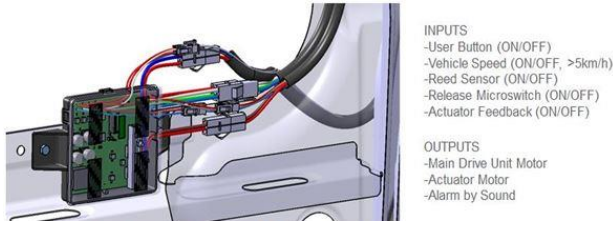


Fig.14. The view of the DCU of designed PSLD





**INPUTS**  
 -User Button (ON/OFF)  
 -Vehicle Speed (ON/OFF, >5km/h)  
 -Reed Sensor (ON/OFF)  
 -Release Microswitch (ON/OFF)  
 -Actuator Feedback (ON/OFF)

**OUTPUTS**  
 -Main Drive Unit Motor  
 -Actuator Motor  
 -Alarm by Sound

Fig.15. The detailed view of the DCU of designed PSLD

DCU reads user buttons, vehicle speed, reed sensor, inclination sensor, release microswitch and actuator feedback as inputs. Then, DCU controls the main drive motor, actuator motors and alarm by sound as outputs. DCU block diagram and PCB (Printed Circuit Board) design are shown in Figure 16 and Figure 16, respectively.

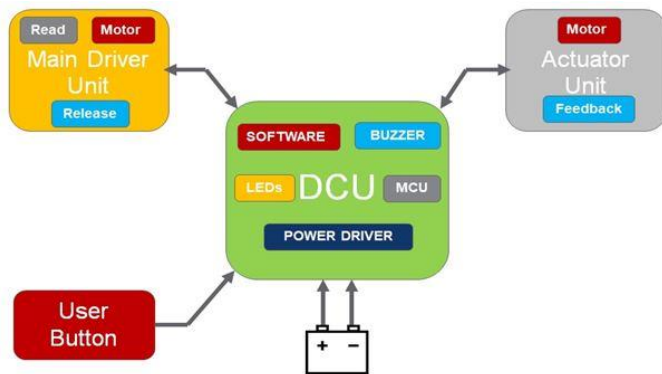


Fig.16. The DCU block diagram

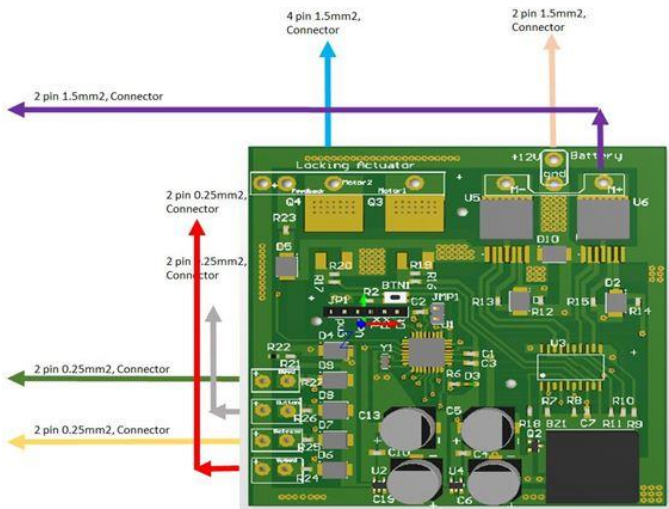


Fig.17. The PCB design of DCU

The nominal operating voltage for the main unit motor used here is 12 Volts. The desired operating conditions are between 9.5 Volts and 16 Volts, and the motor can provide the desired output torque and speed under these operating conditions. Due to the regulator used on the PCB, the microcontroller is designed to work stably without being

affected by voltage fluctuations. In addition, the current drawn by the motor is used as feedback and the torque control of the motor limits the 300N force and the maximum current value does not exceed 15 Amps, provided by the microcontroller on the PCB. However, during the opening and closing of the door, passengers and the driver must be warned by an alarm. The alarm intensity is expected to be at a minimum level of 69dB. This requirement is met by the piezzo buzzer (12 V, 83 dB, 4.0 kHz).

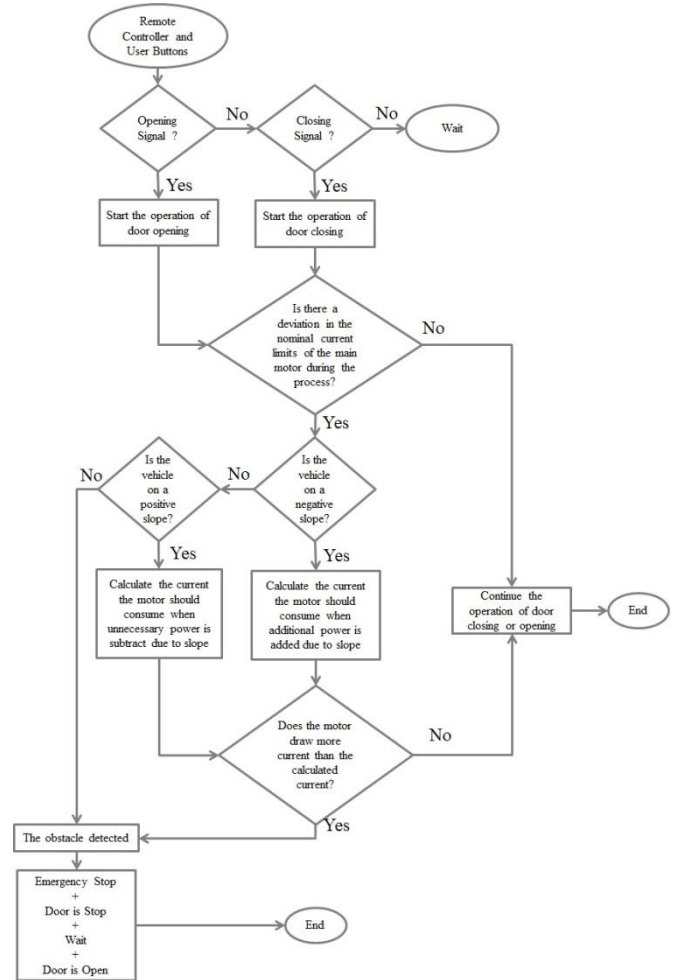


Fig.18. The flow chart of control algorithm

#### 4.4 The Design of Control Algorithm of PSLD

Here, the details of the algorithm running on the electronic control unit are given. First of all, the opening or closing command detected by the user buttons or the remote control is processed. It is determined that the received signal is an opening or closing command. Then, the opening or closing operation of the door is started. During the opening or closing operation, the current from the main unit motor is read continuously and it is checked whether it is within the limit values. Whether there is an obstacle between the door is checked depending on whether the vehicle is on the slope and the amount of current drawn, and if necessary, the door opening or closing process is

stopped. The flow chart including the working algorithm of the electronic control unit is shown in Figure 18.

### 5. Prototyping Studies

In this section, the prototyping studies of the product are carried out. Figure 19 shows electrical wiring cables, rack, electronic control unit and its covers, out of body emergency valve and its bowden cable, main unit cover, programming and debugging tools, user buttons, actuator and its mechanical parts (bowden cable, links), main unit. Where, most materials part are chosen by off shelves. The rest of parts are produced by machining and 3D printing. The total weight of the designed PSLD is 6.4kg.



Fig.19. The prototyping view of designed PSLD

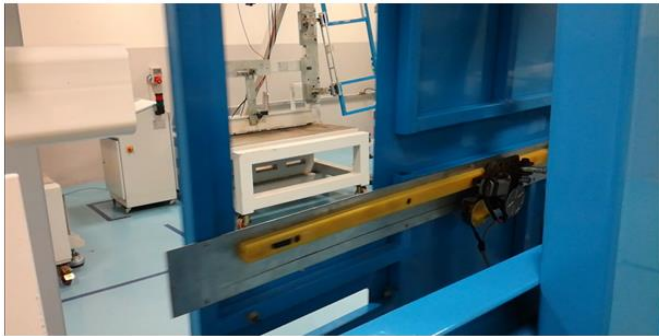


Fig.20. The designed PSLD on the test bench

### 6. Test Results

The verification criteria for the prototype of the PSLD are checked on the test bench. Figure 20 shows the PSLD mounted on the test bench. The opening and closing tests of the door are carried out considering the nominal voltage (12V), operating voltage range (9.5V-16V), and the criteria for the vehicle to be on slope. Besides, the algorithm of obstacle detection is tested in here.

Figure 21 shows no slope test at the nominal voltage (12V). As can be understood in Figure 21, all criteria in Table 2 regarding the maximum current, maximum applied torque, and door speed are met.

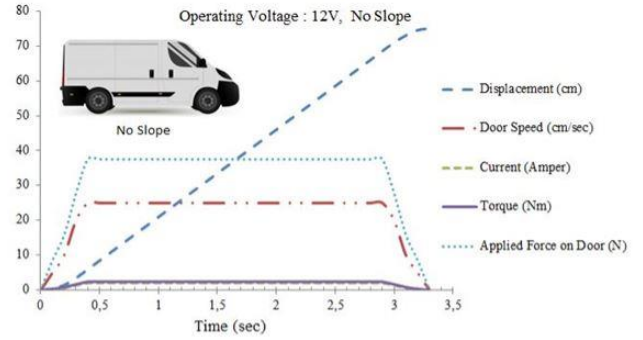


Fig.21. The opening operation test of PSLD (No slope, nominal voltage)

Similarly, Figure 22 shows the slope test at the nominal voltage (12V). Same as here, it is observed that all criteria in Table 2 regarding to the maximum current, maximum applied torque, and door speed are met.

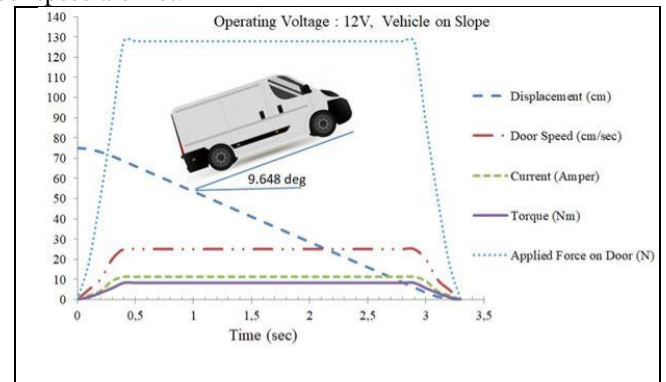


Fig.22. The closing operation test of PSLD (17% slope, nominal voltage)

On the other hand, the low voltage operating test at 9.5V is performed. The obtained results are shown in Figure 23 shows reduction of the door speed in comparison with the nominal voltage test. The total duration of the opening operation of the door is reached to 4.5 seconds by increasing by 1.2 seconds.

The high voltage operating test at 16V is realized. Due to the PWM controller on DCU for the main drive electric motor, the DCU regulates and reduces the voltage on the input of electric motor. Therefore, there is no any change in the operation characteristics of PSLD, the results are shown in Figure 24.

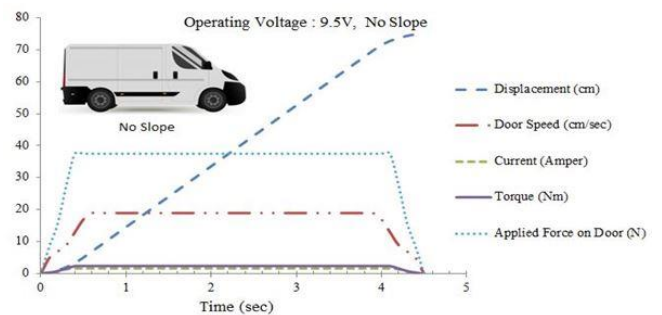


Fig.23. The opening operation test of PSLD (No slope, 9.5V)

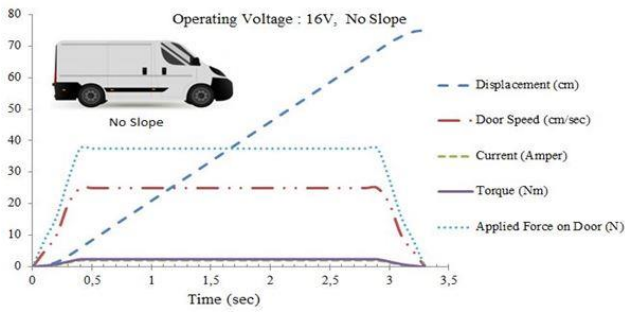


Fig.24. The opening operation test of PSLD (No slope, 16V)

The obstacle detection process is carried out to prevent passengers from getting stuck in the door and accidents while getting on or off the vehicle. In this study, this test is carried out by taking into account the current drawn over the main unit and the additional forces arising from the vehicle slope during the closing of the door by keeping a passenger on the test bench at the part where the door is opened. Figure 25 shows the operation of a standing passenger and PSLD on the test bench. On the other hand, the obtained data during this test are shown in Figure 26. As can be understood from Figure 26, when the current drawn by the main unit motor is 15 Amp., the force applied by the door is 170 N and the electronic control unit first stops the closing process and then starts the opening of the door. It is observed that the door in the design requirements meets the maximum current (15 Amp.) criteria with the criterion that it should not exceed the maximum 300N.



Fig.25. The obstacle detection on the test bench

**7. Conclusions**

In this study, a PSLD system design and its prototype are realized. Firstly, the main unit of the PSLD is designed by determined the design criteria and constraints. Secondly, the door lock actuator is developed, and then the electronic control unit design and algorithm are developed. Finally, compliance with the design criteria is tested.

The PSLD prototype meets the design requirements such as audible noise, operation alarm and prototype weight. The properties of PSLD prototype and design requirements are shown in Table 5. Where it is observed that all values are in the limit given in Table 2.

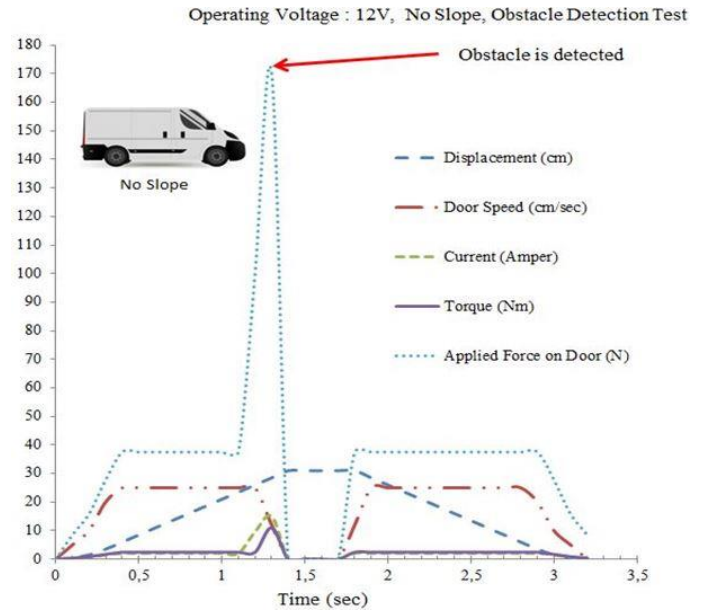


Fig.26. The results of the obstacle detection

Table 5. The properties of PSLD prototype

	Prototype Status	Criteria
Noise (Squeak & Rattle)	4 Sones (Approx. 48dB)	Not to exceed 25 Sones
Operation Alarm	Up to 83dB	Minimum 69dB
Prototype Weight	6.4kg	Maximum 8kg

The PSLD prototype is tested in accordance with the design criteria. These tests are the opening test at nominal voltage, the sliding door closing test when the vehicle on the slope, the door opening tests under the minimum and maximum operating voltage and finally the obstacle detection tests. The test results are summarized in Table 6.

As can be seen from Table 5 and Table 6, the obtained results meet the design requirements given in Table 2. The selection of the electric motor used in the main unit plays an important role in meeting the success criteria. And it provides the system to work with approximately 1.76 safety factor. In the low operating voltage (9.5V) test given in Table 5, the door speed decreased by 24%, and leading to a delay for the closing of the door for 1.2 seconds. This situation is not considered as a problem and the test is confirmed as the main function of the door is provided.

In addition, it was observed that the obstacle detection process works successfully by using the vehicle inclination sensor and motor current information. Therefore, a product development study is carried out in which functional safety is ensured by preventing errors that are frequently encountered in obstacle detection processes.



Table 6. Test results of PSLD prototype

Verification Tests	Max. Door Speed (m/sec)	Average Current (Amp)	Max. Current (Amp)	Average Applied Force on Door (N)	Max. Applied Force on Door (N)
The opening operation test of PSLD (No slope, nominal voltage)	0,25	2,1	2,1	37,5	37,5
The closing operation test of PSLD (17% slope, nominal voltage)	0,25	11,3	11,3	127,8	127,8
The opening operation test of PSLD (No slope, 9.5V)	0,19	1,7	1,7	37,5	37,5
The opening operation test of PSLD (No slope, 16V)	0,25	2,1	2,1	37,5	37,5
The Obstacle detection test	0,25	2,1	15	37,5	170

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## Nomenclature

- $F_{mech}$  : the required force to open or close the door (N)  
 $F_{effort}$  : friction force (N)  
 $F_{loss}$  : mechanical losses force (N)  
 $m$  : door mass of vehicle (kg)  
 $g$  : gravity (m/sec<sup>2</sup>)  
 $a$  : slide slope (degree)  
 $b$  : vehicle slope (degree)

## Conflict of Interest Statement

The author declares that there is no conflict of interest.

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