DESIGN AND EXPERIMENTAL VERIFICATION OF POWER-ASSISTED SMART DOOR SYSTEM FOR PASSENGER VEHICLE

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Abstract: In this study, to enhance the ease of opening and closing the doors of the passenger vehicle, a smart door with a power assist mechanism consisting of a motor and clutch was developed and tested. A power assist mechanism mounted within the vehicle's door is proposed and modeled. The required force necessary to control the designed mechanism during the vehicle's roll, pitch and the opening angle of the door has been established. Finally, the improvement in the ease of opening and closing doors by utilizing the designed ower assist mechanism was tested and proven through an experimental verification.

1 INTRODUCTION

Recently, in the automotive industry, research in creating intelligent parts by integrating various functions is actively conducted. The developed technologies are being commercialized rapidly in North America, Europe, and Korea. Among such intelligent parts, auto sliding door and electric power door systems are developed for doors of vehicles (Yoon, 2002, Grujicic, 2009). However, in most of the conducted research and products in the process of commercialization, studies on mechanisms for compensating changes in the necessary force to open and close doors of a vehicle parked at an angle is limited.

Depending on the structure, shape, and opening & closing force of the vehicle's door, the perceived convenience and safety by the user is affected greatly and it is very frequently used by passengers. Thus, when the door does not operate as intended by the passenger, the inconvenience is drastically felt. Traditionally, a part called the door checker which is attached between the door and the vehicle frame prevented the door from opening instantaneously when the vehicle is parked at an angle.

However, in limited space or when the vehicle is parked at an angle forward or sideways due to the weight of the door it will not become stationary at the passenger's desired position. Therefore, a new power-assist smart door which adjusts the opening and closing force depending on the roll and pitch angle of the vehicle is suggested. It utilizes a motor and clutch to power-assist the passenger while opening or closing the door of the vehicle. When this system is used no matter how the vehicle is positioned the door can be conveniently opened or closed without exerting oneself. The convenience of this kind of a system becomes more important when the weight of the door is heavy or for large passenger vehicles. In order to commercialize such a power-assist smart door system, in depth research in various areas such as power assist mechanism, controlling the opening and closing force, mechanism for understanding the intention of the passenger, dedicated motor and clutch development must be conducted. Among these, for developing the power-assist equipment, the mechanism for understanding the passenger's intention when getting on or off the vehicle and to actively control the necessary force to open or to close the door must

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be organized.

In this study, to enhance the ease of opening and closing the doors of the passenger vehicle, a smart door with a power-assist mechanism consisting of a motor and clutch is developed and a smart door with this mechanism will be designed. A power assist mechanism which can be mounted inside the door is suggested and modeling of a vehicle door with this mechanism conducted. Based on this, a power assist mechanism which is suitable for passenger vehicle is designed. A computer simulation is used to derive the necessary force to open or close the door for a given door opening angle at a given vehicle roll or pitch angle.

2 MODELING OF SMART DOOR

An illustration of the new power assist smart door which can alter the necessary force to change the force required to open or close the door when the vehicle is parked at a roll or pitch angle is provided in Figure 1. It consists of a rack and pinion, a clutch, and a reduction gear and motor. When this mechanism is applied, even when the vehicle is parked at an angle, the necessary force required to open or close the door will be the same as if the vehicle is parked on a flat level surface.

To establish the equation of motion for the power-assist mechanism attached smart door, in the model, as shown in Figure 2, the degrees of freedom was established by the roll ϕ_x and pitch ϕ_z angle of the vehicle and the angle of the door opening θ. The equation of motion is derived based on moment from the weight of the door and the assumption that the external force generated moment by the power assist mechanism.

Initially, as indicated in Figure 3 to obtain the moment of the door due to its own weight, it is assumed that the roll and pitch angle of the vehicle frame is fixed and that the roll and pitch angle(actually the reverse direction of the vehicle frame angle) is created relative to the gravity vector. Thus, the moment by the door's own weight $\tilde{T}_g$ can be summarized as the following.

$$\tilde{T}_g = \tilde{r}_g \times m\tilde{g}_{rot} \quad (1)$$

Here, $\tilde{g}_{rot}$ is the rotated gravity vector caused by the roll and pitch angle and can be represented as equation (2).

$$\tilde{g}_{rot} = \begin{bmatrix} -g\sin\phi_z\cos\phi_x \\ -g\cos\phi_z\sin\phi_x \\ g\sin\phi_x \end{bmatrix} \quad (2)$$

When equation (1) is reorganized by the y directional component, the moment in the y direction by the weight of the door becomes the following equation.

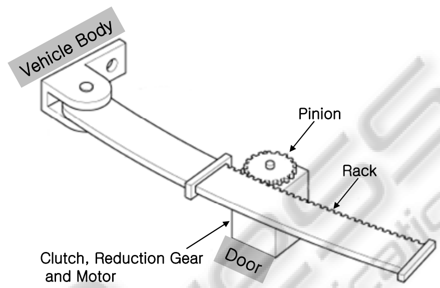


Figure 1: The configuration of the power-assist mechanism for the proposed smart door system.

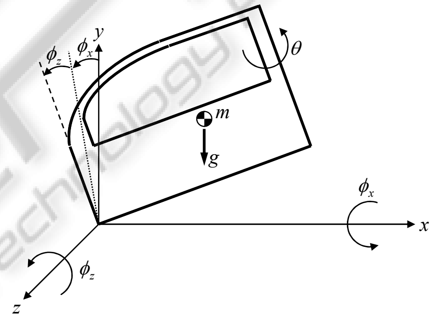


Figure 2: Coordinates for the dynamic model.

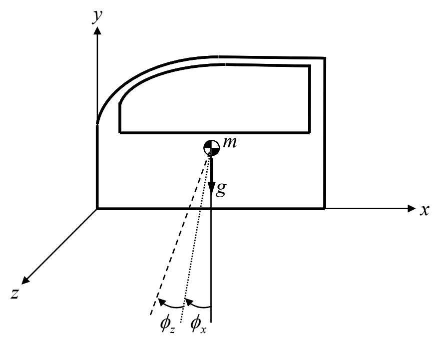


Figure 3: Gravity vector considering the roll and pitch angle of vehicle body.

$$T_{gy} = r_g mg(\sin\theta\sin\phi_z\cos\phi_x - \cos\theta\sin\phi_x) \quad (3)$$

Next, as indicated in Figure 4 the moment of the door $\tilde{T}_F$ created by force of the power assist mechanism(F) is arranged as equation (4).

$$\tilde{T}_F = \tilde{r}_g \times \tilde{F} = F\tilde{r} \times \tilde{e}_t \tag{4}$$

Here, $\tilde{e}_t$ is the directional unit vector created by the power assist mechanism and can be represented as the following.

$$\tilde{e}_t = \begin{bmatrix} r\cos\theta - \varepsilon_x \\ 0 \\ -r\sin\theta - \varepsilon_z \end{bmatrix} / \sqrt{(r\cos\theta - \varepsilon_x)^2 + (r\sin\theta - \varepsilon_z)^2} \tag{5}$$

The following equation is the rearrangement of

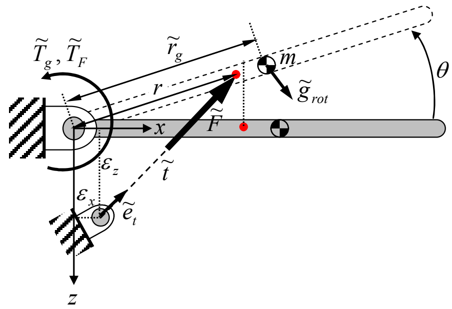


Figure 4: Free body diagram for dynamic model of the proposed smart door system.

the moment in the y direction of the door caused by the power assist mechanism from equation (4).

$$T_{Fy} = \frac{rF(\varepsilon_x \sin\theta + \varepsilon_z \cos\theta)}{\sqrt{(r\cos\theta - \varepsilon_x)^2 + (r\sin\theta + \varepsilon_z)^2}} \tag{6}$$

When equation (2) and (6) is applied to the equation of motion it becomes the following.

$$\begin{aligned} J_y\ddot{\theta} + c\dot{\theta} &= T_{Fy} + T_{gy} + T_{fric} \\ &= \frac{rF(\varepsilon_x \sin\theta + \varepsilon_z \cos\theta)}{\sqrt{(r\cos\theta - \varepsilon_x)^2 + (r\sin\theta + \varepsilon_z)^2}} \\ &\quad + r_g mg(\sin\theta \sin\varphi_z \cos\varphi_x - \cos\theta \sin\varphi_x) + T_{fric} \end{aligned} \tag{7}$$

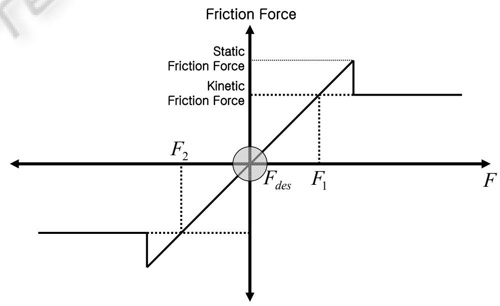
Here, J_y is the mass moment of inertia in the y direction, c is the damping coefficient of the door hinge, and T_{fric} is the frictional force that occurs when the door opened or closed.

3 DESIGN AND MANUFACTURE OF SMART DOOR

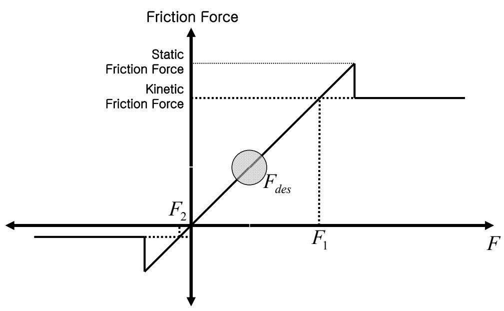
In order to design the power assist mechanism which will be actually mounted in the vehicle, it becomes necessary to estimate the maximum force necessary to open or close the door of the vehicle when it is in a pitch or roll position. Depending on the door opening position the desired control force F_{des} must be estimated. In this mechanism, the maximum force needed to open or close the door during a vehicle's pitch or roll position can be measured experimentally, however, the required control force of the mechanism must be set up depending on the pitch, roll, and door angle. As indicated in Figure 5, in this research, to set up the control force of the pitch, roll, and door opening angle the respective dynamic frictions F_1 and F_2 have been measured. Then the average value has been calculated and the control force has been set up as shown in Figure 6. Thus, as shown in Figure 5(a) only the forces needed to open or close the door when the vehicle is on level ground($F_1 - F_{des}$ and $F_{des} - F_2$) is required for vehicle in a slanted position as indicated on Figure 5(b).

The required control forces for roll ϕ_x , pitch ϕ_z , and door opening angle θ are within the range of -30~30°, -50~50° and 0~80° respectively as shown in Figure 6. As it can be verified from the results the required maximum control force is approximately 1486.3N.

In this study the maximum required control force is used as the boundary condition for the design and the motor, reduction gear, rack and pinion, and selection of parts were conducted.



(a) case I (flat road)



(b) case II (slope road)

Figure 5: The desired actuating force with respect to the vehicle body angle.

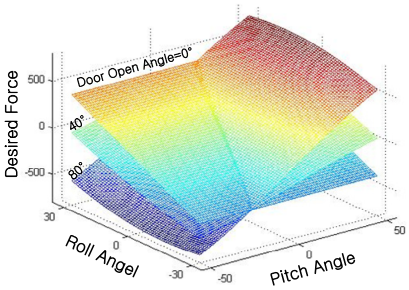


Figure 6: The required control force characteristics for designing power-assist device.

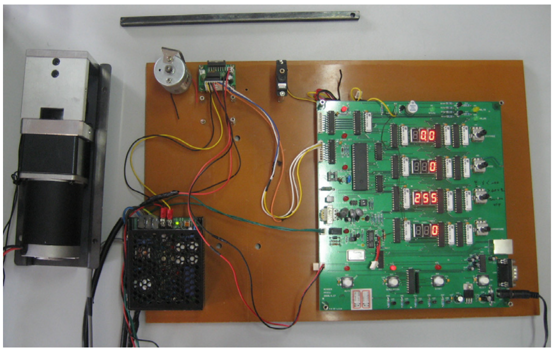


Figure 7: Power-assist mechanism control board.

In order to manufacture a suitable smart door, the door of an actual vehicle has been measured and the parameters are indicated. Based on these values, a control block diagram to control the smart door system is structured. The power assist mechanism control board is shown in Figure 7 and it is attached to the smart door system.

4 EVALUATION OF SMART DOOR

To test and evaluate the designed smart door, the test set up indicated in Figure 8 is constructed. An actual door of a passenger vehicle is attached to the frame. This frame can be set up in a vehicle roll position. The force generated by the power assist system is controlled by the computer D/A signal, the vehicle roll angle ϕ_x, door opening angle θ, and angular velocity $\dot{\theta}$ are measured by using sensors.

In order to investigate the characteristics of the smart door system, the roll angle of the vehicle was set at 15° as indicated in Figure 8 and the required opening and closing forces are actually measured. As it can be found from the experiment in Figure 9 when the door opening angle is adjusted between 0~80 ° if the power assist mechanism is not activated, the necessary force is 60~180N. But when the power assist mechanism is activated approximately 20~80N was required to open or close the door.

5 CONCLUSIONS

In this study, to enhance the ease of opening and closing the doors of the passenger vehicle, a smart door with a power assist mechanism consisting of a motor and clutch was developed and tested. For this purpose a power assist mechanism which can be mounted inside the door is suggested and the smart door is modeled and tested. The required control force for controlling the mechanism due to the vehicle's pitch, roll, and door opening angle is established.

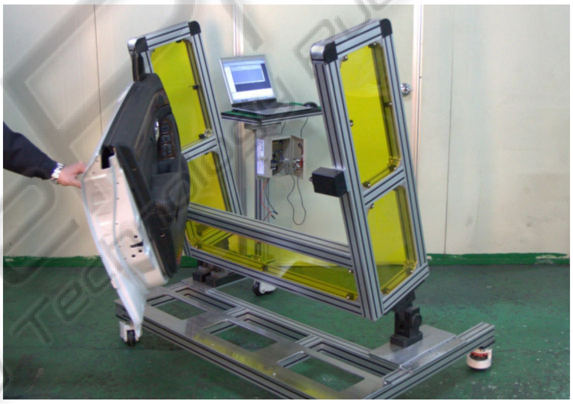


Figure 8: Experimental setup for the power-assisted smart door system.

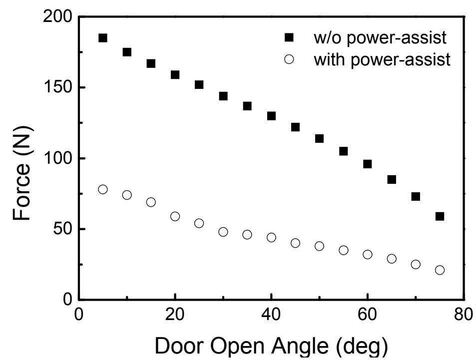


Figure 9: The control responses of the smart door system.

Based on the established results the power assist mechanism with the adequate opening and closing force was designed. A computer simulation was used to evaluate the designed power assist mechanism. The designed power assist mechanism installed smart door will be mounted on a vehicle and will be tested in the near future to prove the usefulness and convenience of the system.

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