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Simulated effect of driver and vehicle interaction on vehicle interior layout

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ABSTRACT

Digital human modeling is an essential tool to reduce cost and to save time in a design process where humans take the part of users of the design. Considering this phenomenon for a vehicle interior, the importance of the seat track location and adjustment ranges become important. This paper presents the effect of driver and vehicle interaction on vehicle interior layout based on simulation approach. This simulation method includes two optimizations. The first optimization problem is the physics-based seated posture prediction. In order to represent physical drivers, 4,500 virtual drivers are generated based on an anthropometric database-ANSUR. Interaction forces between the digital human and pedal, seat, ground, and steering wheel are incorporated in the physics-based posture prediction. Three different pedal reaction moments (0, 20, and 40 N m) are implemented into the formulation to examine the effect of pedal reaction moment on driver seat location and adjustment ranges. To study the effect of shear forces, the physics-based posture prediction is compared to kinematics-based posture prediction. After posture predictions are completed, individuals' preferred seat locations are used in a second optimization problem to predict the seat track location and adjustment ranges. For a specific vehicle with 20 N m pedal reaction moment, adjustment ranges are predicted as 223 mm and 82 mm in horizontal and vertical directions, respectively. Also, it was shown that shear force due to the interaction between the driver and the seat pan and the pedal reaction moment are both influential to the seat track location and adjustment ranges.

Relevance to industry: The simulation model presented in this paper is useful in vehicle and seat design and can be easily used for virtual design assessment in vehicle design.

1. Introduction

Variance in human anthropometry is a primary concern and challenge of vehicle interior design. Positioning of the vehicle interior components (seat track, controls, displays, steering wheel, gear shift, pedals, etc.) should be determined according to a target population's driving postures and reach zones. For this design problem, one of the main issues is the location and size of the adjustment ranges. If the sizes of adjustment ranges were large enough to accommodate the entire population, it would increase cost excessively. Also, correct seat positioning has a major effect on driver response time (Scott et al., 1996). These design considerations should be determined for diverse users in a population where a target percentage is accommodated without any dissatisfaction. From reviewing the literature on seat and occupant interaction studies, it is clear that interaction forces play an important role in seated postures besides the legroom (Cascioli et al., 2011) and lumber spine stiffness (De Carvalho and Callaghan, 2011). In literature, there is no study considering the interactions (interaction forces) between the human and the vehicle for determining the seat track location and adjustment ranges although some studies (Bush and Hubbard, 2007; Rasmussen et al., 2009; Grujicic et al., 2010; Hobson, 1992; Olesen, 2012; Majid et al., 2011) have focused on the physical interactions between the design and the user for seated applications. The motivation of this study is to test two hypothesizes: The shear forces due to the interaction between the seat pan and the driver are influential in determining the seat track location and adjustment ranges; and the pedal moment influences the seat track location and adjustment ranges.

Two methods for vehicle interior design have been reported in the literature. The first method is the usage of the standardized

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practices. The Society of Automotive Engineers (SAE) provides a handbook (SAE International, 2005) that contains recommended practices that standardize the methods and models for component layout. In the early 1960s, a two dimensional template and a weighted 3-D manikin were standardized for defining and measuring vehicle occupant accommodation for passenger cars (SAE J826). A new version of the H-point machine was developed in 1999 (Reed et al., 1999). In the new design, ease of use and biofidelity were improved and also lumbar supports were included. The manikin (H-point machine) is still used to approximate the location of the H-point of a person in a driving posture. The procedure for using the H-point machine is explained in SAE J4002. In SAE J1100, a set of measurements and standard procedures were defined for vehicle dimensions. Besides the aforementioned measurement tools, SAE provides statistical models in practices such as the following: SAE J4004 describes a statistical model to determine seat track length, SAE J1052 describes occupant head location contours, SAE J287 describes boundaries of hand control locations, and SAE J941 establishes distributions of driver eye location.

Another common method is the usage of digital human modeling (DHM) in computer-aided-design processes although DHM has been used in other task for ergonomic assessments (De Magistris et al., 2013). In DHM, human models, which represent vehicle occupants, are placed in digital vehicle mock-ups in early stages of the design. Accurate prediction of the driving posture in DHM is essential in order to save time, and also the production of physical mock-ups is expensive. In DHM, for the seat adjustment range prediction problem, mostly boundary manikins ranging from 5th percentile female to 95th percentile male are used. Gragg et al. (2012) proposed a hybrid method for predicting the optimum driver seat adjustment range based on an optimization-based kinematic posture prediction method. This hybrid method included a boundary manikin approach, a population sampling approach, and a special population of pregnant women. The results of these three approaches were combined to determine an optimum driver seat adjustment range in the horizontal direction only. Gragg and Yang (2011) examined the effect of obesity on seated posture inside a vehicle using kinematic posture prediction. It was shown that the clearance between the waist and steering wheel decreases as waist size increases; thus, obese individuals prefer to move further from the steering wheel than non-obese subjects. The cascade prediction model (CPM) for posture predictions was reported (Parkinson and Reed, 2005; Reed et al., 2002). The CPM method was extended to SAE Class-A vehicles (passenger cars and trucks with design seat heights less than 405 mm) for optimizing a vehicle cabin layout (Parkinson and Reed, 2006; Gordon et al., 1988, 1989). RAMSIS (Van Der Meulen and Seidl, 2007) and JACK (Phillips and Badler, 1988) are two toolkits used in the automobile industry. As computational power is being improved, the usage of DHM should include large numbers of individuals and take into account the interactions between the designed product and the user.

Although both methods are still very useful and currently being used in design processes, their capabilities are limited. For instance, SAE recommended practices focus on percentile accommodations. Usage of DHM with kinematic posture prediction can consider the anthropometric variability only in terms of stature or link length. Also, usage of the boundary manikins was found to be insufficient for the design of workstations (Reed and Flannagan, 2000). Thus, the analysis should include a large number of individuals and incorporate variance in body mass and link lengths. The CPM indirectly incorporates the physical interactions between the vehicle interior and the occupant into the analysis. However, because the interaction forces do not vary in the regression equations, effects of interaction forces on the driving posture characteristics or the seat track location and adjustment ranges cannot be examined.

Physics-based seated posture prediction has the capability to incorporate interaction forces between an occupant and seat. There are only a few studies about the physics-based posture prediction method in literature. Kim et al. (2009) presented a method to predict seated postures considering balance. External loads were incorporated in the prediction of reaching postures in a vehicle. Howard and Yang (2012a, 2012b) developed a physics-based seated posture prediction method that incorporates the prediction of associated reaction forces into the analysis. The average error between the predicted shear force and experimental result found in literature (Hobson, 1992) was 6.95 N. In our pilot study (Ozsoy and Yang, 2013), we developed a physics-based driving posture prediction formulation, which included three types of vehicles (a sedan, a SUV, and a truck), to obtain the size of adjustment ranges in horizontal and vertical directions. However, the interaction shear forces and pedal moment between the driver and seat pan were not considered. Also, in the pilot study, a linear relationship between weight and stature was proposed which is inadequate and far from reality.

In this study, in order to incorporate the interaction forces between the driver and the vehicle, a validated physics-based seated posture prediction method (Howard and Yang, 2012a, 2012b) is adapted to predict driving posture characteristics. For the first hypothesis, the seat track location and adjustment ranges based on kinematic posture prediction (Gragg et al., 2012) are compared with those obtained with the physics-based method. For the second hypothesis, the pedal reaction moment is altered from 0 N m to 40 N m in 20 N m increments. The rest of the paper explains the proposed driver seat adjustment range determination methodology, results, and the discussion.

2. Methodology

The proposed simulation method includes the following steps: 1) Parameterization of the initial vehicle interior layout; 2) generation of the representative driver population including anthropometric variance; 3) development of a digital human model for each individual in the population; 4) formulation of a physics-based posture prediction algorithm; 5) prediction of postural characteristics of each individual such as the location of the center of eyes and $H-point$, which is the connection between the seat and the digital human model. It should be noted that a regression equation (Reed et al., 2002) is embedded into the physics-based posture prediction to calculate the offset from center of hip locations to $H-point$; 6) in the final step, the prediction of the seat track location and adjustment ranges, where a target percentage of the population can be accommodated within the range, is accomplished through solving another optimization problem. Fig. 1 depicts the flowchart of the proposed methodology that includes two optimization problems. The first one, which is the physics-based posture prediction, is solved in MATLAB® by using sequential quadratic programming with parallel computing. The second optimization problem is solved to predict the seat track location and adjustment ranges after the $H-point$ for each individual in the population is predicted.

2.1. Parameterization of the vehicle layout

In order to use DHM to predict the seat track location and the adjustment ranges, a layout of a vehicle interior is modeled and shown in Fig. 2. Modeled components consist of a steering wheel, an accelerator pedal, and a seat. The nomenclatures in parentheses are defined in SAE J1100. The layout is defined by using several parameters taken from a previous study (Gragg and Yang, 2011). Origin z coordinate is defined by the accelerator heel point (AHP), origin x coordinate is defined by the right ball of the foot (BOF), and