Driver Accommodation Assessment Using Physics-Based Posture Prediction Model

Ozsoy Burak and Jingzhou (James) Yang

Abstract Driver accommodation plays an important role in driver and vehicle safety. Many vehicles on the market do not have proper driver seat adjustment range due to the lack of efficient methods to assess an optimal adjustment range for all drivers. Traditional methods are mainly from experiments. They are time-consuming and expensive. This study aims to develop a simulation-based method by using physics-based posture prediction to assess driver accommodation easily and efficiently. Three different types of vehicles-a sedan (Car 1), a SUV (Car 2) and a truck (Car 3) were used to demonstrate the procedure of the proposed method. A global optimization technique-pattern search was adapted for solving the physics-based posture prediction. Population sampling method was used to generate the digital human models between 5th and 95th % females and males (in stature and weight) separately. Also, for a special population-pregnant woman, digital human models were created and used in simulations. The maximum break force 100 N was implemented in the prediction model. As a result, driver seat adjustment ranges in horizontal direction were found to be 218 ± 14, 222 ± 17 and 207 ± 12 mm for Car 1, Car 2 and Car 3, respectively. Likewise, adjustment ranges in vertical direction were found to be 54 ± 3, 57 ± 2 and 59 ± 3 mm. The proposed method can be used in early stages of design as a computer aided engineering tool in order to reduce time and cost.

Keywords Physics-based posture prediction · Driver accommodation · Digital human model

---

F2012-E05-001

O. Burak (✉) · Jingzhou (James)Yang
Human-Centric Design Research Laboratory, Department of Mechanical Engineering,
Texas Tech University, Lubbock, TX 79409, USA
e-mail: james.yang@ttu.edu

SAE-China and FISITA (eds.), *Proceedings of the FISITA 2012 World Automotive Congress*, Lecture Notes in Electrical Engineering 195,
DOI: 10.1007/978-3-642-33835-9_61,

1 Introduction

Comfort plays an important role in vehicle safety because a comfortable design can reduce drivers' fatigue especially in long term drives. Variability in user body dimensions, anthropometry makes this problem challenging. In order to reduce the total number of driver complaints, an optimum driver seat adjustment range is a must. An optimum driver adjustment range is a key factor in whether the driver can accommodate in the vehicle and safely drive it.

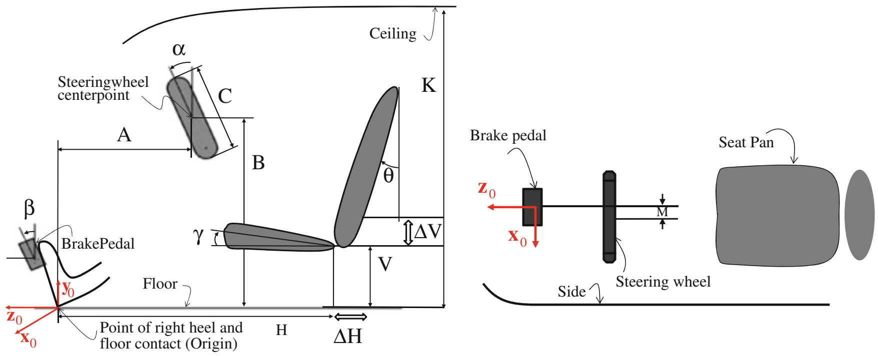
Mostly, experimental methods have been used to determine the driver seat adjustment range. Kolich [1] used experiments to develop a model to predict driver-selected seat positions. 12 subjects, 6 male and 6 female, were asked to sit in each of the three compact cars in a comfortable seat position. After gathering the selected track position data, a model that would be used to predict the seat position as a function of stature was obtained. McFadden et al. [2] studied the reason for differences in seat position of male and female drivers to determine why women typically sit closer to the steering wheel. Differences were attributed mostly to the stature. Park et al. [3] studied the comfortable seated postures of Koreans using a driving posture monitoring system. Also, postural angles and anthropometric characteristics were measured. Relationships between the translational range of the driver seat, postural angles and anthropometric characteristics were discussed. Reed et al. [4] examined the effects of the height of the top of the instrument panel on driving posture using an interactive simulator. Increasing the height of the panel by 150 mm caused a horizontal hip movement of 7 mm towards the steering wheel. The result indicated that the effect of vision restriction imposed by the instrument panel has not significantly changed the driver seat adjustment. Parkinson and Reed [5] showed a case study including three types of populations of simulated drivers, the vehicle cab interior layout-passenger cars and light trucks, focusing on placement and adjustment range of the seat and steering wheel. The first type of population of simulated driver was 28 boundary manikins with no associated random variance. In order to see the effect of random postural variance, the second population was defined with 280 boundary manikins-28 manikins 10 times, each randomly sampled with postural variance values. The third population-1,000 drivers defined as randomly sampled from anthropometric distributions of each gender and including random variance. 4 different scenarios were used for the simulations including: with an adjustable steering wheel configuration, with permitting a small amount of disaccommodation, with a non-telescoping steering wheel and with up vision and down vision requirements for the sight clearance. For the first three scenarios, in optimization formulation, objective function was defined as minimizing the multiplication of adjustment ranges in horizontal and vertical directions. However, for the last scenario, the optimization procedure was split into two parts: first, an optimization procedure to find the steering wheel pivot location which maximizes average down vision, then the second optimization procedure was used to determine the smallest seat track that will achieve 95 % accommodation on seat position for randomly sampled population, and obtaining the maximum average down vision angle maintained earlier. Driver seat adjustment ranges and seat locations were shown in results. It was concluded that the boundary manikin approach does not generally provide accurate assessments of accommodation. Also, it was shown that the inclusion of a steering wheel with a 50 mm telescope range allowed 43 and 2 mm decrease in horizontal and vertical track travels respectively. Finally, the last scenario, where sight clearance was included, yielded a very large adjustment range, and it was stated that a multi-objective approach might reduce the required adjustments. Parkinson et al. [6] included driver variability in the optimization problem in terms of body anthropometry, posture, and eye location as the only source of uncertainty. The design problem was defined as optimizing truck cab layout for driver accommodation. Motozawa et al. [7] studied the difference in longitudinal displacement of the driver seat for 40 women, 20 pregnant women and 20 age-matched non-pregnant women. Gragg et al. [8] proposed a hybrid method for predicting the optimum driver seat adjustment range based on a optimization-based kinematic posture prediction method. 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 horizontal direction only.

In literature, both experimental and simulation approaches have been investigated. Experimental methods are expensive and time consuming. Also, for the simulation-based methods, most of them only considered kinematic aspects of the driver and environment and predicted horizontal adjustment range only. None of them considered joint torque and human environment interaction forces. The objective of this paper is to develop a method to predict an optimum adjustment range in vertical and horizontal directions considering not only varying anthropometry of drivers but also driver-vehicle interactions. A global optimization algorithm was used for the solving the physics-based posture prediction.

2 Problem Definition

In this study, in order to predict an optimum driver seat adjustment range, vehicle cab interior are modeled including a fixed steering wheel, a brake pedal with a maximum pedal force of 100 N, a seat pan and a seat backrest. The layout is shown in Fig. 1. Three types of vehicles, a compact car (Car 1), a SUV (Car 2) and a truck (Car3) were modeled in this study.

Global origin is attached at the contact point of the right heel with the ground. A brake pedal with an angle of β about x_0 axis is defined. Center of steering wheel which has a radius of C is attached at M,B,A in $\mathbf{x_0}$, $\mathbf{y_0}$ and $\mathbf{z_0}$ coordinates with an



(a) **(b)**

Fig. 1 Vehicle cab interior layout. **a** Side view. **b** Top view

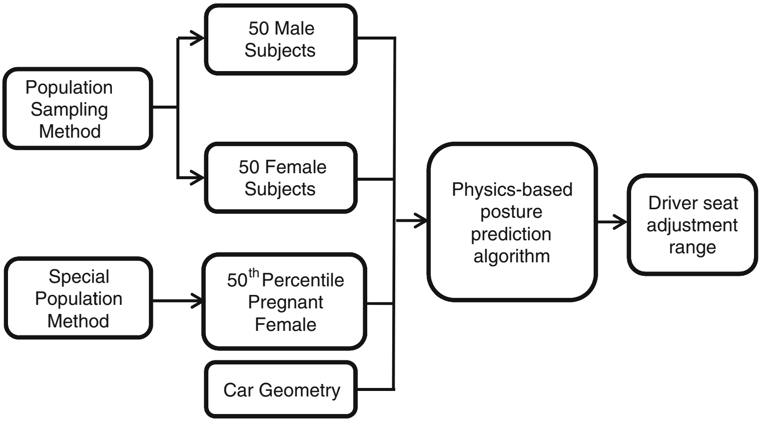
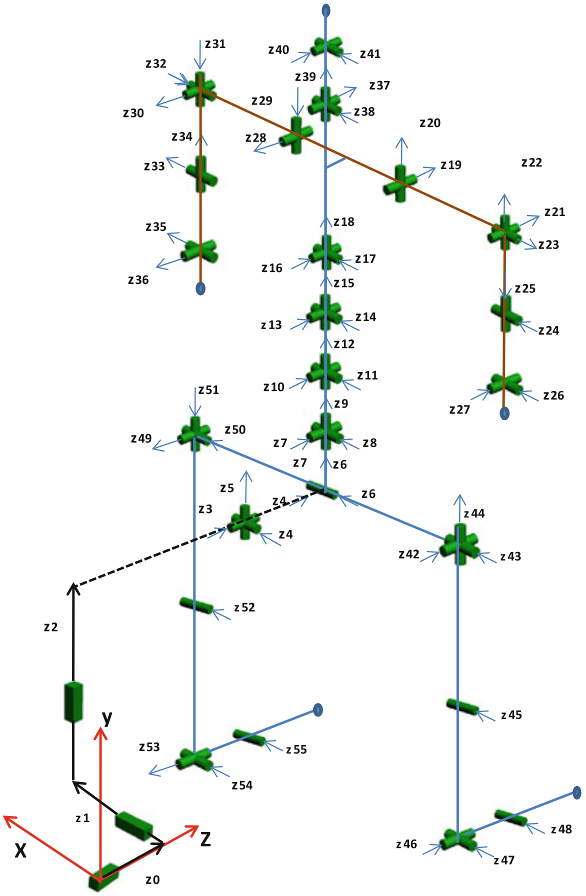


Fig. 2 Flowchart of the proposed method

angle of α about x_0 axis. Parameter H and V are the location of driver's hip point location in horizontal and vertical where they are adjustable. Seat pan and seat backrest are inclined with an angle of γ and θ about x_0 axis respectively. Parameter K is the height of the vehicle ceiling from floor.

The problem is defined as follows: given the geometry of vehicle cab interior, predict the position of the hip in vertical and horizontal directions by physics-based seated posture prediction algorithm. This procedure is repeated with different anthropometric data in order to have an optimal adjustment range, ΔH and ΔV for the majority population including pregnant women with different belly sizes for different months of pregnancy. A flowchart for the procedure is shown in Fig. 2.

Fig. 3 Digital human model



3 Digital Human Model

In order to predict an optimum driver seat adjustment range, a digital human model with appropriate degrees of freedom (DOF) is necessary. In this study, 56 DOF digital human model as shown in Fig. 3 is used.

The human body can be modeled as a kinematic chain consisting of revolute joints representing the musculoskeletal joints and are connected by links that represent the bones. A local Cartesian coordinate system was fixed to each link and predicted posture is created by rotating each of the joints about this local z-axis. The model is represented by generalized coordinates $(q_i,\ i = 1, \ldots, n)$, where n is

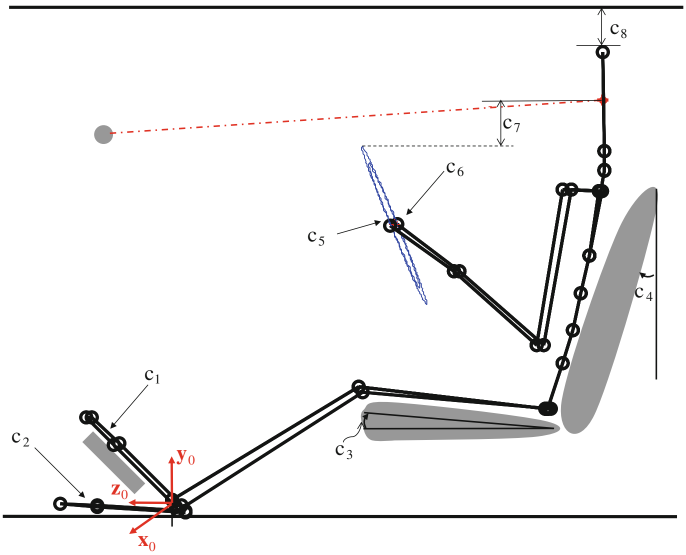


Fig. 4 Schematic of the simulation constraints

total number of degree of freedom. Since the generalized coordinates are measured about the local axis, transformation matrices are needed for each joint. The kinematics of the body model is represented by Denavit–Hartenberg [9] method and the global position of any joint can be calculated in the kinematic chain with multiplication of transformation matrices.

4 Physics-Based Posture Prediction Formulation

The simulation is constructed as a nonlinear constrained optimization problem that is solved with a commercial solver, MATLAB®. The optimization problem is considered as a multi-objective optimization (MOO) problem with two individual terms and each term is normalized by a corresponding maximum value. The weights in MOO are considered to be 1. A pictorial representation of constraints is shown in Fig. 4.

The optimization problem is defined as follows:

- $\text{Find} : \mathbf{q} = [\mathrm{q}_0 \mathrm{q}_1 \cdots \mathrm{q}_{56}]^{\mathrm{T}}$
- $\text{Minimize} : \mathrm{f}(\mathbf{q}) = \left\{ \left[\mathrm{w}_1 \frac{\mathrm{Torque}_{\mathrm{joint}}}{\mathrm{Max}_{\mathrm{joint}}} \right]^2 + \left[\mathrm{w}_2 \frac{\mathrm{Backrest\ Reaction\ Force}}{\mathrm{Max}_{\mathrm{Backrest\ Reaction\ Force}}} \right]^2 \right\}$
- $\text{Subject to} :$

$$
\begin{aligned}
c_1 &= (\mathbf{X}_{\mathrm{right\ foot}} - \mathbf{X}_{\mathrm{pedal}}) \\
c_2 &= (\mathbf{X}_{\mathrm{left\ foot}} - \mathbf{X}_{\mathrm{target\ point}_1}) \\
c_3 &= \text{seat pan angle} \\
c_4 &= \text{backrest angle} \\
c_5 &= (\mathbf{X}_{\mathrm{left\ hand}} - \mathbf{X}_{\mathrm{target\ point}_2}) \\
c_6 &= (\mathbf{X}_{\mathrm{right\ hand}} - \mathbf{X}_{\mathrm{target\ point}_3}) \\
c_7 &= \text{ sight clearence} \\
c_8 &= \text{clearence of head with ceiling} \\
h_{1_\mathrm{i}} &= \text{Self} - \text{collision aviodance} \\
h_{2_\mathrm{i}} &= \text{Torque Limits} \\
&q_{\mathrm{i}}^{\mathrm{L}} \le q_{\mathrm{i}} \le q_{\mathrm{i}}^{U} \\
&-\infty \le c_1, c_2, c_5, c_6 \le 0.001 \\
&c_7 \ge y_{wheel} + \delta_1 \\
&c_8 \le y_{ceiling} - \delta_2
\end{aligned}
$$

c_1 is a contact constraint for the right foot. As mentioned in problem definition, global frame is attached at the right heel. Therefore, a constraint is used to satisfy the position of the right heel coinciding global origin in three dimensions. Although the connection of the virtual joints to the body is at the pelvis, it does not mean that the position of pelvis is at zero in $\mathrm{x}_0, \mathrm{y}_0, \mathrm{z}_0$ coordinates, but the position of the right heel still can be at zero in $\mathrm{x}_0, \mathrm{y}_0, \mathrm{z}_0$ coordinates by adjusting global translations and rotations. c_2 constraint depends on the car type/geometry. For the sedan car used in this study, a left foot support exists, however for the truck and the SUV it does not. Therefore, for the sedan car left foot position is constrained to have a contact with the support, but for the other types of the vehicles left foot is constrained to have contact with the floor only. c_3 constraint is used for the inclination of seat pan. According to the geometry of the car seat, this constraint is used to define a vertical position difference between the knee and hip for each leg. In order to see the effect of seat pan inclination on human-seat interaction forces, in this study it is constrained to be 5–10°. c_4 constraint is used for backrest angle. In this study it is determined to constraint the backrest angle at 10, 15 and 20° in order to see the effect of back-rest angle to the seat shear and normal forces.

c_5 and c_6 constraints are used for end-effector positions of the hands. Since grabbing the steering wheel is not included in this study, two constraints to establish a contact of middle fingertips at each hand to the steering wheel at nine and three position are used. c_7 constraint is used to ensure that the sight vector of the digital human model is above the top position of the steering wheel. c_8 constraint is used to have a clearance of head with the ceiling of the car. Additional to these kinematic constraints, two other constraints were used to avoid self–collision and joint torque limits. Certain posture may be found where segments are colliding with each other which make the predicted posture unrealistic. This constraint ensures that the segments are not colliding with other segments. Spheres are placed at each segment's center of mass position in local coordinate except feet and head. Each sphere is constrained so that the distance between two spheres must be greater than or equal to corresponding two radius. Also, the joint torques are constrained in order to predict posture in a physical range.

5 Results and Discussion

In this study, a population of 50 men and 50 women was obtained through linear interpolations between 5th and 95th percentile males and females. After defining the constraints and objective functions, each body model is used in a single optimization formulation for physics-based posture prediction. In Fig. 5, obtained distances of hip from right heel (global origin) in both vertical and horizontal directions for Car 1 with backrest angle 10° and seat pan angle 5°, backrest angle 15° and seat pan angle 5°, backrest angle 15° and seat pan angle 10° are shown. In this figure it is seen that female digital models sit closer to the steering wheel and need a higher accommodation in vertical direction because of the vision constraint. Driver seat adjustment range for each vehicle is determined from the difference between the maximum and minimum values of hip positions with pre-defined combination of seat pan and backrest angle. Also, in Table 1, tabulated results for all combinations of the backrest and seat pan angles are shown.

For the special population type, pregnant woman case, seat angle and backrest angle are constrained to be both 10°. This configuration is chosen due to in this case the driver seats closest to the steering wheel. Additional sphere is attached to the belly for the existence of pregnancy. 5 and 20 cm belly sphere radius and corresponding weights are chosen for different gestational ages of fetus. In Table 2 pregnant driver accommodation is shown and compared to the non-pregnant case.

The results of the proposed method in this study for adjustment ranges which is shown in Table 3 are in good agreement with the result of the studies given above. In this study predicted hip position for seated posture 95th percentile male is at 898.97 ± 15.28 and 214.51 ± 20.86 mm in horizontal and vertical directions respectively. Likewise, for 5th percentile female the position of hip is predicted at 688.75 ± 22.54 and 253.91 ± 22.54 mm. Driver seat adjustment ranges are found to be in good agreement to the results in literature with a value of 215.78 ± 15.14 and 56.61 ± 3.37 mm in horizontal and vertical tracks.

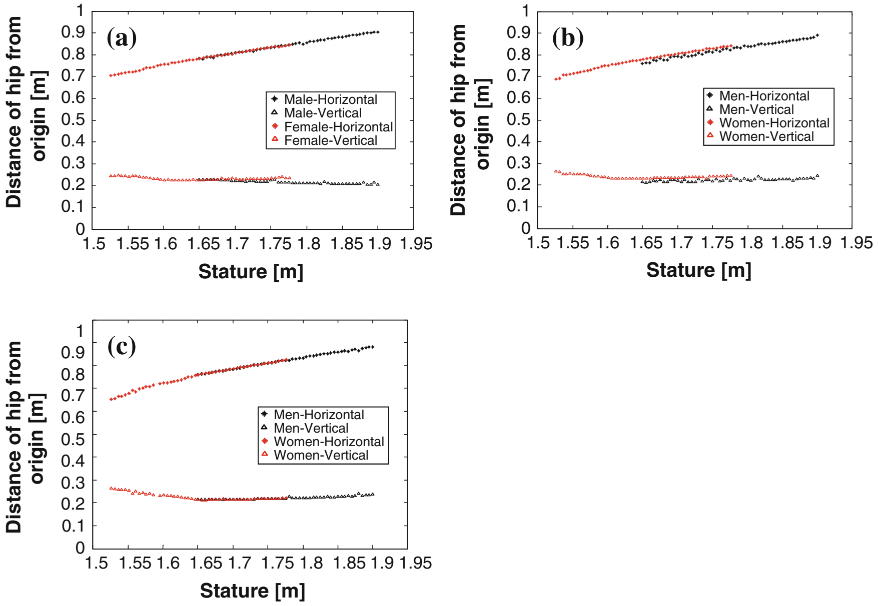


Fig. 5 Driver accommodation in Car 1 **a** backrest angle 10° and seat pan angle 5° **b** backrest angle 15° and seat pan angle 5° **c** backrest angle 15° and seat pan angle 10°

Table 1 Tabulated results for varying seat pan and backrest angles

		Car 1 adjustment range [mm]		Car 2 adjustment range [mm]		Car 3 adjustment range [mm]	
Seat pan angle [degree]	Back rest angle [degree]	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
5	10	51	203	55	222	62	197
10	10	55	232	60	248	60	221
5	15	51	201	57	208	60	206
10	15	50	228	55	231	53	216
5	20	58	214	59	199	61	191
10	20	56	229	58	225	58	213

Table 2 Pregnant and non-pregnant 50th percentile female driver seat accommodation in Car 2

	Pregnant		Non-pregnant
Sphere radius [cm]	5	20	0
Vertical adjustment [mm]	224	222	218
Horizontal adjustment [mm]	776	777	773

Table 3 Comparison of results of proposed method with results in literature

	Experimental		Simulation					
	Kolich [1]		Gragg et al. [8]		Parkinson and Reed [5]		Proposed method	
	95 % male	5 % female	95 % male	5 % female	95 % male	5 % female	95 % male	5 % female
Horizontal seat adjustment [mm]	892	748	910 ± 2.03	623 ± 10.02	N/A	N/A	898.97 ± 15.28	688.75 ± 22.54
Vertical seat adjustment [mm]	N/A	N/A	N/A	N/A	N/A	N/A	214.51 ± 20.86	253.91 ± 15.69
Horizontal adjustment range [mm]	144		287 ± 12.03		218.67 ± 26.39		215.78 ± 15.14	
Vertical adjustment range [mm]	N/A		N/A		54.00 ± 13.89		56.61 ± 3.37	

6 Conclusion

This paper presented a method to determine driver seat adjustment range in vertical and horizontal directions considering not only the varying anthropometry of drivers but also driver and vehicle interaction such as pedal forces, driver-seat, and driver-floor interaction. Three vehicles- a sedan, a SUV and a truck were modeled including seat, backrest, brake pedal, steering wheel. Driver seat adjustment ranges in horizontal direction were found to be 218 ± 14, 222 ± 17 and 207 ± 12 mm for Car 1, Car 2 and Car 3 respectively. Likewise, adjustment ranges in vertical direction were found to be 54 ± 3, 57 ± 2 and 59 ± 3 mm. Validation of the proposed was given through experimental and simulation studies that were found in literature. The proposed method was shown to be useful and can be used in early stages of design process as a computer-aided engineering tool in order to reduce time and cost. Also, the proposed method can be used for custom-made design for other seated applications for injured or disable people.

References

1. Kolich M (2000) Driver selected seat position: practical applications. SAE Technical Paper 2000-01-0644
2. McFadden M, Powers J, Brown W, Walker M (2000) Vehicle and driver attributes affecting distance drom the steering wheel in motor vehicles. Hum Factors 42(4):676–682
3. Park SJ, Kim C-B, Kim CJ, Lee JW (2000) Comfortable driving postures for Koreans. Int J Ind Ergon 26(4):489–497
4. Reed MP, Manary MA, Schneider LW (2000) The effects of forward vision restriction on automobile driver posture. Transp Hum Factors 2(2):173–189
5. Parkinson MB, Reed M (2006) Optimizing vehicle occupant packaging. SAE Trans J Pass Cars–Mech Sys, vol 115, Technical Paper No. 2006-01-0961
6. Parkinson MB, Reed M, Kokkolaras M, Papalambros PY (2007) Optimizing truck cab layout for driver accommodation. ASME J Mech Des 129(11):1110–1117
7. Motozawa Y, Hitosugi M, Tokudome S (2008) Analysis of seating position and anthropometric parameters of pregnant Japanese drivers. Traffic Injury Prev 9(1):77–82
8. Gragg J, Yang J, Howard B (2012) Hybrid method for driver accommodation using optimization-based digital human models. Comput Aided Des 44(1):29–39
9. Denavit J, Hartenberg RS (1955) A kinematic notation for lower-pair mechanisms based on matrices. J Appl Mech 22:215–221