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Seated reach capabilities for ergonomic design and evaluation with consideration of reach difficulties

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ABSTRACT

This paper aimed to identify the reach capabilities of 26 seated subjects considering the reach difficulty, orientation and other potential factors, and to find a method to model the minimum reach capability surfaces for fixed and adjustable seats. The reach capability radius was used as a measure of the reach capability and theoretically modeled. Based on the test data of seated reach, the distribution of the reach capability radius was analyzed. The strategy to select the minimum reach envelopes was constructed to accommodate a sufficient percentage of the target population for both fixed and adjustable seats. For adjustable seats, a method was developed to derive the reach capability data from the tested individual reach capability data by introducing seating position models to re-position the individual reach capability data. An application case was realized based on the cab packaging data of a mini-van, and the minimum reach envelopes of different difficulties were created and validated to accommodate 90% of the target population.

1. Introduction

Seated reach capability study has great significance to the design of vehicle controls. Reach envelopes are widely used to test the reachability of controls considering the required compensations for different operation modes. Studies have been conducted for the reach capability envelopes, which were considered as the position limits of controls in design, with a sufficient confidence level to accommodate the target population. These reach envelopes were commonly built using tests and statistics (Kennedy, 1964; Chaffee, 1969; Hammond and Roe, 1972; Roth et al., 1977; Kennedy, 1978; Asfour et al., 1978; Sengupta and Das, 2000; Chevalot and Wang, 2004, Wang et al., 2007, 2008) and computer simulation (Korein, 1985; Abdel-Malek et al., 2001, 2004; Kee, 2002). In the automotive industry, the most commonly used reach envelopes are the J287 control reach envelopes, which are presented in data tables by the SAE (the Society of Automotive Engineers), where the cab packaging parameters (G factor and cab dimensions), belt type and male-to-female ratio of the target population are input parameters (Society of Automotive Engineers, 1998).

In modern design, both reach capability and reach difficulty should be simultaneously considered so that the accommodation should be for both human anthropometry and reach difficulties. The current SAE control reach envelopes provide no information about the reach difficulties of the operators. In effect, even when the controls are within these reach envelops, the difficulties may be different for the operators with different body sizes. Controls should be packaged according to their importance and frequency of use, which produces different requirements of reach difficulties. Hence, the reach envelopes of different difficulties should be constructed, and the strategies and corresponding criteria should be established to select the envelopes with suitable percentiles of difficulties as the design limits to ensure sufficient accommodation of the target population within confidence level (such as 90%).

As one of the reach capability measures, reach envelopes can be classified into two categories: individual envelopes and population envelopes. The individual envelopes commonly express the maximum reach capabilities of an individual. Studies showed that the current simulated individual envelopes were not sufficiently realistic in kinematics fidelity (Reed et al., 2003b). Extensive studies remain necessary to improve the simulation models (Green and Hilby, 1999; Aoki et al., 2005). Unlike the individual envelopes, the population envelopes commonly express the "minimum" reach capabilities of a population with the expected accommodation level for the target population. For engineering use, it is desirable to

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build the population envelopes, particularly those that consider potential factors such as the reach difficulty, population anthropometry, task variables, accommodation level and packaging parameters of vehicle cabs (Reed et al., 2003a; Chevalot and Wang, 2004). The reach capability data of individuals are relatively easily acquired with test. However, it is not easy to acquire the reach capabilities of a population in an actual vehicle because each individual has his preferred seating position, which is commonly different for different cab packaging dimensions. Can we find a method to rapidly establish the reach capability envelopes from the individual-reach-capability data? If the answer is Yes, a series of population envelopes can be rapidly derived for different vehicles using only the individual-reach-capability data.

As for individual envelopes of US citizen, past studies showed that the average reach capability of males was 10 cm longer than that of the females under unrestrainted circumstance (Asfour et al., 1978). However, it is still unknown of the difference of reach capabilities of US males and females at different difficulties.

In this study, based on the test data of seated reach from the Bioscience lab of the University of Michigan Transportation Research Institute (UMTRI), the reach capabilities of 26 subjects were statistically analyzed for different reach difficulties. Because all subjects sat at the identical seating place in the test, the test data reflected the reach capabilities of these individuals. These individual data formed the basis to model the population reach capabilities. The reach envelopes were theoretically modeled, and the minimum reach envelopes (population envelopes) of different reach difficulties were derived. The individual-reach-capability data were processed for use with two types of driver seats: fixed seat and fore-aft adjustable seat. For the adjustable seat, seating positioning models were introduced to predict the seating positions of the individuals. With statistical analyses of the processed reach capability data, the reach capabilities, their differences for male and female individuals, and factors of the reach capabilities were identified. For the adjustable-seat circumstance, a case was realized and validated to derive the reach capability data to build the population reach envelopes based on the individual-reach-capability data.

2. Data source

The data in this study were gathered as part of a border, unpublished study of seated posture, strength, and reach capability conducted at the UMTRI (Klein, 2012). Participants provided written informed consent using procedures approved by a University of Michigan Institutional Review Board. Twenty-six participants were recruited for this study. Of the 15 male participants 11 were truck drivers at the time of the study or had been a professional driver in the past two years. Two of the 11 female participants also fit these criteria. Standard anthropometric measurements were obtained, including stature, body mass, and erect sitting height. Table 1 listed the mean and standard deviation (SD) of the anthropometry of the participants within each percentile group, which showed that the anthropometry of participants well covered the US citizens.

Motion data of the participants were collected when they reached different targets while seated in a seating mockup. The H-Point of the seat was fixed and used as the origin of the Cartesian coordinate system. The target was placed on a wire grid. Three fore-aft locations of the wire grid were selected and marked “GridAft”, “GridMid” and “GridFor”. At each location,16 lateral and altitude location combinations were also selected to span the range of vehicle interior controls, as shown in Fig. 1. Each time after the subject reached for the target to touch or get the nearest access, a short rating of the reach difficulty was followed on a scale of 1–11, where1 is notably easy, 10 is notably difficult and 11 is unreachable.

Table 1
The statistics of the anthropometry of the participants, compared with NHANES[a] data.

	Measure	Mean	SD	Percentile				
				5th	25th	50th	75th	95th
Female	Age/(year)	45	16	20	32	51	57	65
	Mass/kg	71	21	48	55	65	83	101
	NHANES	69		48	57	66	78	103
	Stature/mm	1592	82	1484	1541	1580	1664	1700
	NHANES	1618		1504	1572	1617	1664	1731
	BMI/(kg▪m^{-2})	28	7	20	23	26	32	38
	NHANES	27		19	22	25	30	39
Male	Age/(year)	50	11	31	44	51	56	66
	Mass/kg	92	14	72	80	90	102	114
	NHANES	82		60	71	80	91	111
	Stature/mm	1749	91	1615	1701	1734	1804	1872
	NHANES	1756		1635	1707	1755	1805	1877
	BMI/(kg▪m^{-2})	30	4	24	27	30	33	35
	NHANES	27		20	23	26	29	35

[a] HNANES = the National Health and Nutrition Examination Survey.

The position of the target marker was set according to the test sequence. In all tests, no fore-aft seat adjustment was made. Only the right-upper-limb reaches were tested in this study.

Past studies and theoretical analysis indicate that the reach capability envelopes are best presented with sphere-like surfaces (Kennedy, 1964; Chaffee, 1969; Hammond and Roe, 1972; Roth et al., 1977; Kennedy, 1978; Asfour et al., 1978; Boydstun et al., 1980; Sengupta and Das, 2000). The reach capability is conveniently described in a spherical coordinate space. Consequently, all target position data with respect to the H-Point of the seat were expressed using the target distance R, zenith angle φ and azimuth angle θ as shown in Fig. 2, where the gray bands illustrate the ranges of orientation angles in this study.

In the following analyses, the target distance R with respect to the seat H-Point was used as the reach capability measure and called the reach capability radius (RCR). Only reachable targets were considered in this paper.

3. Reach capability modeling

Theoretically, the reach capability radius of an individual is affected by the reach difficulty, human body size (particularly the length of the effective kinematic chain from the seating position to the end-effecter of the human upper-extremity such as the right finger) and reach orientation:

$$\mathrm{RCR} = f(D; A; O) + \varepsilon \tag{1}$$

where RCR is the reach capability radius of the individual; D is the reach difficulty; A is the anthropometry vector; O is the orientation vector, which directs from the seat H-Point to the target point; ε is the estimation error. More difficulties cause more changes of posture to the body parts, and the reachable targets are further. The anthropometry length of the body parts of the kinematics chain may affect the maximum reach limit of the individuals. Along different orientations, the reach capability may be different. In the next section, these potential factors are identified.

4. Individual reach capabilities

Because difficulty feeling was a subjective measure of the reach operation, which was affected by the physiological and psychological factors, individuals rated differently for the same target. Therefore, for the same difficulty group, the average RCRs were