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Modeling study of seated reach envelopes based on spherical harmonics with consideration of the difficulty ratings

Xiaozhi Yu, Jindong Ren*, Qian Zhang, Qun Liu, Honghao Liu

State Key Lab of Automotive Simulation and Control, Jilin University, Changchun 130022, China

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ABSTRACT

Reach envelopes are very useful for the design and layout of controls. In building reach envelopes, one of the key problems is to represent the reach limits accurately and conveniently. Spherical harmonics are proved to be accurate and convenient method for fitting of the reach capability envelopes. However, extensive study are required on what components of spherical harmonics are needed in fitting the envelope surfaces. For applications in the vehicle industry, an inevitable issue is to construct reach limit surfaces with consideration of the seating positions of the drivers, and it is desirable to use population envelopes rather than individual envelopes. However, it is relatively inconvenient to acquire reach envelopes via a test considering the seating positions of the drivers. In addition, the acquired envelopes are usually unsuitable for use with other vehicle models because they are dependent on the current cab packaging parameters. Therefore, it is of great significance to construct reach envelopes for real vehicle conditions based on individual capability data considering seating positions. Moreover, traditional reach envelopes provide little information regarding the assessment of reach difficulty. The application of reach envelopes will improve design quality by providing difficulty-rating information about reach operations. In this paper, using the laboratory data of seated reach with consideration of the subjective difficulty ratings, the method of modeling reach envelopes is studied based on spherical harmonics. The surface fitting using spherical harmonics is conducted for circumstances both with and without seat adjustments. For use with adjustable seat, the seating position model is introduced to re-locate the test data. The surface fitting is conducted for both population and individual reach envelopes, as well as for boundary envelopes. Comparison of the envelopes of adjustable seat and the SAE J287 control reach envelope shows that the latter is nearly at the middle difficulty level. It is also found that the abilities of reach envelope models in expressing the shape of the reach limits based on spherical harmonics depends both on the terms in the model expression and on the data used to fit the envelope surfaces.

1. Introduction

The capability of seated reach has great significance to the design of the controls. To aid the design, studies have been conducted regarding the maximum reach envelopes based on tests and statistics (Kennedy, 1964; Chaffee, 1969; Hammond and Roe, 1972; Roth et al., 1977; Asfour et al., 1978; Chevalot and Wang., 2004, 2007, 2008; Klein, 2012) or by computer simulation (Korein, 1985; Kee, 2002; Abdel-Malek et al., 2001, 2004; Reed et al., 2003a,b; Kozey and Das, 2004; Parkinson and Reed, 2007; Klopčar et al., 2007), which are considered as the position limits of the controls. Fig. 1 shows the typical reach capability limits of pilots in section views (Kennedy, 1964). The most commonly used reach envelopes in the automotive industry are the SAE J287 control reach envelopes, which are presented in data tables with the input parameters of the packaging dimensions (expressed as G factor), the belt type and the male/female ratio of target population (Society of Automotive Engineers, 1988; 2007).

Reach capability limits are usually represented using data tables or envelope surfaces. The data tables are used in early studies and can be easily included in the design validation of controls. However, for modern simulation, it is desirable to use envelopes, especially ones expressed analytically. In addition, the test data of reach capability are usually conditional and restricted to small ranges of body postures (Boydstun et al., 1980). For practical use, these data must be derived and expanded for a variety of postures.

* Corresponding author.
E-mail addresses: renjindong@jlu.edu.cn, renjindong@163.com (J. Ren).

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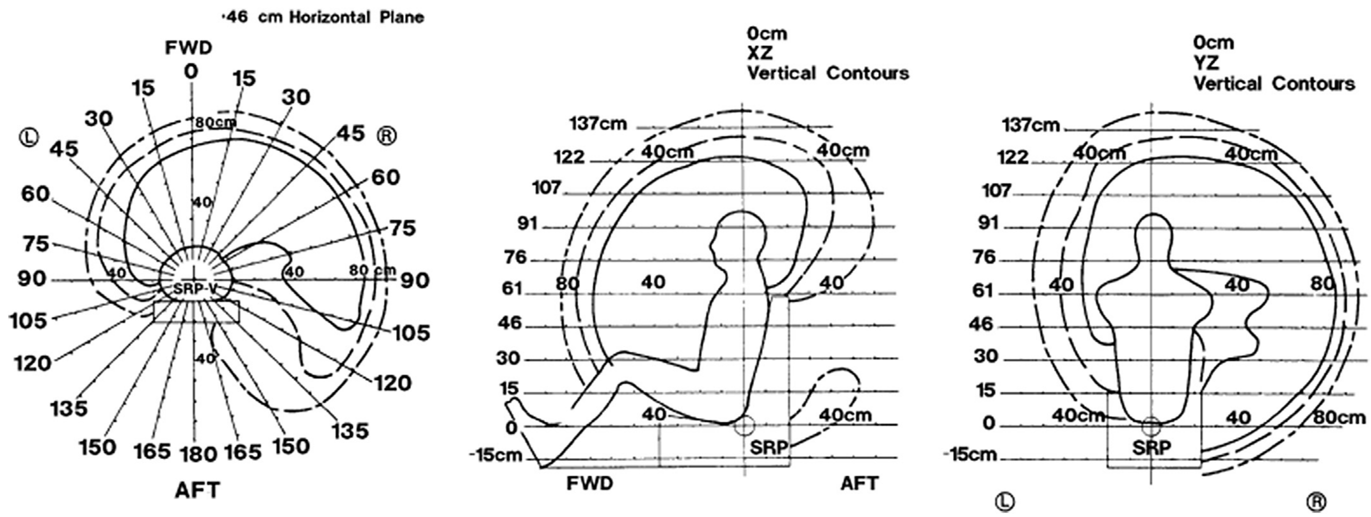

Fig. 1. Typical reach capability data of pilots, with 5th, 50th and 95th percentile contours.

There are two types of reach envelopes: individual envelopes and population envelopes. For industrial use, population envelopes are more suitable, as they have the ability to accommodate an adequate percent of the target population. In building the population envelopes, the potential factors such as reaching difficulty, anthropometry, task variables, and seating positions must be kept in mind (Reed et al., 2003a; Chevalot and Wang, 2004).

Traditional percentile contours of the reach capability data are usually processed along the horizontal or vertical planes (Kennedy, 1964; Chaffee, 1969; Hammond and Roe, 1972; Roth et al., 1977); which brings laborious work to data processing and is inconvenient to use in simulation. Another method of generating reach envelopes is by building the model of the kinematic chain of the human body to conduct the simulation of reaching tasks (Korein, 1985; Kee, 2002; Abdel-Malek et al., 2004; Parkinson and Reed, 2007; Klopčar et al., 2007). However, the correct envelopes can be acquired only when accurate kinematic parameters are set. Regarding the mathematical description and generation of reach envelopes, spherical harmonics are recommended because of their ease of use compared with spline regression and periodic spline regression (Boydstun et al., 1980) and because the use of spherical harmonics is an accurate and less biased method for the representation of reach envelopes. Traditional reach envelopes provide little information about the operators' experience of difficulty when reaching. In effect, even the controls are within the traditional reach envelopes, the experience of difficulty may be different for drivers with different postures and body anthropometry. A recent study (Klein, 2012) extends the application of the spherical harmonics in fitting the seated reach capability data with different difficulty ratings. In their study, the combinations of the first two order spherical harmonics are used to model the seated reach capability radius. Because the population envelopes are preferable for design, a more generalized expression with the capability of providing various combinations of the components of the spherical harmonics is desirable to be established.

In this study, reach envelopes of seated drivers were modeled using spherical harmonics. The model coefficients were derived using the least square method (LSM). The abilities of envelope models in expressing the shape of the reach capability limits based on spherical harmonics were analyzed for different combinations of the real and imaginary terms of the spherical harmonics. Based on the test data of seated reach and the corresponding difficulty ratings from the Bioscience lab of the UMTRI (University of Michigan Transportation Research Institute), the individual and population reach envelopes were fitted with spherical harmonics for different reach difficulties. The surface fitting using spherical harmonics was studied for the circumstances both with and without seat adjustments. For use with adjustable seat, the seating position model was introduced to re-locate the test data. The re-positioned reach data were fitted, and the population reach envelopes were acquired and compared with the SAE J287 control reach envelope. The boundary envelopes were also fitted and compared with the population envelopes for different difficulty ratings.

2. Spherical harmonics

Previous studies show that the maximum reach envelopes for an operator can be expressed as sphere-like surfaces (Kennedy, 1964; Chaffee, 1969; Hammond and Roe, 1972; Roth et al., 1977; Korein, 1985; Kee, 2002; Abdel-Malek et al., 2001, 2004; Reed et al., 2003a; Kozey and Das, 2004; Chevalot and Wang., 2004; Wang et al., 2007, 2008; Parkinson and Reed, 2007; Klopčar et al., 2007; Klein, 2012) and can be described well using spherical harmonics. Spherical harmonics are the angular solution to the Laplace's equation in spherical coordinates and are generally defined as:

$$Y_l^m(\varphi,\theta) = NP_l^m(\cos\varphi)e^{im\theta} \tag{1}$$

where$Y_l^m(\varphi,\theta)$ is called the spherical harmonic function of degree l and order m, with $-l \le m \le l$; N is the normalization constant;$P_l^m(\cos\varphi)$ is the derivative of the associated Legendre polynomial of degree l, order m; φ is the zenith coordinate,$\varphi\in[0,\pi]$; θ is the azimuth coordinate,$\theta\in[0,2\pi]$.Spherical harmonics are sometimes separated into their real and imaginary parts. In physics, the normalization constant takes the following value:

$$N = \sqrt{\frac{(2l+1)(l-m)!}{4\pi(l+m)!}} \tag{2}$$

The first several degrees and orders of analytic expressions of the orthonormalized spherical harmonics are listed in Table 1.

3. Modeling reach envelopes using spherical harmonics

The surface of the reach envelope can be expressed using a