

Research on Driving Posture Comfort Based on Relation between Drivers' Joint Angles and Joint Torques

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ABSTRACT

Driving comfort is one of the most important indexes for automobile comfort. Driving posture comfort is closely related to the drivers' joint angles and joint torques. In present research, a new method is proposed to identify the most comfortable driving posture based on studying the relation between drivers' joint angles and joint torques. In order to truly reflect a driving situation, the accurate human driving model of 50 percent of the size of Chinese male is established according to the human body database of RAMSIS firstly. Biomechanical model based on accurate human driving model is also developed to analyze and obtain dynamic equations of human driving model by employing Kane method. The joint torque-angle curves of drivers' upper and lower limbs during holding wheel or pedal operation can be obtained through dynamic simulation in the MATLAB. Through curve-fitting analysis, the minimum joint torque of a driver' limb and the optimal joint angel can be found. As an important reference, these parameters can be used to optimize driving seat structure and offer an important support for the optimization of cab package.

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INTRODUCTION

By now, the knowledge and understanding of human-body dynamics have increased substantially. There are many methods which have been used to analyze the dynamics of rigid bodies such as Newton's laws, Lagrange's equations, Lagrange's form of d'Alembert's principle, Kane method and so on. In this paper, Kane method is employed to analyze and obtain dynamic equations of human driving model. This method could eliminate nonworking constraint forces and also avoid the lengthy differentiation of energy functions by using vector derivatives which in turn may be computed through multiplication algorithms[1]. In traditional way, the driver comfort is often evaluated by subjective feeling of driving posture. While this paper is intent to substitute a new method for comfort angles and tries to evaluate driver comfort in theoretical and objective way.

THE ESTABLISHMENT OF DYNAMIC MODEL

In the process of actual driving, driving operations are generally completed in the driver's sitting position. And most of driving operations can be done by upper or lower limbs' independent participation.

For example, pedal operations are mainly completed by driver's lower limbs, while steering operation is substantially achieved by upper limbs. And the driver hip point (H-point) will

not have too much displacement from its initial position in the driving process. Based on these factors, the human driving model can be simplified in reason, and the method of subsection modeling is adopted to simplify human body dynamic modeling process.

In order to find the relation between drivers' joint angles and joint torques, driving model of 50 percent of the size of Chinese male is taken for example. According to the human body database of RAMSIS, Mass and length of 50th percentile Chinese male body segments can be obtained as shown in [table 1](#). (Position of Mass Center λ = the distance between mass center of the body and upper joint / the dimension of the corresponding body. For example, the position of mass center of thigh: λ_1 = the distance between mass center of thigh and the hip joint / the dimension of the thigh.)

In human driving model, limbs are connected through hinges and ball-and-socket joints. Hinges are located at the ankles, knees, elbows, and spine and ball-and-socket joints are located at the neck, shoulders, hands, and hips. Each hinge introduces 1 degree of freedom and each ball-and-socket introduces 3 degrees of freedom[2]. In driving situation, hand and lower arm can be thought on the same line, so the wrist joint angle can be ignored. In order to analyze and obtain dynamic equations, the simplified human driving model is established as [figure 1](#).



Table1. Mass and Length of 50th percentile Chinese male Body Segments.

Body Segment	Mass(kg)	Length(mm)	Position Of Mass Center (λ)
Upper arm	1.672	252.29	0.52
Lower arm	1.279	227.48	0.44
Hand	0.455	90	0.5
Thigh	7.2	417.3	0.44
Lower leg	2.7	361.4	0.41
Foot	1.66	153.3	0.48

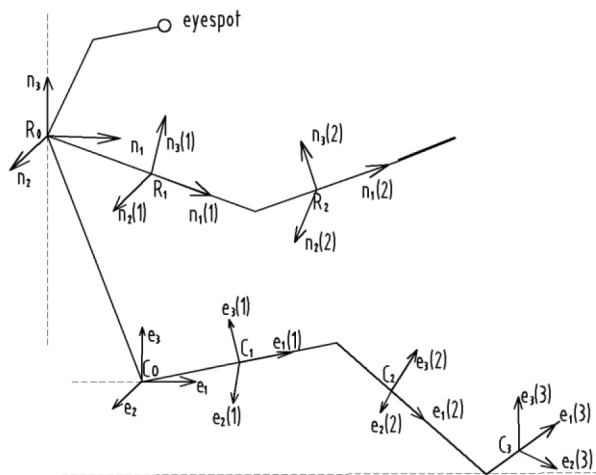


Figure 1. The establishment of the coordinate system of the driving model.

In this driving model, C_0 and R_0 are inertial reference frames. $e_i(k)$ and $n_i(k)$ ($i, k=1, 2, 3$) are orthogonal unit vector, and the vectors are parallel respectively. Then, three successive dextral rotations of C_0 (R_0) about axes parallel to e_1 , e_2 and e_3 (n_1 , n_2 and n_3) through the angles α, β and γ (α_1, β_1 and γ_1) brings C_0 (R_0) into a general orientation with respect to C_i (R_i) ($i=1, 2, 3$). The reference frames C_i (R_i) ($i=1, 2, 3$) are built on the position of mass centers of the system bodies. So the position of hip and shoulder joint is fixed, and the other joints' position changes with the angles of corresponding joints.

GOVERNING DYNAMIC EQUATIONS

In this driving model, thigh(upper arm) can only rotate around the vectors e_2 or e_3 (n_2 or n_3), so the ball-and-socket joints at hip and shoulder introduce 2 degrees of freedom, while hinges at the ankle, knee, elbow and wrist introduce 1 degree of freedom.

Geometry, Shifter Matrices

The Cardan coordinate of R_1 relative to R_0 is assumed as $(0, \beta_1, \beta_2)$; the shoulder joint angle and elbow joint angle are assumed as α_1, α_2 respectively; The generalized coordinates $(\beta_1, \beta_2, \alpha_2)$ represent these degrees of freedom. So the shifter matrix of each reference frame of upper limb can be expressed as follows:

$$A^{01} = A^1(\beta_1) * A^2(\beta_2)$$

$$A^{02} = A^{01} * A^{12}(\alpha_2)$$

(1)

Where $A^1(\beta)$, $A^2(\beta)$ and $A^{12}(\alpha)$ are defined as

$$A^1(\beta) = \begin{bmatrix} \cos \beta & \sin \beta & 0 \\ -\sin \beta & \cos \beta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$A^2(\beta) = \begin{bmatrix} \cos \beta & 0 & -\sin \beta \\ 0 & 1 & 0 \\ \sin \beta & 0 & \cos \beta \end{bmatrix}$$

$$A^{12}(\alpha) = \begin{bmatrix} -\cos \alpha & \sin \alpha & 0 \\ -\sin \alpha & -\cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

(2)

In the same way, the Cardan coordinate of C_1 relative to C_0 is assumed as $(0, \theta_1, \theta_2)$; the hip joint angle and knee joint angle are assumed as α_3, α_4 respectively; the ankle joint angle is assumed as α_5 . The generalized coordinates $(\theta_1, \theta_2, \alpha_4, \alpha_5)$ represent these degrees of freedom, the shifter matrix of each reference frame of lower limb can be expressed as:

$$B^{01} = B^1(\theta_1) * B^2(\theta_2)$$

$$B^{02} = B^{01} * B^{12}(\alpha_4)$$

$$B^{03} = B^{02} * B^{23}(\alpha_5)$$

(3)

Where $B^1(\theta)$, $B^2(\theta)$, $B^{12}(\alpha)$ and $B^{23}(\alpha)$ are defined as

$$B^1(\theta) = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$B^2(\theta) = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{bmatrix}$$

$$B^{12}(\alpha) = \begin{bmatrix} \cos \alpha & 0 & \sin \alpha \\ 0 & 1 & 0 \\ -\sin \alpha & 0 & \cos \alpha \end{bmatrix}$$

$$B^{23}(\alpha) = \begin{bmatrix} -\cos \alpha & 0 & -\sin \alpha \\ 0 & 1 & 0 \\ \sin \alpha & 0 & -\cos \alpha \end{bmatrix}$$

(4)

Angular Velocity

The angular velocity of a typical body of the model can be obtained from the addition formula of Kane method. So the angular velocity of the body can lead to the expression: