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A Simplified Human Body Model for Assisting in Electric Bicycle Design

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ABSTRACT

Compared to non-electric bicycles, power-assistance ones could be designed for more postural comfort with less consideration of power production when pedalling. The present work aimed to develop a simplified human body model to assist in the design of power-assisted bicycles to better accommodate a target user population. To characterize body posture in bicycle use, the inter-segmental angles corresponding to a reference posture were measured from a sample of 63 males and females testing 4 existing bicycle models for comfort and long distance use. As a first approximation, only upper body was modelled as a 2D linkage composed of trunk (hip to shoulder) and arm (shoulder to grip) segments. To better account for postural effect, functional segment lengths were measured in a reference posture, and used to build the regression equations with body height. For a given bicycle characterized by saddle and handlebar position, the hip and shoulder angles could be fully determined for a rider using the proposed model. To validate the model, we compared the measured and predicted inter-segmental angles and showed that the proposed human model could account for the effects of both body height and bicycle's geometry. To show the usefulness of the proposed model, a comfortable range of hip and shoulder angles was defined from the experimental data and was used to predict the fit area of handlebar and saddle position for both short and tall persons. Simulation results show that a more reclined seat tube could better accommodate both short and tall users.

Keywords: Electric bicycle, Postural comfort, Anthropometry, Kinematic model

INTRODUCTION

Bicycling is not only a popular recreational activity, but also becoming an alternative means of transport for many people. For ecological, economical and health reasons, there is an increasing demand on electric bicycles. Compared to non-electric bicycles, power-assistance ones could be designed for more postural comfort with less consideration of power production when pedalling. Saddle height, saddle tube angle and handlebar position are the design parameters, which affect cycling posture the most. To optimize pedal power, it is generally recommended that the saddle should be positioned so that the knee is directly above the pedal spindle with the cranks at 3 o'clock position (Burt, 2014), thus limiting the choice of saddle tube angle. Price and Donne (1997) showed that a steeper tube angle lowered oxygen consumption at a fixed power output. With lower demand in power production for electric bicycles, it is possible to choose a larger range of tube angle including more reclined saddle tube, and to reduce number of model sizes (thus design and production time and cost) for a product to fit a target population. However, few studies have been carried out to look at the effects of tube angle and rider's anthropometrics on comfortable bicycle design. The present work aimed to develop a simplified human body model to assist in the design of power-assisted bicycles to better accommodate a target user population.

Experimental Observations

To characterize body posture in bicycle use, the inter-segmental angles corresponding to a reference posture were measured from a sample of 63 male and female adult riders, who tested four existing bicycle models for comfort and long distance use. The participants, aged from 21 to 64 years old, were selected to cover a large range of anthropometrics with body height ranging from 1m52 to 1m96. Prior to experiment, their main anthropometric dimensions were measured including body height (H), weight, crotch height, acromion to wrist length. The selected test bicycles covered a large range of city bicycles with the saddle tube angle being from 17° to 26° (with respect to the vertical). For all models except one, participants tested either the large or medium size depending on body height for 10 minutes in an outdoor tour during which they could adjust saddle height. They were then asked to adopt a reference riding posture inside a room with the arms being fully extended and two pedals on their vertical positions (Figure 1). A photo was taken to measure the corresponding trunk (A1) and trunk to arm (A2) angles as well as the hip to shoulder (HS) and shoulder to wrist (SW) lengths. Markers were attached on the surface positions of wrist, acromion, greater trochanter, knee and ankle to help locate joint position from photos. The adopted saddle height L was measured with a tape. At the end, participants were asked to answer a questionnaire about their feeling on handlebar and saddle position and its

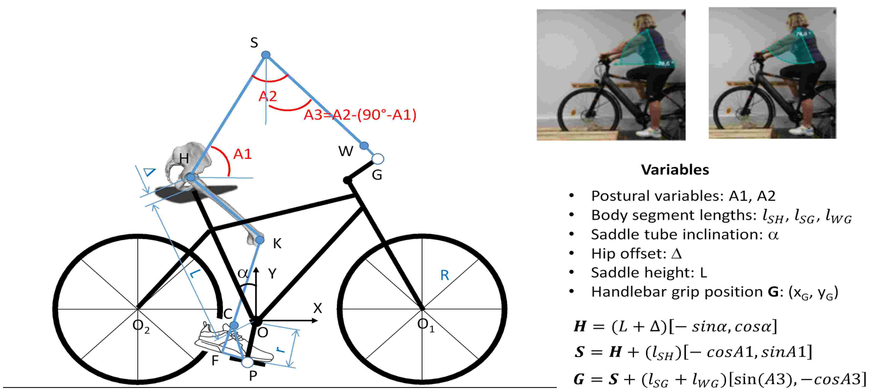

Figure 1: Main bicycle design parameters and postural angles.

acceptability for everyday use. For the 4^{th} test bicycle, only the indoor test was performed without outdoor testing.

Upper Body Kinematic Model

For the reference posture, body posture was mainly characterized by trunk (A1) and trunk to arm (A2) angles (Figure 1). We made the following simplification hypotheses:

- Saddle position is only dependent on its tube orientation (α) and body height (or inside leg length/crotch height).
- Upper body is simplified as a 2D linkage of hip, shoulder and grip points. The lengths of these two segments (hip to shoulder and shoulder to grip) are only dependent on body height, and the wrist to grip length l_{WG} is a constant to be determined.
- The offset Δ between saddle and hip joint center H is a constant along the saddle tube axis to be determined.

To better account the effects of riding posture, the hip to shoulder and shoulder to wrist lengths measured from the photos of reference posture were used to establish the regression equations from the experimental data (Table 1).

Table 1. Coefficients of regression equations without constant for the simplified kinematic model. *H, Se* and R^2_{adj} are body (or crotch) height, standard error of estimate and adjusted R-squared value.

Variable	Height (H)	S_e (cm)	R^2_{adj}(%)
Saddle height (L)	0.412	2.79	99.8
Saddle height (L)*	0.898*	3.15	99.8
Hip to shoulder length l_{SH}	0.313	3.43	99.6
Shoulder to wrist length l_{SW}	0.318	2.58	99.8

*coefficient of crotch height

For a given bicycle with known saddle and handlebar positions, the trunk (A1) and trunk to arm (A2) angles are fully determined for a rider assuming that two constants Δ and l_{WG} are known. Δ and l_{WG} of 2.8 and 4 cm were found by trial and error using the experimental data. To validate the proposed model, the predicted trunk (A1) and trunk to arm (A2) angles were compared with experimental ones using the regression equations in Table 1 (Figure 2). The mean errors were −0.38 (±4.82) and −0.27 (±4.0) degrees for A1 and A2.

APPLICATION

One of important design problem is to find an appropriate saddle tube angle α and handlebar position **G** to fit a target population with a large variation in body height. From the collected data, we observed that trunk (A1) and trunk to arm (A2) angles were significantly correlated, as shown in Figure 3. A contour curve of the bivariate Gaussian distribution of A1 and A2

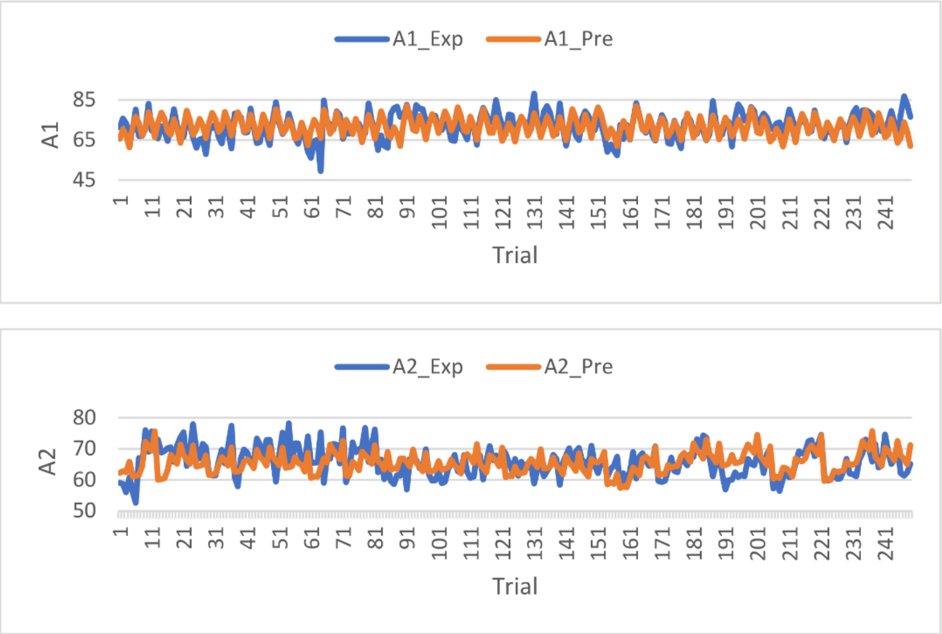

Figure 2: Comparison between experimental and predicted trunk (A1) and trunk to arm (A2) angles in degrees.

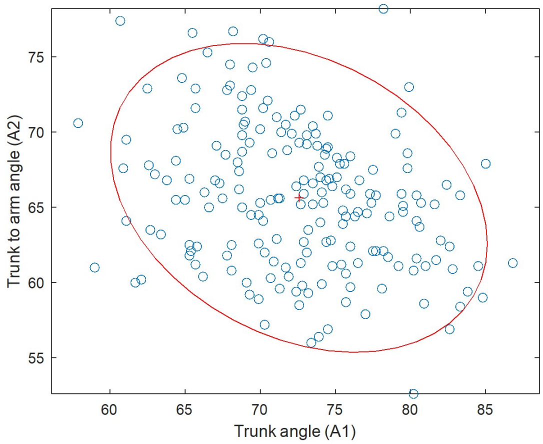

Figure 3: 90% confidence ellipse of the distribution of the trunk to arm (A2) and trunk (A1) angles observed from the trials for which the test bicycles were considered as 'acceptable' by participants.

was thus used to define the acceptable postural region. Figure 4 shows the 'acceptable' saddle and handlebar positions for two 155cm and195cm tall persons and two tube angles (15° and 25°) when applying the 90% confidence ellipse of acceptable postural angles. One can see that a design with an adjustable saddle and a fixed handlebar position could fit both short and tall riders for the two saddle tube angles. A more inclined saddle tube increases

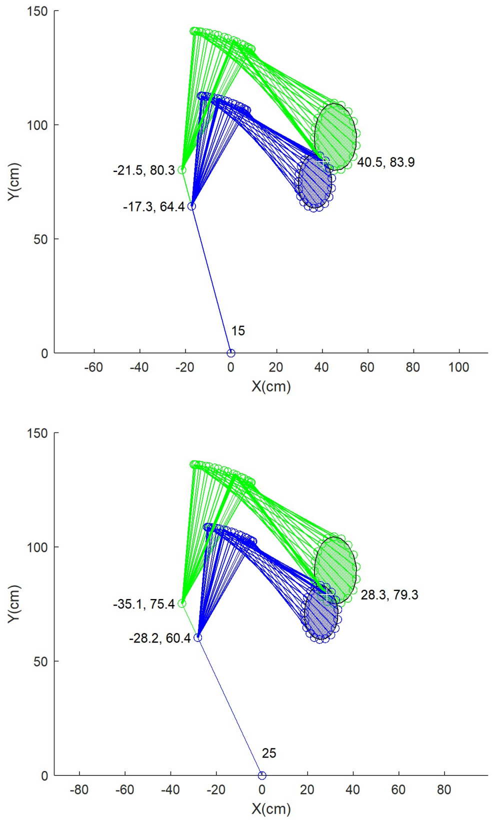

Figure 4: Simulated saddle and handlebar positions for a short (155 cm, bleu) and a tall (195 cm, green) rider corresponding to the 'acceptable' ellipse of the trunk to arm (A2) and trunk (A1) angles defined in Figure 3 for saddle tube angles of 15° and 25°. '+' is the barycentre of the common area of the simulated handlebar positions of both extreme persons.

the superimposed area of acceptable handlebar positions between the two extreme riders. This suggests a more reclined saddle tube is preferred for a better accommodation of a target population.

DISCUSSION

In the present work, we proposed a simplified upper body geometric model to assist bicycle design. The segment lengths were determined from a reference riding posture for city use as well as corresponding regression equations with respect to body height. Applying the 'acceptable' range of trunk and trunk to arm angles observed from 63 volunteers testing 4 bicycle models, we found that a more reclined saddle tube could provide a larger common area of acceptable handlebar positions for both short and tall users.

Compared to a similar study by Hsiao et al (2015), the handlebar position predicted by the proposed model to fit both short and tall persons is closer and higher with respect to the saddle. For the city bicycle type, Hsiao et al proposed a handlebar position at (38.3cm, 66.0cm) with the tube angle varying from 23.6° to 19°. For a tube angle of 22°, our model predicts a position of (31.2cm, 78.8cm) for two 155 and 185cm tall persons, the same height range as tested in Hsiao et al. This implies that the comfortable range of riding posture defined in the present study corresponds a more upright trunk and smaller trunk to arm angle. This could be explained at least partly by difference in body size between two studies (participants from France and Taiwan) as well as in experimental protocol. The comfortable riding postural range used in the present study was based on the 'acceptable' ellipse of trunk and trunk to arm angles obtained by testing only 4 existing bicycle models. Further investigations are needed to define comfortable postural range for riding electrical bicycles especially by testing a larger number of existing models and/or through a parametric study with an adjustable experimental bicycle setup allowing larger range of adjustment of bicycle design parameters.

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