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CAR FOLLOWING BY OPTICAL PARAMETERS

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Summary: A model for car following based solely on optical parameters was developed and compared with performance of human drivers in a simulator. The model uses the optical size of the back of the car being followed and the first derivative of its optical size as inputs. The model consists of two components: one that accelerates to maintain the visual size of the leading car, and another that accelerates to minimize changes in the rate of change of the visual size of the leading car. The simulator presented drivers with a leading car that was changing its velocity according to a sum of non-harmonic sines. Comparisons of human drivers' performance with the models' show a high degree of similarity.

INTRODUCTION

Most existing models of car following (e.g., Chandler, Herman, & Montroll, 1958; Helly, 1959) assume that the control system uses 3D environmental variables (distance between cars, velocity of cars) as inputs. Certainly the goal of drivers who are car following is to manage these 3D parameters. The present research focused on the perceptual information used by a driver for car following (see Michaels, 1963). When considering the perceptual information for car following it is important to note that the visual system does not have direct information for recovering 3D parameters for car following (an exception of course is the speedometer of the driver's vehicle). In order to understand the perceptual information for car following one must consider the projected 2D visual information available to the retina. The present model is based on the visual information available to the driver. The model uses visual angle (of the back of leading vehicle) and change in visual angle to regulate speed during car following.

Michaels (1963) suggested that visual size of the leading vehicle (LV) be used to model car following. A few researchers have already presented models of car following based on visual parameters (e.g., Lee & Jones, 1967; van Winsum, 1999), but they suffer from other problems that are addressed in the model. Lee (1976) added valuably to this issue by showing that time to contact (TTC)—the inverse rate of expansion of an approaching object—during braking was an optical variable. TTC is of limited usefulness in actual car following, as successful car following entails keeping TTC infinite. Van Winsum's model employs TTC, but only addresses negative accelerations, and so is difficult to evaluate in general terms. Lee and Jones present a model that scales acceleration by the rate of change of the visual angle, a model that does a very good job of matching the velocity of the LV. It suffers though (as do many of the 3D parameter models) by failing to match distance. With these models, when relative velocity between the LV and following vehicle (FV) is zero (and consequently so is the rate of change of the visual angle of the LV), the acceleration response of the model is also zero.

An example of when this would be a problem for car following is when the LV enters the lane ahead of the FV at the same velocity as the FV, but at a distance too close for comfort. The velocity matching models have no ability to affect a deceleration to address this problem. Velocity matching models make another mistake in assuming that the acceleration/braking performance of the LV and the FV are equal. If the FV's ability to accelerate was not as great as the LV's, quick increases in speed by the LV would be unmatchable by the FV, and it would lose headway, even when the LV stopped accelerating. There must be a component of the model able to change speed in order to achieve desired distance headway.

Helly (1959) presented a model that contains a linear combination of a velocity difference minimizing factor with a distance headway minimizing factor. In models of this nature, the acceleration response is only zero when both a) velocity difference is zero and b) the desired distance headway has been achieved. Helly's model will serve as a basis for the present model, with 3D parameters replaced by appropriate 2D visual parameters.

Visual angle is related to width and distance by the following:

$$\theta = \frac{w}{d}$$

This simple relation can be used in a control system to scale acceleration response in order to maintain a desired headway, by scaling acceleration by distance headway (d), or equivalently by $1/\theta$.

$$d = \frac{w}{\theta}$$

In order for this parameter to function properly, it must be equal to zero when the appropriate distance headway (or visual angle) is reached. This is accomplished by subtracting the desired distance headway from the above expression.

After substituting in visual parameters for 3D parameters, Helly's model becomes:

$$acceleration = j \cdot \left(\frac{1}{\alpha} - \frac{1}{\alpha'} \right) + k \cdot \frac{d}{dt} \alpha$$

Where alpha is the visual angle extent of the lead car, alpha prime is the desired visual angle extent of the lead car, $d\alpha/dt$ is the rate of change of α, and j and k are scalars.

In line with safety recommendations, the desired distance headway can vary with the driver's speed. The present model incorporates a safe distance by replacing the constant α' with a functional α':

$$\alpha' = 2 \cdot atan \left(\frac{w}{timegap \cdot FVv} \right)$$

Where w is the width of the lead car, timegap is the desired time headway, and FVv is the velocity of the driver.

METHODS

Drivers were presented with a car following scenario in which the lead vehicle varied its velocity according to a sinusoid. We used 5 levels of frequency (0.0513, 0.05913, 0.0711, 0.08617, and 0.1111 Hz) and 6 levels of amplitude (5, 10, 15, 20, 25, 60 km/h). Five undergraduates from UCR served as drivers. Drivers were told to maintain their initial separation from the lead car despite changes in velocity of the lead car. At the beginning of each drive, participants were given 5 seconds of driving at a constant speed behind a constant speed lead car to establish the distance to be maintained. Trials lasted 60 seconds. Each combination of frequency and amplitude was presented once during each of two sessions.

RESULTS

Driver performance is summarized by gain and phase angle relative to the lead car's velocity profile for each frequency and amplitude presented (Figure 1).
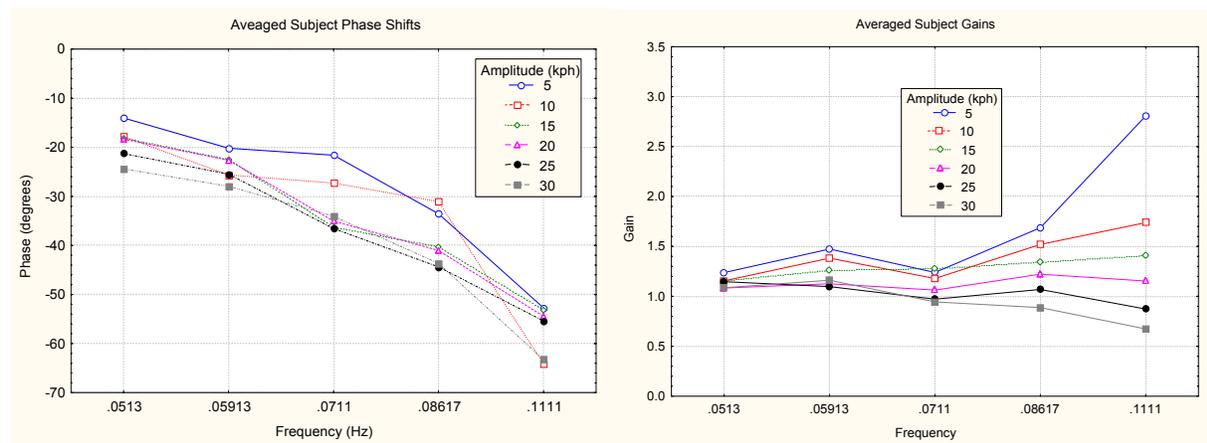

Figure 1. (a) Phase shift for each combination of frequency and amplitude; (b) Gains for each combination of frequency and amplitude.

The model was presented with the same scenarios that were presented to the subjects. Its parameters were found through a series of Monte Carlo simulations designed to produce similar parameters to those found by averaging over the subjects. The desired timegap used by the model was 1.35 sec, which was the initial timegap at the beginning of each trial. A model with $j = .3$ and $k = -5$ produces the gains and phase angles shown in Figure 2.
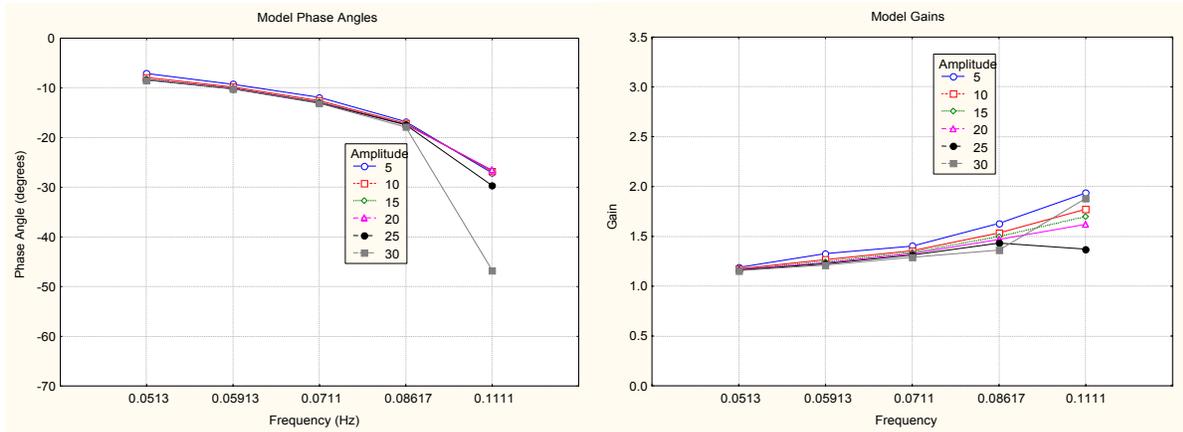
Figure 2. (a) Model phase angles and (b) model gains for each combination of frequency and amplitude.

Figure 3 shows a velocity profile over time for a representative driver, the model, and the lead car for the scenario with frequency = 0.0711 Hz and amplitude = 20 kph.
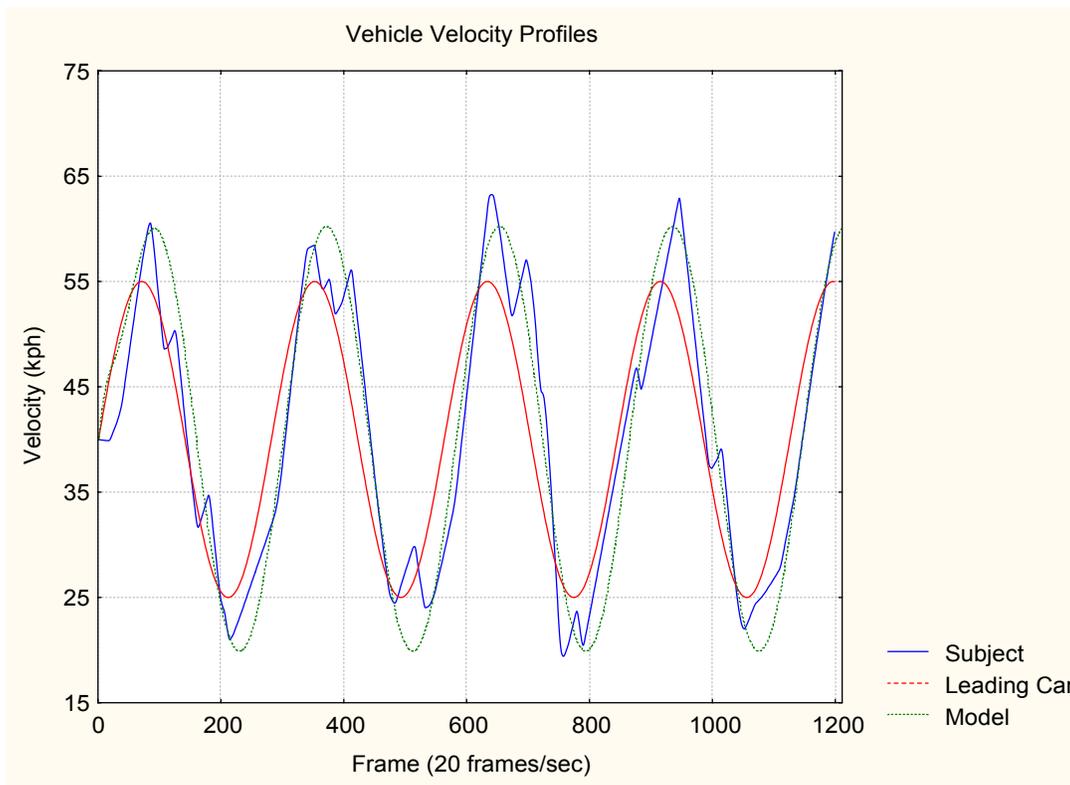

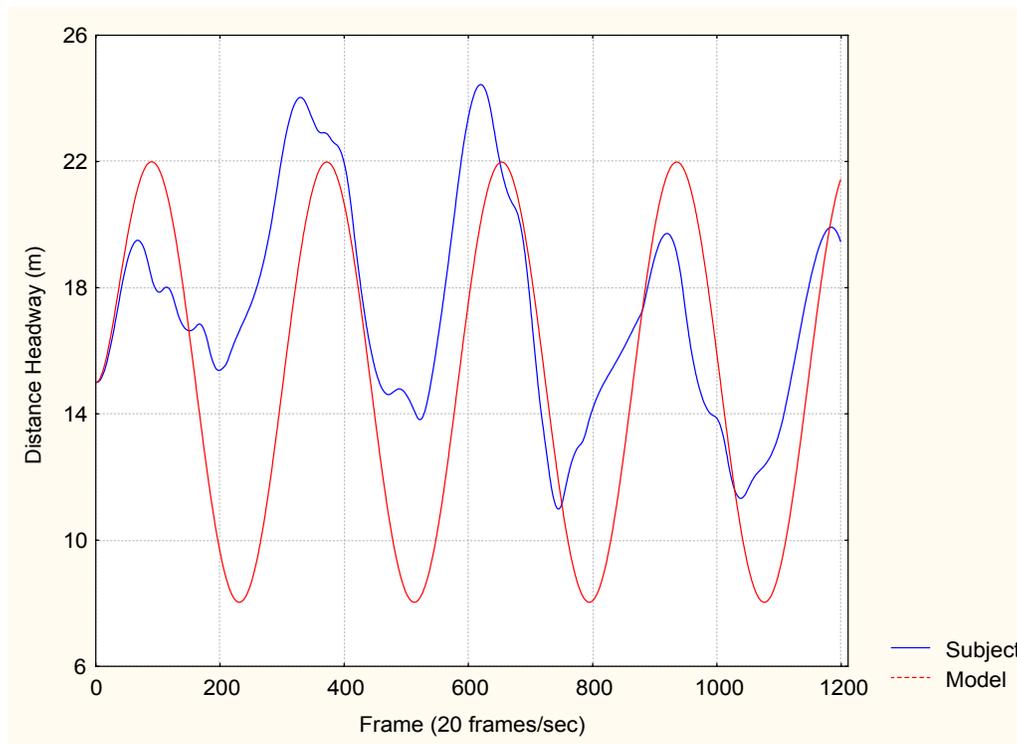**Figure 3. A representative velocity profile for a human subject, leading car, and model.**

Figure 4. A representative headway profile for a human subject, leading car, and model.

CONCLUSIONS

In general, the performance of the model successfully matched the performance of human drivers. The lower gains and phase shifts found in the model's performance are probably due to the variable attention of the human drivers. The human driver also shows an asymmetry in distance headway (the distance between the lead and following vehicles) that is not present in the model's performance. This would be a good feature to incorporate into future versions of the model: it is more important to avoid small headways than large headways.

ACKNOWLEDGEMENTS

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