A KINETICS MODEL OF INTELLIGENT VEHICLE GUIDANCE

ABSTRACT

This paper proposes a kinetics model which drives safely through traffic environments and smoothly accelerates, decelerates, stops and starts in the same manner as human drivers do. The environmental force, which is a virtual force, is introduced to physically express the motion of a vehicle. The field of environmental force keeps the vehicle to act on calculated behavior. Examples of the environmental force equation for specific traffic environments and results of calculation are shown.

INTRODUCTION

Most people familiar with ITS are of the opinion that a fully automatic driving system, which represents the ultimate accident avoidance system that will virtually replace the driver, will not materialize even thirty years from now. In the United States and other countries, the R&D efforts for driving control systems are shifting their focus from the automated highway system (AHS) to driver assistance systems.

To produce a driver assistance system, the involvement of the car with the traffic environment which can be obtained from visual information needs first of all to be physically quantified. This paper will introduce one of such physical expressions.

MOTION OF VEHICLE

The motion of a vehicle is more of a human motion than a mechanical motion. Since there are human occupants in a vehicle, the motion of the vehicle should be comfortable and smooth to fit the human physiology. The vehicle should comply with the traffic environment, stop whenever the traffic lights turn red, follow the vehicle ahead at a safe distance, actions which constitute normal human behavior. The next section will discuss with the physical expression of such motion.

ENVIRONMENTAL FORCE

The environmental force, which is a virtual force, is introduced to physically express the motion of a vehicle. When a vehicle stops at a red light, it is assumed that the traffic light is exerting a force upon the vehicle to stop its motion. When the driver does not close the distance from the vehicle ahead, it is assumed that the vehicle can not move any closer to the vehicle ahead because of the force exerted by the vehicle ahead. There is force by static environment (road shape, road width, etc.),force by other vehicles & other moving objects) and force by traffic control. These forces will be called the “environmental force”. Moreover, the environmental force must be smooth and comfortable to fit the human physiology. Equation (1) is the general expression of the environmental force equation.

$$x'' \;=\; f\left(x, x', X, V\right) \qquad (1)$$

Safe velocity V at position X in the environment

Fig. 1 shows the image of the environmental force. Since the vehicle receives the environmental force, and moves with human occupants inside the vehicle, the human physiological properties needs to be considered first in the determination of *f*( ).

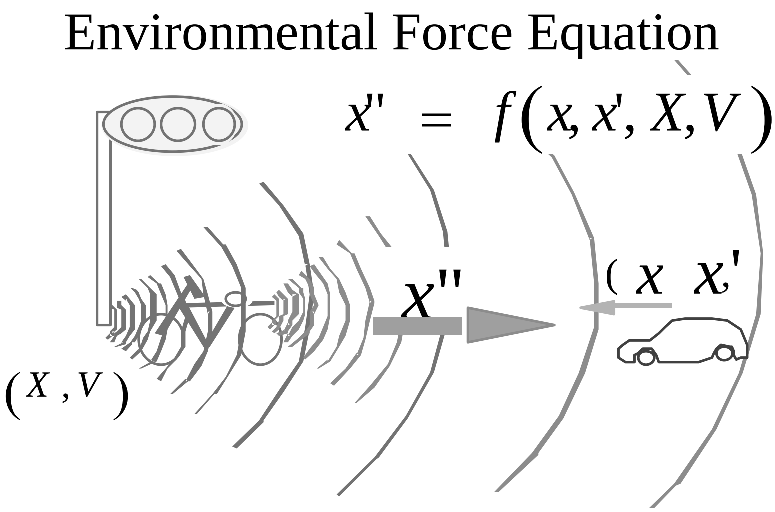


Fig.1 The acceleration of t he vehicle which approach the environment is generated according to the vehicle velocity x' and vehicle relative position X- x.

ENVIRONMENTAL FORCE DERIVED FROM HUMAN PHYSIOLOGY

Most human sensations are known to follow the Weber’s law.

According to this law , $\frac{\Delta S}{S} = C \;\; : const$ when the increment ΔS of the stimulus S is the just noticeable difference of stimulus.

The smooth motion of a vehicle is produced by the sensation of inertial force as it is better perceived with our eyes closed.

Substitute acceleration x'' for stimulus S

$$\frac{x''' \Delta t}{x''} = C$$

Integrate this equation

$$x'' = a - C\,x' \qquad \text{a , C is constant} \qquad (2)$$

To control not only the passenger comfort but also the speed and the position, this equation of motion is changed into the environmental force equation which is dependent on speed and position. This will achieve smooth stopping of the vehicle at a traffic light, and while following a vehicle ahead, with excellent passenger comfort and travelling comfortably at a safe speed to fit the traffic environment.

ENVIRONMENTAL FORCE THAT FIT THE TRAFFIC ENVIRONMENT

It is physically impossible for a vehicle of considerable mass to radically change its speed. To control the speed and the position, the speed of the vehicle must be reduced in a pre-planned manner based on the prediction of the future traffic condition.

Since people often act on the prediction of future conditions, Professor Hirao assumed that traffic accidents are caused by “miscalculation”, and clearly explained the causal relationship between human behavior and traffic accident. It is important to consider the fact that “people act on calculations” when expressing the human behavior in the physical equation.

Here, equation (2) is solved for various initial velocities, and the velocity is plotted on the vertical axis against time on the horizontal axis as shown in Fig. 2. Fig. 2 shows that equation (2) is an equation of motion in which the velocity ultimately converges to a/C from any initial velocity.

The vehicle that moves according to equation (2) is capable of traveling through the traffic environment at the predicted environmental speed a/C (as determined by the traffic environment C) at any initial speed. In other words, equation (2) is capable of taking an action based on predictions just as people do.

Thus, the environmental force exerted by the traffic environment can now be expressed in the form of equation (2) which has been derived on the basis of human physiology.

The element of position must be added since it is required to complete the equation as the environmental force equation.

The environmental force equation (2) is defined as $a - Cx'$, where "a" is the constant that expressed the driving force of the vehicle (the maximum acceleration of the vehicle) and Cx' is the environmental force.

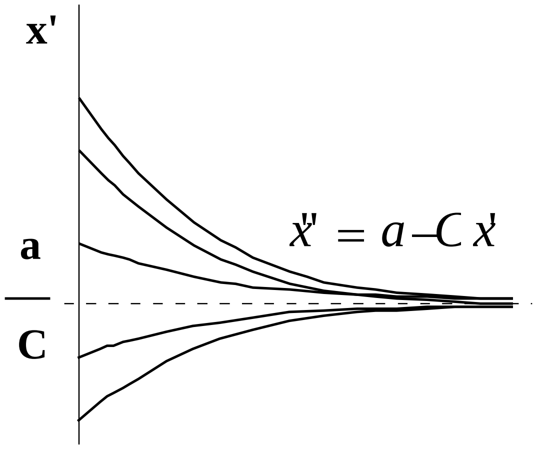


Fig.2 The equation converges the given velocity a/C for any initial condition.

By defining the environmental coefficient C as equation (3),it is possible to generate the environmental force which not only is proportional to the vehicle speed but also inversely proportional to the square of the distance (or any other power of the distance as long as it can be expressed as a function of the distance).

$$C = \frac{a}{V}\left(\frac{SL}{X - x}\right)^2 \qquad (3) \qquad\qquad x'' = a - \frac{a}{V}\left(\frac{SL}{X - x}\right)^2 x' \qquad (4)$$

Safe velocity *V* at position *X* and standard distance *SL* in the environment.

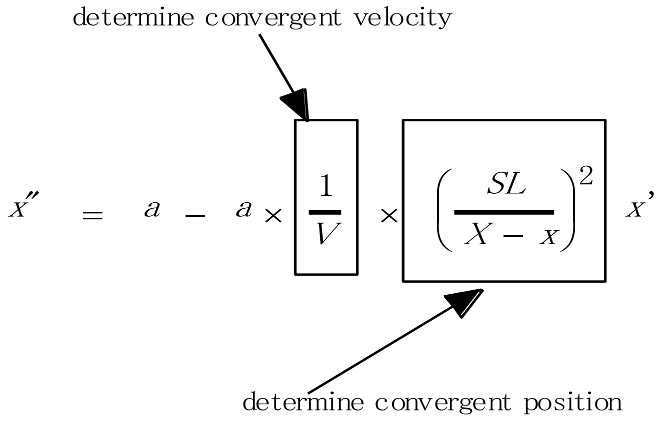


Fig.3 The structure of the environmental coefficient

The standard distance *SL* is the unit to measure the distance and it will be allowed to assume an appropriate form according to the environment. In the second term on the right-hand side of equation (4), $\frac{1}{V}x'$ is the term for the velocity and becomes 1 when the velocity x' reaches the target velocity *V*;

$\left(\frac{SL}{X - x}\right)^2$ is the term for the position, and becomes 1 when the distance *X* - *x* reaches the standard distance *SL*; and when it is achieved the acceleration acting on the vehicle will be eliminated as shown by the expression $x'' = a - a \times 1 \times 1 = 0$.

Thus, a specific form of the environmental force equation (1) with which a force can be exerted in a safe and comfortable manner in compliance with the traffic environment is obtained.

$$x'' = f(x, x', X, V) = a - \frac{a}{V}\left(\frac{SL}{X - x}\right)^2 x' \qquad (4)’$$

In the next section, the environmental force equation for the actual traffic environment will be obtained on the basis of the above environmental force equation.

EXAMPLES OF THE ENVIRONMENTAL FORCE EQUATION FOR CONCRETE TRAFFIC ENVIRONMENTS

FOLLOWING VEHICLE ENVIRONMENT

A lead vehicle’s displacement and velocity is *y* and *y’* respectively. Headway time is *T* and the space headway at stop is *L*.

$X = y \quad V = y' \quad SL = T x' + L$ Then the environmental force equation is as follows.

$$C_1 = \frac{a}{y}\left(\frac{T x' + L}{y - x}\right) \qquad x'' = a - \frac{a}{y'}\left(\frac{T x' + L}{y - x}\right)^2 x' \qquad (5)$$

SPEED LIMIT ENVIRONMENT

There is a no critical point X along the way. Then there is a no term for the position.

$$C_2 = \frac{a}{V} \qquad x'' = a - \frac{a}{V} x' \qquad (6)$$

Modify because of leading vehicles are more aware of the speed limit than a following vehicle.

$$C_2 = \frac{a}{V}\left(1 - \frac{T\,x' + L}{y - x}\,\eta\right) \qquad \eta \cong 1$$

$$x'' = a - \frac{a}{V}\left(1 - \frac{T\,x' + L}{y - x}\,\eta\right) x' \qquad (7)$$

TRAFFIC SIGNAL ENVIRONMENT

The stop line displacement is X and the velocity of this displacement *X is*

Signal is red : $V = \varepsilon \cong 0$

Signal is blue : $V = \infty$

Deceleration $\alpha = 0.3\,g$ standard distance $SL = \frac{x'^2}{2\,\alpha}$ then

$$C_3 = \frac{a}{V}\left(\frac{\frac{x'^2}{2\,\alpha}}{X - x}\right)^2 \qquad x'' = a - \frac{a}{V}\left(\frac{\frac{x'^2}{2\,\alpha}}{X - x}\right)^2 x' \qquad (8)$$

SLOW DOWN ENVIRONMENT

Deceleration $\alpha = 0.2\,g$ and slow down to velocity *V*, then $SL = \frac{x'^2 - V^2}{2\,\alpha}$

$$C_4 = \frac{a}{V}\left(\frac{\frac{x'^2 - V^2}{2\,\alpha}}{X - x}\right)^2 \qquad x'' = a - \frac{a}{V}\left(\frac{\frac{x'^2 - V^2}{2\,\alpha}}{X - x}\right)^2 x' \qquad (9)$$

GENERAL TRAFFIC ENVIRONMENT

Four environmental equations have been developed. The actual traffic environment is a combination of the above environment (and other environmental factors not mentioned in this paper).

The environmental force tends to act on the vehicle strongly especially in the vicinity of the environmental position X. If there are several positions X being the constant (the fixed position on the road), the nearest environmental force will act on the vehicle as the dominant force as it moves. The environmental force associated with the positions down stream of the nearest environmental force remain negligible therefore the force can be summed. When two or more environmental forces in which the position X is not a constant are added, the interference between two environmental forces are described in the form of an equation. Since the position X is not fixed in the following environment and the speed limit environment, the interference has been devised to be shown in the form of equation (7).

Basically, the force is applied locally onto a position in the environmental force equation, the ingenuity against the interference is incorporated and each environmental force is added in the formulation of the environmental force equation for the general traffic environment as equation (10).

$$x'' = a - (C_1 + C_2 \bullet \bullet \bullet + C_n)\, x' \tag{10}$$

For example, if there is a vehicle ahead (the following environment C1) and a speed limit sign (the speed limit environment C2) on a highway, the environmental force equation is as follows: $x'' = a - (C_1 + C_2)\, x'$

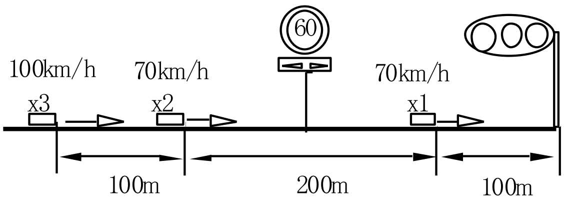
Although an environmental equation has been successfully formulated, there is a doubt as to whether or not the vehicle defined by the above equation can actually stop at a traffic light, follow the vehicle ahead, slow down, follow the speed limit and comply with other traffic environment as an ordinary driver.

Despite its simplicity, the equation takes the form of nonlinear differential equation, and can not be solved analytically. Thus, the validity of the equation will be determined on the basis of numerical calculation by producing an easy-to-understand environmental equation for a specific traffic environment which is capable of predicting the driver’s behavior.

EXAMPLES OF CALCULATION: VERIFICATION OF ENVIRONMENTAL FORCE EQUATION

The behavior of three vehicles traveling together in a traffic environment which is a combination of the traffic light environment, the following environment and the speed limiting environment as shown in Fig. 4 is realized by the environmental force equations of individual vehicles.

Passenger comfort will be omitted from the present verification since it has to be checked on vehicle. Only the acceleration and velocity wave forms are examined.
A total of three environmental equations are made because each vehicle requires a separate environmental equation, but different parameters are given in consideration of the characteristics of each driver. Actual equations and the results of the calculation are given.
Fig. 4 shows the traffic environment of a traffic signal, a speed limit sign, and three vehicles , the environmental force equations of the three vehicles with their parameters and initial values, and graphs of their solution. The graphs are plots of the environmental force equations of the three vehicles.
By looking at the graphs it can be seen that all three vehicles come to a stop. When the light turns green, the lead vehicle start off and accelerates to 60km/h. The second and third vehicle follow in succession, but they initially accelerate to higher speeds before adjusting their speeds to match the lead vehicle. Thus the equations produce acceleration curves which are similar to normal human behavior. Nevertheless, an actual riding experience is needed to determine the riding comfort.

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a1=4.5; a2=3.5; a3=2.5;  T1=2.5; T2=1.0;
T3=2.0;  L2=7.0; L3=8.0;  Xsig=1000.;
x10=900.; x20=700.; x30=600.;
v10=20.; v20=20.; v30=30.;
ε=0.05; SW=0 ( t<40 ) SW=10000. ( t>=40 )
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$$x_1'' - a_1 + a_1 \frac{x_1' + \varepsilon}{SW + \varepsilon} \left(\frac{1}{X_{sig} - x_1} \right)^{\frac{3}{2}} + a_1 \frac{x_1' + \varepsilon}{x_0' + \varepsilon} \left(\frac{T_1 x_1' + L_1}{x_0 - x_1} \right)^2 + a_1 \frac{x_1'}{V_{60}} \left(1 - \frac{T_1 x_1' + L_1}{x_0 - x_1} \right) = 0$$

$$x_2'' - a_2 + a_2 \frac{x_2' + \varepsilon}{SW + \varepsilon} \left(\frac{1}{X_{sig} - x_2} \right)^{\frac{3}{2}} + a_2 \frac{x_2' + \varepsilon}{x_1' + \varepsilon} \left(\frac{T_2 x_2' + L_2}{x_1 - x_2} \right)^2 + a_2 \frac{x_2'}{V_{60}} \left(1 - \frac{T_2 x_2' + L_2}{x_1 - x_2} \right) = 0$$

$$x_3'' - a_3 + a_3 \frac{x_3' + \varepsilon}{SW + \varepsilon} \left(\frac{1}{X_{sig} - x_3} \right)^{\frac{3}{2}} + a_3 \frac{x_3' + \varepsilon}{x_2' + \varepsilon} \left(\frac{T_3 x_3' + L_3}{x - x_3} \right)^2 + a_3 \frac{x_3'}{V_{60}} \left(1 - \frac{T_3 x_3' + L}{x_2 - x_3} \right) = 0$$

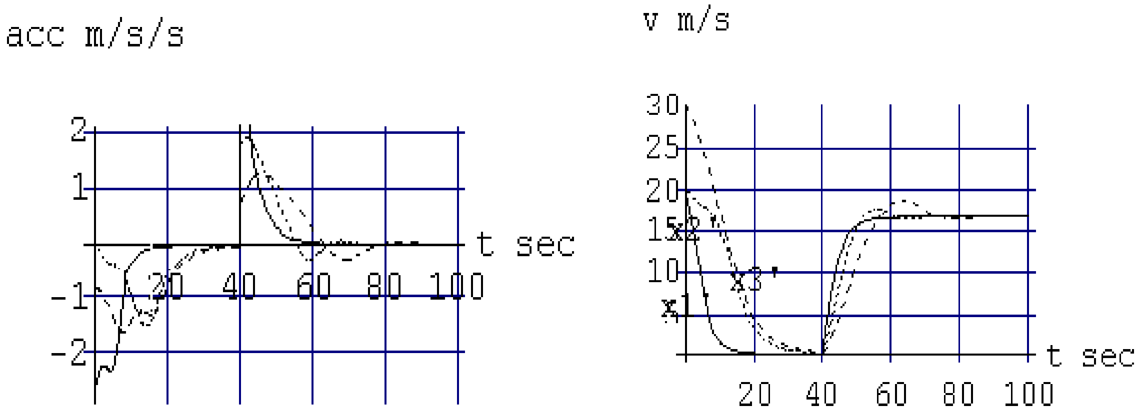

Fig.4 Environmental Equations , initial values and graphs of solutions

CONCLUSION

1. The traffic environment has been shown in terms of a physical environmental force equation.

$$x'' = f(x, x', X, V) = a - \frac{a}{V}\left(\frac{SL}{X - x}\right)^2 x' \qquad (4)'$$

2. It has been shown that an actual complex traffic environment can be expressed by the environmental force equation which is the sum of the environmental force for each environment, and that a motion similar to that of a vehicle with a driver can be reproduced by a verification based on calculation.

$$x'' = a - (C_1 + C_2 \bullet \bullet \bullet + C_n)\, x' \qquad (10)'$$

If guided at the acceleration indicated by the environmental force equation, a vehicle can be driven safely and smoothly in a given traffic environment.

AFTERWORD

While this paper has introduced the environmental force equation as a means of determining the physical guiding acceleration corresponding to the traffic environment for the purposes of driving support, the environmental force equation can not be formulated without the position of the environment and the description of the environment (e.g. recognition of an object as the traffic light and recognition of the color of the traffic light) which can be obtained from visual information. In order to obtain such visual information, a stable and reliable image processing system additionally capable of recognizing the distance is needed; and highly accurate map information that incorporates the information on the traffic environment with which the driver learns the static traffic environment beforehand will be necessary to efficiently recognize the traffic environment.

There are many problems, technical and otherwise, including how far the system should support the driver who has the responsibility of driving safely, that need to be addressed. However, it is the intention of the authors to develop a safe driving support system in a manner acceptable to the driving public to make sure that those drivers keen on careful driving will not face traffic accident.

The environmental force equation was formulated under the guidance of Professor Hirao at the Institute for Traffic Accident Research and Data Analysis on the basis of the notion that “the traffic accident is caused by miscalculation”.