Collision Resolving Modeling Based on Computational Verb Theory

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***Abstract*—Computational verb rules are efficient tools to represent dynamical experiences of a system in the form of natural languages. In this paper, a face-to-face collision resolving model based on an ultrasonic blind navigation system is built. The computational verb rule bases are constructed for the collision resolution and their validation is showed.**

Keywords-collision resolving modeling; ultrasonic blind navigation system; face-to-face collision; computational verb rule; verb similarity

I. INTRODUCTION

An ultrasonic navigation system for the blind employs the ultrasonic locating technology to help visually impaired people to avoid obstacles and possible collisions. The system usually can detect the precise position of static obstacles in the way and guide blind users to pass them safely. To evade a collision with a moving object, factors such as the environment, the pattern of the motion and so on should be taken into consideration. Thus, the system need take more care of the moving object. In this paper, we discuss how to make the blind avoid coming into collision with the object in motion. And the face-to-face collision is studied as an example.

Computational Verb Theory (CVT) [1], as an important part of Physical Linguistics (PL) [2], was invented in the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley in 1997. CVT has a powerful knowledge representation ability with its building blocks—- computational verbs. For an ultrasonic blind navigation system, its input-output relation should be modeled, which can be achieved by constructing a set of computational verb rules [3].

The organization of this paper is as follows. In Section II a face-to-face collision resolving model will be presented and the precise resolution to the collision will be given. In section III, rule bases with different numbers of the rules will be constructed and resolutions to the collision by computational verb reasoning [1] will be showed. In Section IV, the concluding remarks will be presented.

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II. THE FACE-TO-FACE COLLISION RESOLVING MODELING AND THE PRECISE RESOLUTION

A. *Face-to-face Collision Resolving Modeling*

The goal of the blind navigation system is finding a optimal route that can guarantee the bind user can move forward with a maximal displacement in the vertical direction of the blind track. Assume that in a possible face-to-face collision, the speed of the blind is constant, but the direction of motion is variable according to the moving object's speed such that the user can avoid the collision while the moving object in the way is at a constant speed in a fixed direction of motion. Therefore, we construct a master-slave system. The face-to-face collision resolving modeling is shown in Fig. 1, in which D is the valid detection distance of the ultrasonic device, d is the minimal safe distance between the moving object (master) and the blind (slave), θ is the maximum evasion angle, v_1 and v_2 are speeds of the slave and the master, respectively.

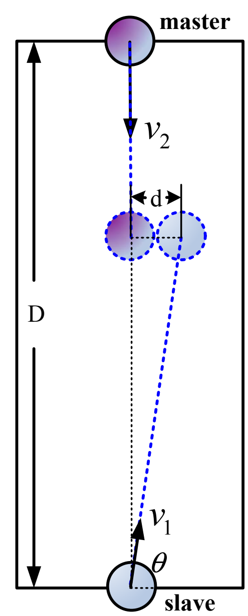

Figure 1. A face-to-face collision resolving modeling.

B. The Precise Resolution to a Face-to-face Collision

Since an ultrasonic blind navigation system can detect the pattern of motion of the moving object (including its position, velocity and change of velocity), v_2 can be detected then θ can be calculated.

From Fig. 1 we have following relations:

$$D - v_2 t = v_1 t \sin\theta, \tag{1a}$$

$$(D - v_2 t)^2 + d^2 = (v_1 t)^2 \tag{1b}$$

where $0 \le \theta < \pi/2$, $v_2 \ge 0$, $v_1 > 0$, $D > 0$, $d > 0$. It follows from Eq. (1a) that

$$t = \frac{D}{v_1 \sin\theta + v_2}. \tag{2}$$

Let $k = v_1 \sin\theta + v_2$, then we have

$$t = \frac{D}{k}, \tag{3}$$

which is substituted back into Eq. (1b), we get

$$(D^2 + d^2)k^2 - 2D^2 v_2 k + D^2 v_2^2 - D^2 v_1^2 = 0. \tag{4}$$

The resolution of k is given by

$$k = \frac{2D^2 v_2 \pm \sqrt{4D^4 v_2^2 - 4(D^2 + d^2)(D^2 v_2^2 - D^2 v_1^2)}}{2(D^2 + d^2)}. \tag{5}$$

For $\sin\theta = k/v_1 - v_2/v_1$, we obtain

$$\begin{aligned} &\sin\theta \\ &= \frac{2D^2 v_2 \pm \sqrt{4D^4 v_2^2 - 4(D^2 + d^2)(D^2 v_2^2 - D^2 v_1^2)}}{2(D^2 + d^2)v_1} - \frac{v_2}{v_1} \\ &= \frac{-d^2 v_2 \pm D\sqrt{D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2}}{(D^2 + d^2)v_1} \end{aligned} \tag{6}$$

which has following constraint conditions:

$$D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2 \ge 0; \tag{7}$$

$$0 \le \sin\theta \le 1. \tag{8}$$

It follows from Eq. (7) that

$$0 \le v_2 \le \frac{\sqrt{D^2 + d^2}\, v_1}{d}. \tag{9}$$

According to Eq. (6) and Eq. (8), we have

$$\sin\theta = \frac{-d^2 v_2 + D\sqrt{D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2}}{(D^2 + d^2)v_1} \tag{10}$$

such that

$$0 \le \frac{-d^2 v_2 + D\sqrt{D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2}}{(D^2 + d^2)v_1} \le 1 \tag{11}$$

whose resolution is give by

$$0 \le v_2 \le \frac{D v_1}{d}. \tag{12}$$

According to Eqs. (9)(10)(11), we have following conclusions.

$$\begin{aligned} &\sin\theta = \frac{-d^2 v_2 + D\sqrt{D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2}}{(D^2 + d^2)v_1}, \\ &0 \le v_2 \le \frac{D v_1}{d} \end{aligned} \tag{13}$$

$$\begin{aligned} &\theta = \arcsin\frac{-d^2 v_2 + D\sqrt{D^2 v_1^2 + d^2 v_1^2 - d^2 v_2^2}}{(D^2 + d^2)v_1}, \\ &0 \le v_2 \le \frac{D v_1}{d} \end{aligned} \tag{14}$$

Notice that if $v_2 > Dv_1/d$, the bind will have no time to evade a collision.

When $D = 6\text{m}$, $d = 1\text{m}$, $v_1 = 0.5\text{m/s}$, we have

$$\begin{aligned} \theta(v_2) &= \arcsin\frac{-1^2 v_2 + 6\sqrt{(6^2 + 1^2) \times 0.5^2 - 1^2 v_2^2}}{(6^2 + 1^2) \times 0.5} \\ &= \arcsin\frac{-v_2 + 6\sqrt{9.25 - v_2^2}}{37 \times 0.5}, \quad 0 \le v_2 \le 3. \end{aligned} \tag{15}$$

Fig. 2 shows maximum invasion angles θ corresponding to different v_2.

III. Computational Rule Bases for the Collision Resolution

In this section, computational rule bases [4] are constructed based on the precise resolution of the face-to-face collision and by using computational verb reasoning the collision resolution is given.

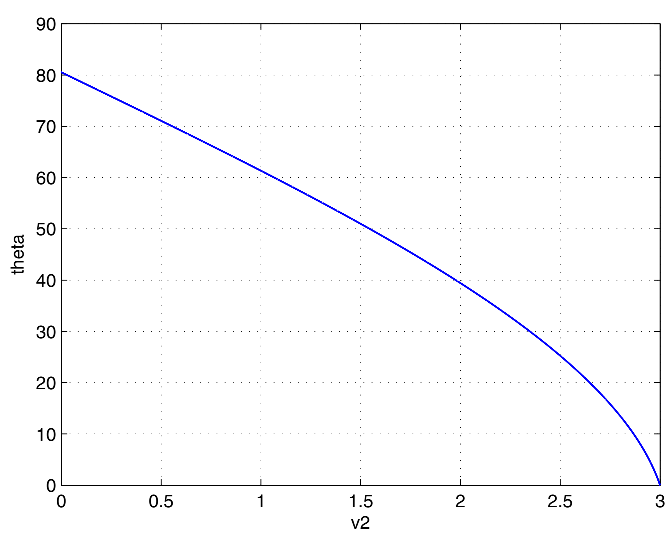

Figure 2. Maximum invasion angles θ corresponding to different v_2.

A. Two-rule Bases

The following computational verb rule base can be constructed for resolving a face-to-face collision:

IF the master stands `still`, THEN the evasion angle $\theta = \theta_1$;
IF the master moves `fast`, THEN the evasion angle $\theta = \theta_2$.

(16)

Notice that stand and move are spatial verbs [2], which are related with the moving object's velocity (including its direction of motion and speed).

We can compose the following computational verb similarity [5] between temporal verbs V_1, V_2.

$$S(\mathsf{V}_1, \mathsf{V}_2) = \frac{2}{1 + e^{d_t(\mathsf{V}_1, \mathsf{V}_2)}}. \tag{17}$$

where $d_t(\mathsf{V}_1, \mathsf{V}_2)$ is the contribution to the similarity S from the trends of temporal verbs, which correspond to the moving objects' velocities that can determine spatial verbs. The master moves in a fixed direction such that Eq. (17) can be recast as follow to compose a spatial verb similarity regardless of the moving direction of the master.

$$S(\mathsf{V}_1, \mathsf{V}_2) = \frac{2}{1 + e^{\kappa|v_1 - v_2|}} \tag{18}$$

where κ is a constant and v_1, v_2 are the constant speeds of the moving objects. When $\kappa = 1.2$, the computational verb similarities are shown as a function of parameter $\Delta = |v_1 - v_2|$ in Fig. 3.

Given a speed of the slave and the measured speed of the master, the maximum evasion angle θ can be found by computational verb reasoning. For the rule base shown in Eq. (16) the output of the entire computational verb algorithm

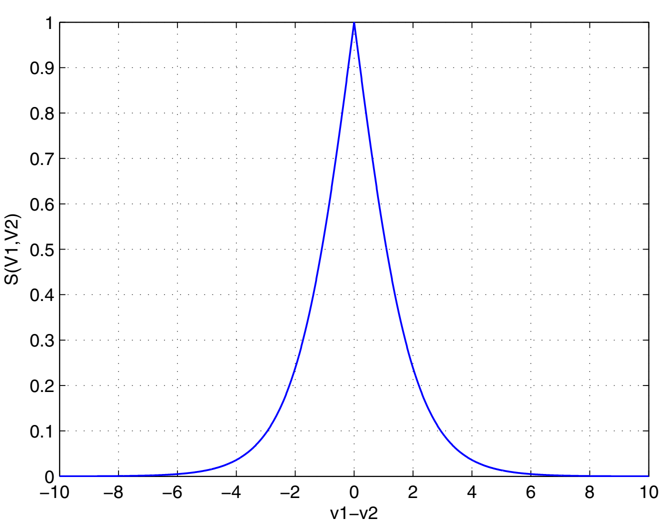

Figure 3. The computational verb similarities with $\kappa = 1.2$.

is given by

$$\theta = \frac{\sum_{i=1}^{n=2} S(\mathsf{V}, \mathsf{V}_i)\theta_i}{\sum_{i=1}^{n=2} S(\mathsf{V}, \mathsf{V}_i)} \tag{19}$$

where V is the observed verb and V_i is a template verb for the ith verb rules. Substitute Eq. (18) into Eq. (19) we have

$$\theta(v) = \frac{\sum_{i=1}^{n=2} \frac{2}{1 + e^{\kappa|v - v_{mi}|}}\theta_i}{\sum_{i=1}^{n=2} \frac{2}{1 + e^{\kappa|v - v_{mi}|}}} \tag{20}$$

where the speed v_{mi} and v determine spatial verbs V_i and V, respectively.

Suppose that $D = 6\text{m}$, $d = 1\text{m}$, $v_1 = 0.5\text{m/s}$ and $\kappa = 1.2$. We choose following three groups of parameters for the rule base in Eq. (16) based on the results in Section II.

$$\begin{aligned} v_{m1} &= 0\text{m/s}, & v_{m2} &= 2.87\text{m/s}, & \theta_1 &= 80^\circ, & \theta_2 &= 10^\circ; \\ v_{m1} &= 0\text{m/s}, & v_{m2} &= 2.95\text{m/s}, & \theta_1 &= 80^\circ, & \theta_2 &= 5^\circ; \\ v_{m1} &= 0\text{m/s}, & v_{m2} &= 3.00\text{m/s}, & \theta_1 &= 80^\circ, & \theta_2 &= 0^\circ. \end{aligned} \tag{21}$$

Corresponding to each group, the functions in Eq. (20) with different parameters are shown as the red (dashed), blue (dash-dot) and green (dotted) curves in Fig. 4, respectively. To show the validation of the constructed rule base, the curve of Fig. 2 is shown as the black (solid) curve in Fig. 4 of next page.

Compared with the black (solid) curve in Fig. 4, it can be observed that most part of the curve (red (dashed), blue (dash-dot), green (dotted)) is below the black (solid) curve, namely, the blind can avoid the collision in most of the range of v_2 ($[0, 3]$). The range of v_2 in which the collision is inevitable can be excluded when the detection distance D is large enough such that there is not the moving object with such a high speed.

B. Three-rule Bases

One more computational verb rule is added in the rule base shown in Eq. (16), a new computational verb rule base is given by

IF the master stands `still`, THEN the evasion angle $\theta = \theta_1$;
IF the master moves `fast as well as slowly`, THEN the evasion angle $\theta = \theta_2$;
IF the master moves `fast`, THEN the evasion angle $\theta = \theta_3$.

(22)

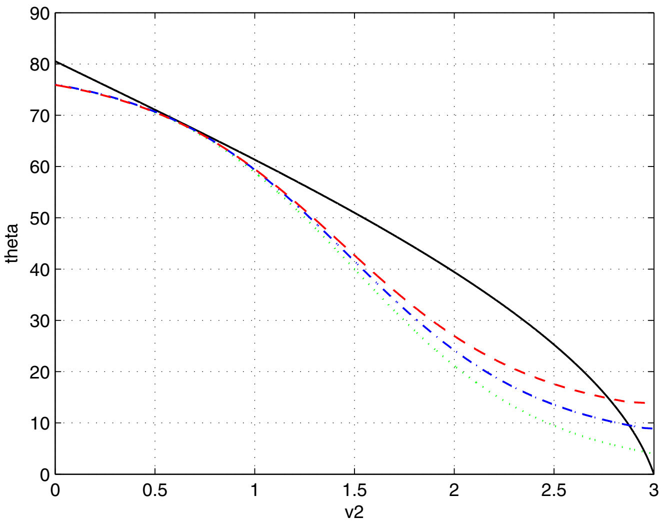

Figure 4. The functions of v_2 in Eq. (20) with three groups of parameters in Eq. (21).

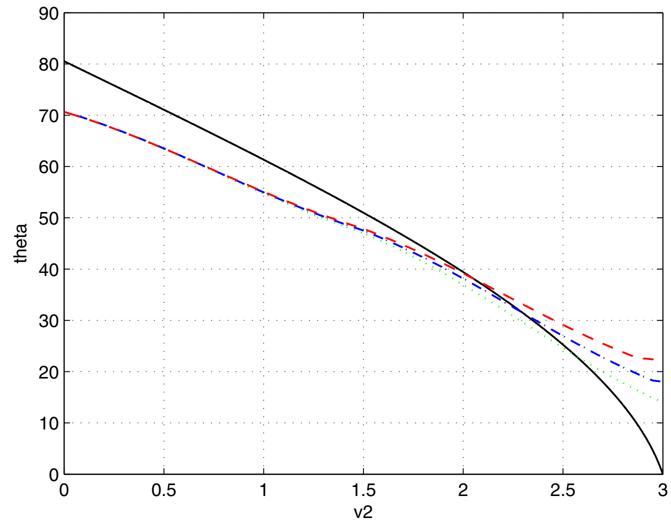

Figure 5. The functions of v_2 in Eq. (23) with three groups of parameters in Eq. (24).

We can have

$$\theta(v) = \frac{\sum_{i=1}^{n=3} \frac{2}{1+e^{\kappa|v-v_{mi}|}}\theta_i}{\sum_{i=1}^{n=3} \frac{2}{1+e^{\kappa|v-v_{mi}|}}}. \quad (23)$$

To compare with the rule base in Eq. (21), we still assume that $D = 6\text{m}$, $d = 1\text{m}$, $v_1 = 0.5\text{m/s}$ and $\kappa = 1.2$ and three groups of parameters for the rule base shown in Eq. (22) based on the results in Section II are given by

$$\begin{aligned} & v_{m1} = 0\text{m/s},\ v_{m2} = 1.5\text{m/s},\ v_{m3} = 2.87\text{m/s},\ \theta_1 = 80^\circ, \\ & \theta_2 = 51^\circ,\ \theta_3 = 10^\circ; \\ & v_{m1} = 0\text{m/s},\ v_{m2} = 1.5\text{m/s},\ v_{m3} = 2.95\text{m/s},\ \theta_1 = 80^\circ, \\ & \theta_2 = 51^\circ,\ \theta_3 = 5^\circ; \\ & v_{m1} = 0\text{m/s},\ v_{m2} = 1.5\text{m/s},\ v_{m3} = 3.00\text{m/s},\ \theta_1 = 80^\circ, \\ & \theta_2 = 51^\circ,\ \theta_3 = 0^\circ; \end{aligned} \quad (24)$$

Corresponding to each group, the functions in Eq. (23) with different parameters are shown as the red (dashed), blue (dash-dot) and green (dotted) curves in Fig. 5, respectively. To show the validation of the constructed rule base, the curve of Fig. 2 is shown as the black (solid) curve in Fig. 5.

Notice that because of the introduce of the second rule in Eq. (22), the range of v_2 in which the blind may come into collision with the object in motion is enlarged, but at the same time the 3-rule base gives more precise resolutions in most of the range of v_2 ($[0, 3]$) than the 2-rule base.

IV. CONCLUSIONS

By constructing computational rule bases and using computational verb rule reasoning, a face-to-face collision can be resolved successfully. The reasons why the method of obtaining precise resolutions are not used but the computational verb rules are designed and employed can be concluded as follows.

- All the rules are written in natural languages, they are much more readable for engineers;
- Computational verb rules describe the characteristic of the system qualitatively such that they have a great dynamical knowledge representation ability, thus, they are reusable.

In this paper, the face-to-face collision resolving modeling is discussed, the following work is studying the side collisions.

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