Collision Estimation Using Single Camera

Discussion under the condition of constant velocity

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***Abstract*— Robots and autonomous vehicles that operate in complex dynamical environments have attracted considerable attention in recent years. Avoiding obstacles and finding a passable route to the destination is one of the important and basic functions of mobile robots. In this paper, we take our cue from the obstacle-avoidance mechanism in animals, and discuss how to enable robots to find a passable route using only two-dimensional images from a single usual camera without any distance information. We simulate the dynamic changes in visual information and obtain the necessary conditions for a mobile robot to determine impending collisions with an obstacle in its path.**

***Keywords*- Autonomous vehicles; Estimation of collision; visual information single camera.**

I. INTRODUCTION

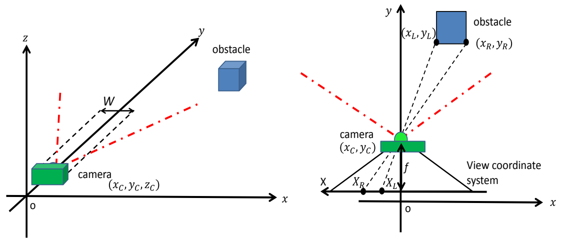
In recent years, robots and autonomous vehicles that operate in complex dynamical environments such as daily life have attracted considerable attention. Autonomous navigation of automobiles or personal robots is among these fertile areas of research. Conventional robots were designed for well-known, simple environments, such as a factory. Thus, conventional methodology does not work effectively in designing robots that operate in unknown dynamic environments.

Considerable research has been conducted to solve this problem and develop effective autonomous robots. DARPA ground challenge [1] and Google car [2] are one of them. In these conventional studies, the most common approach to such a problem is to create three-dimensional models of the environment in question. In this approach, robots have sensors, such as a laser range-finder, to measure distances to obstacles and create a precise three-dimensional model of the environment [3]-[7]. A passable route is obtained by calculations that use information from the three-dimensional model. While this approach is effective, the mechanism to obtain the passable route is very different from that of animals. Even lower-level animals and insects can act quickly to avoid obstacles, in spite of their small brains. They have no distance sensor and their brain is too small to find a passable route to their destination as quickly as they do. How these animals are nonetheless able to do so is still an open question. However, research in ecological psychology has revealed that animals can evaluate the time-to-contact for an object in their path based solely on available visual information and without any distance information. Information about the time-to-contact is perceived directly and no complex computation is presumably required.

In this paper, we focus on this mechanism in animals and discuss how to enable robots to find a passable route to their destination using two-dimensional images from a single camera without any distance information. We simulate the dynamic changes in visual information and establish the necessary conditions to accurately determine impending collisions with an obstacle.

II. MODEL AND DEFINITION

We define the global coordinate system and the view coordinate system as shown in Fig. 1 and Fig. 2, respectively. Table 1 elaborates on the meaning of the symbols used in these figures. The robot (camera) moves on the y-axis at a constant velocity and the direction of the camera is fixed, as shown in Fig 1(b). There is a static obstacle in the robot's path, and the position of the obstacle in the global coordinate system is converted to that in the view coordinate system by (1) and (2).



(a) Side view (b) Top view

Figure 1. Global coordinate system.

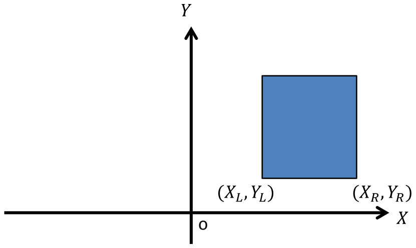


Figure 2. View coordinate system.

TABLE I. DEFINITION

f	Focal length
W	Width of the body
$(X_{L(R)}, Y_{L(R)})$	Position of the obstacle in the view coordinate system
$(x_{L(R)}, y_{L(R)})$	Position of the obstacle in the global coordinate system
(x_C, y_C)	Position of the camera in the global coordinate system

$$X_L = f \times \frac{x_L}{y_L - y_C} \tag{1}$$

$$X_R = f \times \frac{x_R}{y_R - y_C} \tag{2}$$

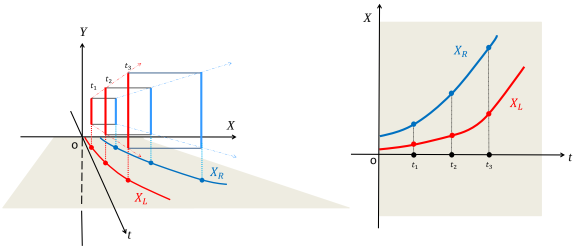


Figure 3. Temporal response of the edges of object.

Fig. 3 illustrate the temporal response of the edges of the object in the view coordinate system. In this study, we focus on this temporal change, and discuss how to determine collision to the obstacle.

III. SIMULATION

A. *Case of ignoring body size*

In this subsection, we assume that the body of the robot is a point and has no width. We conduct simulations for two cases, as shown in Fig. 4 and Fig. 5. Fig. 4 shows the case where the robot comes into contact with the obstacle and Fig. 5 represents one where the robot successfully evades it. In both cases, the robot moves in a straight line at the same constant velocity. By comparing these results, we can learn how to estimate future crashes using the visual information at hand.

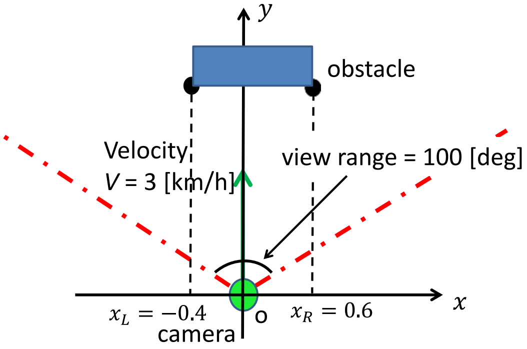


Figure 4. Case A-1: Robot contacts the obstacle.

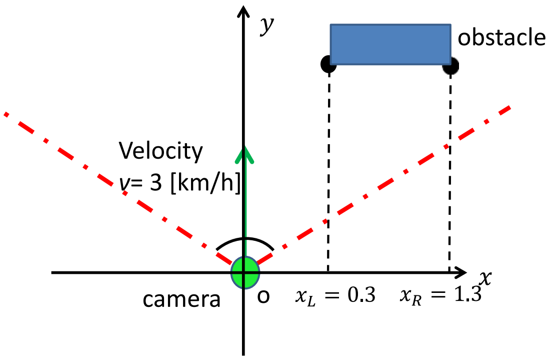


Figure 5. Case A-2: Robot does not contact the obstacle.

Fig. 6 and Fig. 7 show the results of our simulation. These graphs show the change in position of the obstacle relative to the robot's visual coordinate system as it moves forward. From these results, it is obvious that if both sides of the obstacle appear to expand outwards from the robot's visual perspective, the robot will hit the obstacle. On the other hand, if both sides of the obstacle appear to move in one direction from the perspective of the robot's visual coordinate system, the robot can evade the obstacle.

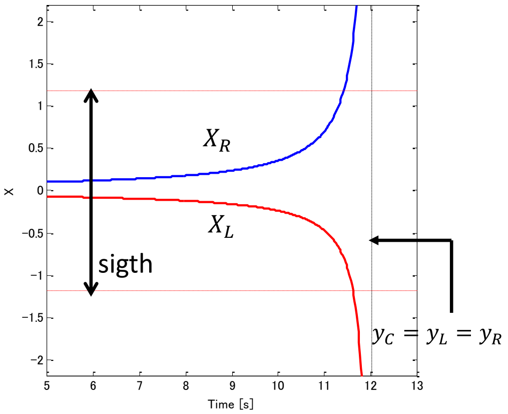


Figure 6. Result of Case A-1

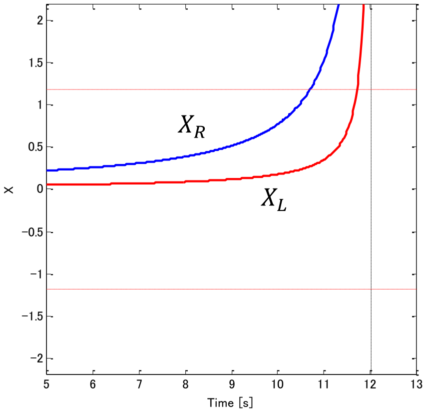


Figure 7. Result of Case A-2

B. *Case of considering body size*

In this subsection, we assume that the body of the robot has a certain non-negligible width. We conduct simulations with the robot at different distances from the obstacle, as shown in Fig. 8 and Table 2. In all cases, the robot moves in a straight line at the same constant velocity.

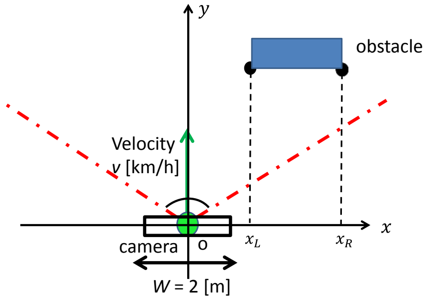


Figure 8. Case B: Robot has a certain width

TABLE II. POSITION OF THE OBSTACLE

Case B-1	$x_L = 0.1, x_R = 1.1$
Case B-2	$x_L = 0.5, x_R = 1.5$
Case B-3	$x_L = 1.0, x_R = 2.0$
Case B-4	$x_L = 1.5, x_R = 2.5$
Case B-5	$x_L = 2.0, x_R = 3.0$

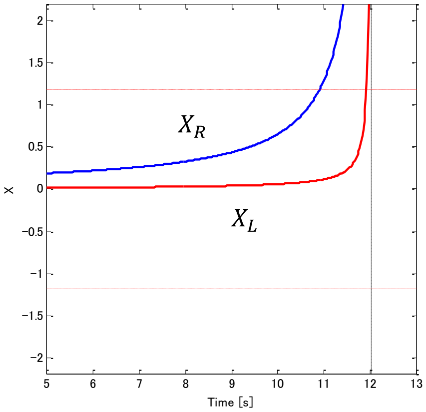


Figure 9. Result of Case B-1

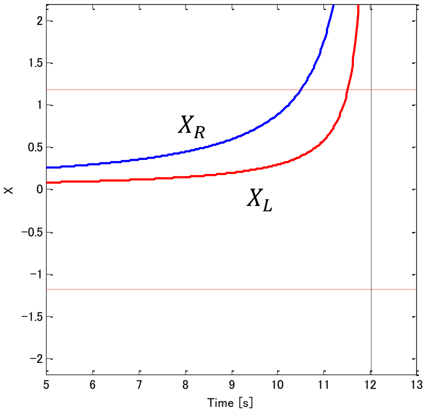


Figure 10. Result of Case B-2

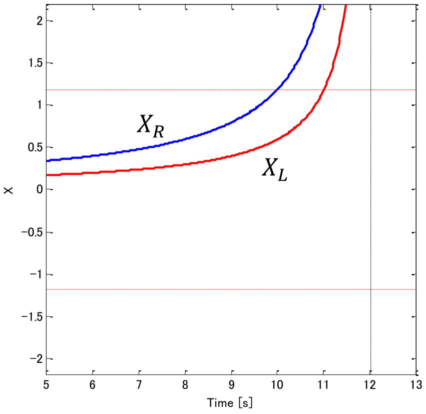


Figure 11. Result of Case B-3

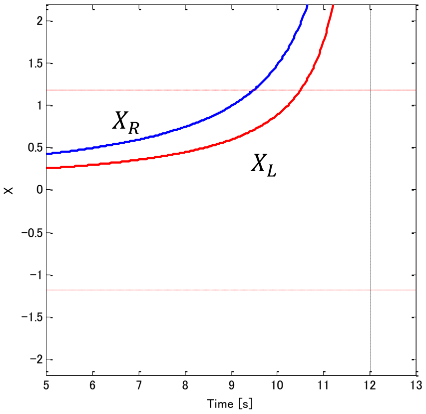


Figure 12. Result of Case B-4

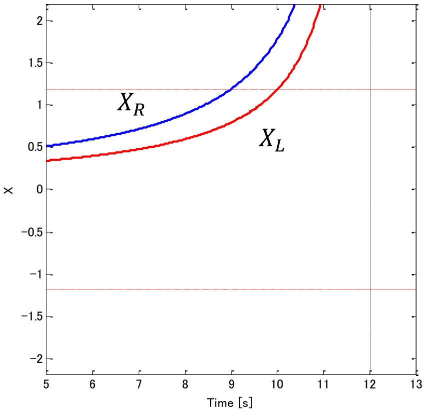


Figure 13. Result of Case B-5

Figs. 9 to 13 show the simulation results. In all cases, both sides of the obstacle appear to move in the same direction from the robot's visual perspective. Thus, according to the condition stated in Section III.A, the robot should pass the obstacle by. However, in this simulation, the width of the robot's body is 2m, because of which it hits the obstacle in cases B-3, B-4 and B-5. From these results, we can conclude that the condition in Section III.A is not sufficient for the robot to avoid the obstacle when it is sufficiently large in size.

To take the size of the robot's body into consideration, we focus on the temporal changes in values of X_L and X_R, the horizontal coordinates that demarcate the width of the obstacle, with the robot's motion. Fig. 14 shows the temporal change in the value of X_L. We see that this change depends on the distance between the robot and the obstacle. Therefore, we can calculate if a collision will occur from the change in the horizontal coordinates of the obstacle relative to the robot's motion, if the width of the robot's body and its velocity are known.

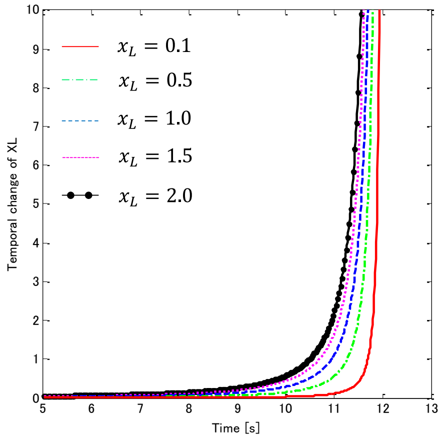


Figure 14. Temporal change of X_L for different settings of x_L

C. *Case of different velocities*

In this subsection, we consider the influence of the velocity of the robot on obstacle avoidance. The simulation setting is the same as in Section III.B, except for the velocity of the robot.

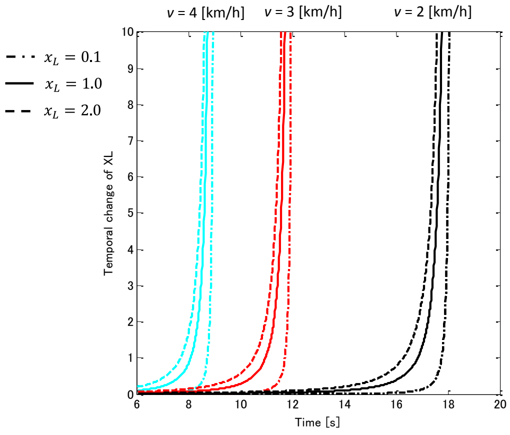


Figure 15. Temporal changes of X_L for different velocities

Fig. 15 shows the results. We see that the temporal change in X_L depends on the robot's velocity in addition to its distance from the obstacle. Thus, to determine if a collision will occur, the velocity of the robot relative to the obstacle is also required.

Animate living beings do not have velocity sensors. They estimate relative velocity using visual information. Thus, the determination that a collision will occur or that a passable route that avoids obstacles is available can only be made through visual information.

Our future research in this area will focus on the calculation of relative velocity using available visual information.

IV. CONCLUSION

In this paper, we discuss a method for a mobile robot to detect impending collision with an obstacle in its path and to find a passable route using only two-dimensional images from a single usual camera without any distance information. We simulated the dynamic changes in visual information and determined the necessary conditions to determine future collisions with an obstacle.

Our future research will be geared towards estimating the relative velocity of a mobile robot with respect to obstacles using visual information, and applying it to determine impending collisions.

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