Experiment of Collision Avoidance Control Law with Information Amount Feedback Using Vehicle Model

Takehiro Higuchi*, Kensuke Kokubu**, and Seiya Ueno*

Abstract: This paper is on the experiment of the collision avoidance control law with information amount feedback using a vehicle model. The collision avoidance is a key technology for future mass transportation systems. The amount of information obtained by the evader is treated as a physical value for the collision avoidance feedback control. This will lower the risk of collision when information of the environment cannot be obtained due to various reasons and when the intruder is coming in from out-of-sight. This paper demonstrates the effect of collision avoidance control with information amount feedback using a vehicle model. The results show that the control law has the ability to lower the risk of the collision and works in the actual environment for collision avoidance with similar motion with that of humans.

Key Words: collision avoidance, information amount, vehicle experiment.

1. Introduction

The collision avoidance control is a key technology for future mass transportation. As the demand for aerial vehicles are increasing, the appropriate collision avoidance system is needed. For the conventional commercial and private planes, there is a Traffic alert and Collision Avoidance System (TCAS) which gives guidance for the danger of incoming threats [1]. For the rotorcrafts and Unmanned Aerial Vehicles (UAVs), there is no conventional collision avoidance system due to their special flight characteristics and limit of the payload.

The collision avoidance has been researched in many different fields starting with ships [2]. The studies on cars and robots become popular as the demand for these systems increases [3]–[5]. Some researches treat avoidance problems as the formation control which requires the cooperative information control [6], [7].

In the field of aeronautics, TCAS has been the reference for the collision avoidance. TCAS exchanges the information of the aircraft and advises the aircraft to avoid in the vertical direction. For aircrafts, various studies have been presented to enhance the ability of collision avoidance for various cases. Frazzoli et al. have given a solution to the collision avoidance problem using centralized conflict resolution with the decentralized aircraft preferences [8]. Shioiri et al. have treated the collision avoidance problem in three-dimensions for safer flight of an aircraft using the risk function and fuzzy logic [9]. Gates has proposed rule-based collision avoidance control strategies for real-time online collision avoidance [10]. Miele et al. have proposed collision avoidance control for case of abort landing with low computational load which can be calculated by an on-board computer [11]. Though there are several studies that treat collision avoidance, the information obtained from the sensors or navigations systems are treated as certain, in most of the studies. Thus the evader knows all of the information about the surrounding environment.

The avoidance control system under uncertain information has been studied in numerical simulation [12], [13]. In these studies, information amount which is treated as a physical value for collision avoidance is used. This control can easily be adopted in various flight/vehicular systems. In this paper, the control law is applied to 2-dimensional environment with a vehicle and tested to see the ability of the control law for the first time.

2. Experimental Model and Information Amount

2.1 Experimental Model

In the experiment, the 4-wheeled truck model as shown in Fig. 1 is used to test the collision avoidance control law with information amount feedback. The 4-wheeled truck is loaded with the laser range sensor (Hokuyo) shown in Fig. 2, and measures distance between the vehicle and the obstacle/intruder. This sensor demonstrates the environment of the actual information that can be obtained from eye sight or radar. The sensor scans the range of surrounding environment every 2.7 degrees. The schematic image of the sensing data is shown in Fig. 3. The environment data is transmitted to the personal computer and goes through data processing, the control law, and the D/A converter. The output is send to the vehicle through the transmitter and the vehicle is controlled according to the control law.

2.2 Information Amount

Figure 4 shows a schematic image of the vehicle, laser range sensor, and the information amounts. The vehicle is heading toward right and focused on what is coming up ahead. \( S_E \) is the focused area where the evader is to search any obstacle/intruder. This area can be changed according to the designer’s concept or environmental conditions. For example, when the vehicle is moving slowly, the area could be wide and short, and when the vehicle is moving fast, the area could be narrow and long, according to the requirement. \( S_C \) is the cleared area where the vehicle can obtain information. \( S_B \) is the blocked area where
the vehicle is unable to obtain information.

The parameter for information amount is defined as,

\[ I_L = \frac{S_C}{S_E}, \]  

(1)

where, \( I_L \) is called Information Localization which defines the percentage of the cleared area. This amount will define the availability of the information in the focused area. The control law will try to obtain this value higher than a certain desired value in order to avoid sudden collision.

### 3. Information Amount Feedback

There are three control laws combined in this control system. In the conventional avoidance control law, there are two steps, that is, collision avoidance and course keeping. If there is any danger up ahead, the vehicle takes avoidance control, if there is no danger, it goes back to the course keeping control. In this paper, the information amount feedback control is added between the avoidance and course keeping control. The input is the steering angle in all controls.

#### 3.1 Course Keeping Control

In the case where there is no danger and is enough information, the control system chooses course keeping control as input. The course keeping control uses the information from the laser range sensor and derives the amount of displacement from the designated course and the attitude angle of the vehicle. The input is driven as,

\[ \delta = -k_1\psi - k_2\text{gap}. \]  

(2)

Here, the \( \delta \) is the input rudder angle, \( k \) is the gain, \( \psi \) is the attitude angle, and \( \text{gap} \) is the displacement from the designated course. This control input will keep the vehicle in the designated course facing straight.

#### 3.2 Information Gathering Control

When the vehicle is not in danger and the information amount is lower than the designated value, the information gathering control starts to obtain more information for the safer cruise. The input for steering control is given as,

\[ \delta = -\frac{k_3}{I_R - I_L} \frac{S_R - S_L}{S_E}, \]  

(3)

where, \( I_L \) is required information amount, \( S_R \) and \( S_L \) are the right and left cleared areas, respectively, of the focused area which gives the sign for the control. The vehicle will try to obtain enough information in order to avoid sudden dangers.

#### 3.3 Collision Avoidance Control

When the vehicle is in danger, which means that the evader has strong possibility of coming close to the intruder in near future, the collision avoidance control will take over all the decisions of the control.

The system switches to collision avoidance control according to the risk function \( \phi \). The risk function is derived as the following equation.

\[ \phi = \frac{R_0^2}{R_0^2 + R_{CPA}^2}. \]  

(4)

Here, \( R_0 \) represents the safety range which means the constant distance between the vehicles set as safety requirement by the users. \( R_{CPA} \) is the “range of the closest point of approach”, which is the minimum range between the evader and the intruder when their present velocities and directional angles are kept as the current condition. The collision avoidance control is switched on when the value of the risk function \( \phi \) is larger than 0.5, which means that the vehicle will be within the range of \( R_0 \) in the future, if the current condition is kept. The \( R_{CPA} \) and \( \phi \) disappear after the vehicles pass each other.

The collision avoidance control input is given as follows.

\[ \delta = \pm \frac{k_4}{T_{CPA}}. \]  

(5)
Fig. 5 Intruder model.

Fig. 6 Experiment site.

where $T_{CPA}$ in the avoidance control is the “time to closest point of approach” which is derived from the relative distance and the velocity of the evader and intruder. The precise definition and calculation of the values can be referred to [12].

4. Experimental Results

The experiment is held with the control law explained in previous section. The intruder is the model truck that is passing through an environment with low information amount. Figure 5 shows the photo of the intruder with the pole loaded for detection. As the total system, Fig. 6 is the photo of experiment site. The evader comes in from the left top with the designated course at the center. The obstacle which lowers the information amount is set in the right side of the designated course. The intruder starts behind this obstacle, and hence, in case the evader has no collision avoidance system, the intruder will appear suddenly behind the obstacle and approaches the evader.

4.1 Basic Information Amount Feedback Control

4.1.1 Experimental condition and results

The experiment starts with the case where there is no intruder. The conditions of the experiment are shown in Table 1. The gains are given heuristically. The velocity of the evader and the intruder are constant as shown in the table and the information requirement is also constant at 0.8. This value indicates that the evader wants to obtain more than 80% of the information of the focused area.

Table 1 Experiment condition 1.

<table>
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<tr>
<th>constants</th>
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<tr>
<td>$k_1$</td>
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<tr>
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<td>0.624</td>
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<tr>
<td>$k_3$</td>
<td>37.5</td>
</tr>
<tr>
<td>$k_4$</td>
<td>125</td>
</tr>
<tr>
<td>$V_E$</td>
<td>265mm/s</td>
</tr>
<tr>
<td>$V_I$</td>
<td>68.9mm/s</td>
</tr>
<tr>
<td>$I_R$</td>
<td>0.8</td>
</tr>
<tr>
<td>$R_{0i}$</td>
<td>500mm</td>
</tr>
</tbody>
</table>

Figure 7 shows the trajectory of the evader for the cases with and without the information amount feedback (IAF). Though there is no intruder, we can see that the case w/o IAF keeps the straight course compared to the cases with IAF show big right turn when the obstacle lowers the information amount. The collision avoidance is not used in this case. For this case, the control w/o IAF is better than the case with IAF since there was no risk coming in.

Figure 8 shows the case when the intruder does exist. The lines coming in from behind the wall are the trajectories of the intruder. The black line from the left is the trajectory of the case w/o IAF, meaning the evader uses only course keeping control and collision avoidance control after the intruder comes in sight. On the other hand, the gray line shows the case with IAF which starts the information gathering control in the first half and avoids the intruder in the latter half.

The relative distance of the evader and intruder is shown in Fig. 9. The case with IAF keeps longer distance throughout the control. The circles on the trajectory show the distance of the evader and intruder at first contact and also the crossover distance, both of which will be used for evaluating the risk of collision.

Figure 10 shows the time history of information localization which defines the amount of information obtained in the control. The case with IAF keeps higher level of the information for safer cruise and the value did not exceed the requirement of 0.8.

4.1.2 Evaluation

To compare the results, several evaluation indexes are brought in for comparing the risk of collision. The first index is the relative distance of the evader and intruder at first contact. This index shows how fast the evader can find the intruder and start avoidance. When the value is higher, the time allowance till the collision will increase. This will not only lower the risk of collision but also let the evader make smoother trajectory for avoidance when there is an actual chance of engaging. The result is shown in Fig. 11. The average value of the distance in case with IAF has increased 44.6% compared to the case w/o IAF. This leads to significant increase in the time allowance and safer collision avoidance.

Another index is the crossover distance of the evader and intruder. This value is the distance between the evader and intruder when the evader passes through in front or back of the
intruder. The index shows the actual safety margin for the collision. As the average, the case with IAF has shown 22.5% increase in distance for safer cruise as shown in Fig. 12. The crossover distance is evaluated instead of the closest distance since the control system goes back to the course keeping control after the evader passes the intruder. The vehicles have no chance of collision after they cross each other, i.e. RCPA does not exist, which means that the vehicles are safe unless they intentionally try to collide with each other.

In all of the results, the cases with IAF have shown higher ability of collision avoidance and safer cruise. Although the control has shown significant improvement, there is still some modification that can be done. That is, from Fig. 8, in the cases with IAF, the trajectory of the vehicle starts with information gathering, then back to course keeping because there is no danger up ahead. Then the evader approaches the intruder which makes wiggly trajectory. This makes large effect on the final crossover distance because the vehicle is facing toward the intruder when the collision avoidance control starts. To overcome this problem, the modified control law is brought in.

4.2 Modified Information Amount Feedback Control

4.2.1 Experimental condition and results

As the modified control law, the course keeping control is modified. When there is increase in the possibility of the collision after enough information is obtained from the information gathering control, modified course keeping control is applied. The possibility of collision is measured from the increase in the risk function (4). If the control system measures increase in $\phi$, the modified course keeping control keeps the current course until the risk is gone or the collision avoidance control takes over. For the experiment conditions, some of the gains are modified as shown in Table 2. Other conditions and parameters are same as the cases with the basic information feedback control.

Figure 13 shows the case when the intruder does not exist. The results show the similar result with the basic control law when there is no possibility of increase in risk because there is no intruder up ahead.

Figure 14 shows the trajectories of evader and intruder in same condition of the previous results. The trajectories of the cases with IAF are smoother compared to the previous control laws. Figure 15 shows the time history of the relative distance of the evader and intruder. The cases with IAF show that it is keeping longer distance throughout the control. Figure 16 shows the time history of the information localization. The information localization does not differ much compared to that of the basic control law.
Table 2 Experiment condition 2.

<table>
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<tr>
<td>$k_1$</td>
<td>72.0</td>
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<tr>
<td>$k_2$</td>
<td>0.666</td>
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<tr>
<td>$k_3$</td>
<td>37.5</td>
</tr>
<tr>
<td>$k_4$</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Fig. 13 Trajectory of evader in case the intruder does not exist.

Fig. 14 Trajectory of evader and intruder : case A.

For comparison, different initial conditions of the intruder were tested to see the difference in the control system. In the case of Fig. 14, the initial $y$ coordinate of the intruder is set at $-610$mm. This case is called case A. By declining the initial position of the intruder, it is harder to see the intruder till the last minute of engaging. So as for comparison, the initial position of the intruder is set at $-762$mm as case B and $-915$mm as case C. The trajectories of case B and C are shown in Fig. 17 and Fig. 18, respectively.

4.2.2 Evaluation

In case B, the intruder appears slower than case A. This makes the situation difficult for the case w/o IAF. For the result with IAF, the results seem similar to the case A.

In the results of case C, the intruder appears much slower than the case A and case B. In some cases, the evader did not enter the collision avoidance control. The results with IAF again show smooth trajectory away from the obstacle then back to the original trajectory. In every case with IAF, the trajectory is similar to that of the humans as we try to look in to the corner before approaching the blind wall.

Figure 19 shows the average of the relative distance of the evader and intruder at first contact. In all cases, the distance has enlarged 8.0%, 34.2%, and 39.5% in cases A, B, and C, respectively. In case A, the intruder appears quickly, and hence, is not much change but the other results have shown significant increase.

Figure 20 shows the crossover distance of the evader and intruder. Again the results have increased 50.8%, 79.5%, and 55.9%. This leads to safer cruise of the vehicle.

The modified control has shown the smoother trajectory with larger avoidance at the crossover point which gives the safer cruise condition.
5. Conclusion

The collision avoidance control law using information amount feedback is introduced and investigated through vehicular tests. The results show that the control law is feasible for collision avoidance for vehicles. The original control law had some disadvantages when the vehicle had to enter the collision avoidance control when it was in course keeping control after enough information was obtained by the information gathering control. This problem was solved by modifying the course keeping control phase so that the vehicle keeps its current course when the possibility of the collision enlarges. The modified system has shown significant increase in safety margins for safer cruise. The control with IAF has shown similar motion with that of humans and has feasibility for actual collision avoidance systems.

References


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