Automatic Collision Avoidance System Coping with Various Emergency Levels

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Abstract

In the congested waterway like Singapore Strait and Shanghai area, due to the high density of traffic flow, emergent encounter of multiple ships will occur frequently, which may result in near misses and even collisions. Marine Traffic Simulation System (MTSS) is a tool to reproduce the marine traffic flow in these areas. The main part of it is an automatic collision avoidance subsystem based on the conception of fuzzy reasoning regarding to collision risk. In this paper, first, simulation of Imazu problem, which is a series of ship encounter situations, has been conducted to check our system’s reliability. Then, for the more severe situation, in which some ships’ behaviors don’t follow the international regulation of collision avoidance at sea (COLREG), in order to make sure no collision happens in the water area, three levels of emergency degree has been put forward to distinguish how dangerous the ship is and instruct the ship to take appropriate avoiding actions. From the simulation results, our system could detect the target ship’s irrational behavior and make appropriate reaction against it.

Key word: Collision Avoidance, Imazu Problem, Emergency level,

1. Introduction

Marine Traffic Simulation System (MTSS) is a powerful tool to reproduce realistic marine traffic flow. It is equipped with a collision avoidance subsystem based on Fuzzy reasoning\(^{(1)(3)}\). The system, therefore, can instruct every ship to search for the most dangerous ship in the area to take appropriate action against it while focusing on the other threat and take action again if necessary\(^{(2)}\). The avoiding action includes the right turning and speed reduction. Now the system has been proposed for various applications such as safety assessment of port, intelligent ship simulator and waterway design.

Imazu problem\(^{(7)}\) is a series of ship encounter situations which are considered to be difficult for collision avoidance. In the congested waterway like Tokyo bay and Shanghai area\(^{(4)(5)}\), dangerous encounter of multiple ships similar to Imazu problem may occur frequently. If some ships’ behaviors don’t follow the international regulation of collision avoidance at sea (COLREG), the situation could be more severe. In this paper, simulation of these special emergency cases based on Imazu problem has been conducted.

2. Imazu Problem and Its Simulation

Imazu problem was summarized by Imazu from Tokyo University of Marine Science and Technology based on the real ship sailing data. It includes relatively easier two ships’ encounter and the more complicated multiple ships’ encounter situation. The Figure 1 shows the 22 cases of Imazu problem.

The circle shows the position of every ship while short bar gives the speed direction for easy looking. The speeds of all the ships are similar in the figure. Equipped with our automatic collision avoidance system, all the ships’ movements have been simulated.

In our avoiding rule\(^{(2)}\), for the two approaching ships, we defined 7 kinds of encounter types based on the
encounter angle and relative angle. According to different encounter types, one ship will take different avoiding action towards the other at different time based on the value of collision risk (CR).

Simulation of all the 22 cases have been conducted, here we choose case 14 for explanation. Figure 2 and 3 give the simulation result.

![Ship Trajectory for case 14](image1)

**Figure 2**  Ship Trajectory for case 14

![Ship heading change, speed and CR for case 14](image2)

**Fig. 3**  Ship heading change, speed and CR for case 14

In figure 2, four triangles give the positions while the arrows reveal the direction of every ship. The four color lines show the trajectories in time series. Figure 3 gives the ship heading change, speed and collision risk for all the four ships.

In our rule, according to the encounter type, the ship will be defined in 2 ways towards the target ship. One is give-way ship, and the other is stand-on ship. The give-way ship will take right turning or reduce speed immediately when CR become higher than 0.7. However, for the stand-on ship, it will wait until CR become higher than 0.9. Due to the fact that most of the seamen aren’t willing to reduce ship speed when they pass by other ships, the stand-on ship in our system has been divided 2 groups again with different avoiding behavior after CR exceed 0.9. One will act just like the give-way ship. However, the other will not reduce speed even if the situation is dangerous.

It is noted that the give-way ship and stand-on ship are relative conceptions. A ship may be give-way ship towards one ship, but be the stand-on ship to another ship.

From the results of case 14, due to different encounter type, some ships take avoiding action when CR exceeds 0.7 and some ships react after CR become higher than 0.9. After a series of avoiding actions, we can see that no collision happened in the area. For the other 21 case, our system also instructs every ship to avoid collision successfully. Hence, we can conclude that our system has solved the Imazu problem.

3. Emergency levels and Simulation Result

From the simulation result, we can understand that when all the ships follow our avoiding rules, no collision happens in the simulation area. However, it is impossible equip all the ships in the world with our system and even for the equipped ships, sometimes the system could break down. Besides, in the real world, many other different reasons will also result in the ship’s abnormal behavior to make the situation become much more dangerous. Therefore, it is necessary to make sure our system could deal with those emergency ship encounters.

When sailing on the sea, the own ship will always search for the potential threat and take action against it when necessary. If the target ship’s behavior are abnormal, the own ship should detect it and take avoiding action earlier, especially for the stand-on ship, because, if the give-way ship doesn’t avoid, there will be a high possibility of collision. In our system, an additional detecting function has been added to every ship. The stand-on ship will start to check the target ship’s movement usually when CR become higher than 0.7. The checking time is set as 10 seconds temporarily in the system. In some extreme case, if the checking
procedure starts after CR become higher than 0.9, the checking time will be shorten to 5 seconds. It is noted that this checking time is only set for our system, and the time span should be discussed and set more carefully depend on different situations. For the give-way ship, there is no need to check the target ship’s behavior since it will take avoiding action when CR exceeds 0.7 anyway.

According to the degree of the risk, three emergency levels have been defined in this paper. The higher the number is, the more dangerous the encounter is. The situations for give-way ship and stand-on ship are discussed separately. The emergency levels and avoiding actions for give-ship and are showed in table 1.

Table 1 Emergency Levels for Give-way Ship

<table>
<thead>
<tr>
<th>Emergency Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (CR&lt;0.7)</td>
<td>No Avoiding Action</td>
</tr>
<tr>
<td>1 (CR&gt;0.7)</td>
<td>Right Turning or Reducing Speed (According to ACR)</td>
</tr>
</tbody>
</table>

For the give-way ship, when CR becomes higher than 0.7, the own ship will start to take avoiding action, thus there will be only two levels. The action will be decided by ACR, if ACR is higher than 0.7, it means that it is dangerous to turn right, therefore the ship will start to reduce speed. However, the situation for stand-on ship is more complicated. Table 2 gives the emergency levels for stand-on ship.

Table 2 Emergency Levels for Give-way Ship

<table>
<thead>
<tr>
<th>If target ship’s behavior is normal</th>
<th>Hold-on</th>
<th>Hold-on without speed reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Level 0 (0.9&gt;CR&gt;0)</td>
<td>No Avoiding Action</td>
<td>No Avoiding Action</td>
</tr>
<tr>
<td>Emergency Level 1 (CR&gt;0.9)</td>
<td>Right Turning or Reducing speed</td>
<td>No Avoiding Action</td>
</tr>
</tbody>
</table>

If target ship’s behavior is abnormal

<table>
<thead>
<tr>
<th>Emergency Mode 2 (0.9&gt;CR&gt;0.7)</th>
<th>Right Turning (30 deg.)</th>
<th>Right Turning (30 deg.) Reduce Speed (1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Mode 3 (CR&gt;0.9)</td>
<td>Right Turning (45 deg.) Reduce Speed (1/3)</td>
<td>Right Turning (45 deg.) Reduce Speed (1/3)</td>
</tr>
</tbody>
</table>

As you can see in this table, according to the encounter type, there are two types of stand-on ship. One will not reduce speed and the other will if necessary. There are four emergency levels. If the target ship’s behavior doesn’t follow the COLREG, the own ship will take avoiding action earlier than usual, when CR exceeds 0.7. Usually the encounter type of Hold-on without speed reduction will be more severe because the target ship comes from the left behind side. If the own ship turn right to avoid, two ships heading will be almost the same, then they will keep moving in parallel for a long time to deviate too far from the original path. Thus, the own ship will start reduce speed as soon as CR exceeds 0.7.

Simulation of two ships encounter has been conducted. In the simulation, the target ship approaches our own ship from different directions. The following Figure 4 and Figure 5 give a simple example in which the own ship is stand-on ship. It is the case 4 of Imazu Problem.

Fig. 4 Ship Trajectory for case 4

Fig. 5 Ship heading change, speed and CR for case 4
In the above example, the ship ID 10 is set as the own ship and ID 20 is the target ship. According to the encounter angle and relative angle, the ship ID 20 is the give-way ship and it should avoid ship ID 10 actively.

However, in this case, due to some unknown reasons, the ship ID 20 keeps its heading and speed all along. Ship ID 10 starts to check the target ship’s behavior after CR exceeds 0.7 and then finds out that the give-way ship doesn’t take any avoiding action. So it starts to avoid by itself. First, the own ship turns right for 30 degree, but the collision risk decreases for a while but increases again and reaches 0.9. It means that turn 30 degree is not enough. Then the own ship starts to reduce speed and increase the turning angle to 45 degree at the same time. The result shows that the own ship avoids the target ship successfully and returns to its original path. The minimum distance between two ships is near 100 meters.

For multiple ships encounter, the situation is much more complicated. The following figure 6 gives the four ships’ trajectories for case 14.

![Figure 6 Ship Trajectory for case 14](image)

4. Conclusion

In this paper, several simulation of Imazu Problem has been done. Main conclusion can be drawn as follows:

1. When an automatic navigation system is evaluated, it is necessary to be done with various simulations including emergency cases.

2. Different emergency levels have been defined for give-way and stand-on ship, based on the behavior of the target ship and the collision risk (CR).

3. The MTSS succeeds to instruct every ship to avoid the collision with the ship whose behavior doesn’t follow the COLREG.

4. There are still discussions regarding to the time span for judging target’s behavior in the automatic system.

5. Reference


