Process map for collision avoidance based on information exchange for autonomous navigation of vessel

Ho Namgung¹, Jung Sik Jeong², Kwangil Lee³, and Sun-Young Kim⁴

¹Graduate school of Maritime Transportation System, Mokpo National Maritime University, Mokpo, Republic of Korea
²Department of Maritime Transportation Science, Mokpo National Maritime University, Mokpo, Republic of Korea
³Department of Control and Automation Engineering, Korea Maritime and Ocean University, Busan, Republic of Korea
⁴Maritime Safety and Environmental Research Division, Korea Research Institute of Ships & Ocean Engineering, Daejeon, Republic of Korea

Email: jsjeong@mmu.ac.kr

Abstract. A reliable collision avoidance method is essential when operating an autonomous vessel. For this to become a reality, a number of researches have been conducted in order that the autonomous vessel could take an action for collision avoidance by herself. However, it may lead to dangerous situation without knowing the navigation intention of target-ships. In order to solve the issue, we developed the process map for collision avoidance based on information exchange via the communication relay system as follows: (i) the navigation situation analysis of the autonomous vessel was conducted based on manned ship voyage definition; (ii) the sequence diagram for information exchange was developed based on the autonomous vessel’s navigation context and the communication relay system, and (iii) the process map for collision avoidance based on information exchange was proposed based on the developed sequence diagram and the existing collision avoidance method. It would be expected that the autonomous vessel could avoid collision more safely than taking an action by herself.

1. Introduction

Preventing collision with approaching target-ship is one of the most critical ability to ensure safety and effectiveness during an autonomous vessel’s operation. For this to become a reality, trustworthy and effective algorithms for collision avoidance by herself have been developed [1-6]. However, according to “A Guide to the Collision Avoidance Rules” [7], it stated that information exchange between vessels can be useful in circumstances of collision avoidance because of analysing navigation intentions prior to taking an action.

Recently, the communication relay system based on available communication interfaces at sea has been developed to enable information exchange between the autonomous vessel and approaching target-ship [8]. Therefore, in the paper, we propose the process map for collision avoidance based on information exchange between the autonomous vessel and target-ship. This paper has essentially three parts: In the first part, the autonomous vessel’s navigation situation context is defined. In the second part, sequence diagram for information exchange is made via the defined navigation situation context.
and the communication relay system. In the third part, the process map for collision avoidance based on information exchange is proposed via the sequence diagram and collision avoidance method.

The remainder of the paper is organized as follows: Section 2 describes the communications relay system and collision avoidance method. Section 3 presents the process map. Finally, a summary of the work and the conclusion are drawn in Section 4.

2. Related Work

2.1. Communication Relay System

![Diagram of Communication Relay System](image)

**Figure 1.** Configuration of the communication relay system [8].

The communication relay system [8] consisted of three type of controller: Very High Frequency (VHF) communication controller can transmit the voice message received from the Vessel Traffic System (VTS) or manned ship to the Maritime Control Station (MCS) via the Voice over Internet Protocol (VoIP), and the MCS respond the VTS or manned ship by sending the voice message generated from the MCS over the VoIP. The TTS controller can receive the voice message composition from the MCS, requesting the TTS server by sending the message converted into the Speech Synthesis Markup Language (SSML) format. Then the TTS server synthesizes the voice as the WAV file, and transmits it to the WAV player to play it. The output is passed through the voice switch to the VHF transmitter or the broadcast amplifier. The AIS controller is responsible for transmitting AIS-ASM messages received from the autonomous vessel to the MCS via VHF Data Exchange System (VDES).

2.2. Collision Avoidance Method

All vessels must take an action for collision avoidance in compliance with the International Regulations for Preventing Collision at the Sea (COLREGs) [9] as presented in Figure 2. First, every vessel shall at all times maintain a proper look-out by using all available means in order to assess of the risk of collision. Second, encounter relation (i.e., head-on situation, crossing situation, and overtaking) is determined if the risk of collision exists. Third, a give-way vessel or a stand-on vessel is determined according to encounter relation. Fourth, any action to avoid collision shall be taken.
In other words, collision avoidance starts assessment of the risk of collision. In particular, it stated that the radar plotting is suitable equipment in order to obtain early warning or the risk of collision from observation of detected objects according to “Rule 7: Risk of Collision” [9].

Therefore, a number of researches have been conducted by using the radar plotting [1-6]. At this time, the risk of collision was assessed by Collision Risk Index (CRI), which is calculated by Distance to Closest Point of Approach ($D_{CPA}$) and Time to Closest Point of Approach ($T_{CPA}$). In particular, access to the CRI calculated by fuzzy logic was not only assess CRI at the same time when approaching multiple-ship, but also a point of time for a give-way vessel and a stand-on vessel were defined according to the encounter relation. Figure 3 shows the inference process of Fuzzy Inference System (FIS) [4,5].

Range of the CRI is from 0.00 to 1.00 [4,5], and a point of time for collision avoidance is as follows: (i) a give-way vessel must take an action for collision avoidance when the CRI exceed more than 0.33, and (ii) a stand-on vessel must take an action for collision avoidance when the CRI exceed more than 0.66.

where a give-way vessel and a stand-on vessel must take an action according to type of encounter relation [9].

- In case of the head-on situation, both vessels should alter course to the starboard for collision avoidance.
- In case of the crossing situation, the vessel having the other vessel on its starboard is a give-way and should alter its course so it passes behind the other vessel. The other vessel should keep a steady course and speed as a stand-on vessel. But if a give-way vessel does not take appropriate action, a stand-on shall take an action as will best aid to avoid collision.
- In case of the overtaking, the vessel being overtaken should keep steady speed and course. The overtaking vessel could pass the other vessel on both sides.
3. Process Map for Collision Avoidance based on Information Exchange

3.1. Navigation Situation Analysis

The autonomous vessel’s navigation phase was set as the departure-navigation-arrival phase. Then, the information exchange message [10] was constructed by identifying and extracting the required information that may occur during the navigation phase. Figure 4 shows the autonomous vessel’s navigation situation context. First, we analysed the navigation situations of manned ships and set the navigation situations for the purpose of carrying out the autonomous vessel’s navigation. In the case of manned ships, a pilot, who carry the ship to a safe channel, will board the ship and guide the ship to the pilot station. However, in the case of the autonomous vessel, maneuvering by the pilot was unnecessary because a person does not board. Therefore, the autonomous vessel added an access phase to enter the navigation route. Based on this, the autonomous vessel’s navigation route was established to construct various situations that can occur in each navigation route, and a standard information exchange message for information exchange was applied.

![Diagram showing autonomous vessel's navigation situation context](image)

**Figure 4.** Autonomous vessel’s navigation situation context.
3.2. Sequence diagram

Based on the autonomous vessel’s navigation context, sequence diagram for information exchange between the autonomous vessel and VTS and/or target ship was configured via the communication relay system and standard information exchange messages as presented in Figure 5. In case of departure and arrival, the MCS sends created report messages to the autonomous vessel by using VHF telephone, AIS, TTS via dedicated communication channel [8] between the MCS and the autonomous vessel. Then, the autonomous vessel transfers created message to VTS and/or target ship by using VHF telephone, AIS, TTS via existing communication channel [8] between the autonomous vessel and VTS. In terms of navigation, target ship sends created navigational message to the autonomous vessel by using VHF telephone and AIS via exiting communication channel. Then the autonomous vessel transfers received message to the MCS by using VHF telephone and AIS via dedicated communication channel. After analysing navigation intention from target ship, the MCS respond to target ship via the autonomous vessel. Like the preceding, the MCS is able to send navigational messages to target ship via the autonomous vessel in case of navigation.

Figure 5. Sequence diagram for information exchange based on navigation situation context.
3.3. Process Map
Process map was established as shown in Figure 6. First, the autonomous vessel infer the CRI via the FIS. Second, in case of the CRI more than 0.33, encounter relation (i.e., head-on situation, crossing situation, and overtaking) is analysed according to the COLREGs. Third, in case the autonomous ship is a give-way vessel, the MCS creates navigation intention message. But if the autonomous ship is a stand-on vessel, the MCS creates navigation intention message according to whether the CRI more than 0.66 or not. Fourth, the MCS inputs the created message as a voice data or a text data, and then transfers the data to the communication relay system. Fifth, the communication relay system sends the received data to target ship via VHF radio and AIS controller.

![Process Map for Collision Avoidance](image)

**Figure 6.** Process map for collision avoidance based on information exchange.
4. Conclusion
To avoid collision between the autonomous vessel and target ship via information exchange, the process map was proposed. In order to develop it, the navigation situation analysis for the autonomous vessel and the sequence diagram for information exchange via the communication relay system were made. Then, by synthesizing the preceding, the process map for collision avoidance based on information exchange was established systematically. It would be expected that the autonomous vessel is able to take and action for a reliable collision avoidance because of analysing navigation intentions of target ship in advance. In the near future, we are looking forward to extending our work on simulation and experiment at sea.

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