On the sea trial test for the validation of an autonomous collision avoidance system of unmanned surface vehicle, ARAGON

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***Abstract*—ARAGON is an unmanned surface vehicle (USV) for ocean observation and sea surveillance of Korea Research Institute of Ships and Ocean Engineering (KRISO). It has been constructed through the research and development project, which is entitled with "The development of intelligent unmanned surface vehicle for multipurpose mission of ocean observation and sea surveillance" under the financial support of Korea Ministry of Oceans and Fisheries since 2011. Now, it is the final eighth fiscal year of the project. The length of ARAGON is about 7.5 meter and its maximum speed is over 40 knots. ARAGON has 400-HP diesel engine with single water-jet. In order to make USV navigate safely according to the convention on the international regulations for preventing collisions at sea, 1972 (COLREGs) without human operation, autonomous navigation system is needed. A collision avoidance system is developed by using changeable action space searching. Action space can be flexibly changed according to the collision risk, which is estimated by using obstacle information on a basis of fuzzy inference. Navigational information of USV such as position, speed, course and attitude are acquired by using real-time kinematic (RTK) GPS and Integrated Navigation System (INS). Obstacles can be detected and tracked by using multi-sensors fusion of automatic identification system (AIS), Pulse radar, light detection and ranging (Lidar) and EO/IR (Electro Optical/Infra-Red) camera. Optimal route for collision avoidance is estimated according to the cost functions related to collision risk in real-time. Autopilot and speed controller is actuated for the following to the optimal route. In order to evaluate the performance of autonomous navigation of ARAGON, field tests are carried out in actual sea area, Busan on the complicated colliding situations such as head-on, crossing and overtaking with multiple obstacles. Three physical powerboats are used as moving obstacles in the colliding situation of head-on, port-crossing and starboard-crossing. Two virtual boats are used as moving obstacles in the colliding situation of the 2nd head-on and overtaking. In this paper, the main features of ARAGON and main results of field test are described.**

Keywords—unmanned surface vehicle; autonomous navigation; changeable action space searching; collision avoidance; obstacle avoidance

I. INTRODUCTION

Unmanned Surface Vehicle (USV) has been developed in order to perform difficult missions as a substitute of manned vehicle in bad sea weather condition. USV is a small boat, which can be controlled remotely or autonomously. Its weight is about 0.5 tons to 9 tons [1]. USV was firstly developed for military purposes in Spartan project in USA. Multi-purpose USV has been developed to perform intelligence, surveillance and reconnaissance (ISR) together with the support for UUV and UAV. In Korea, a basic technology for unmanned observation vehicle has been developed and a control system for remotely controlled vessel has been developed from 2004 to 2009. Rigid Hull Inflatable Boat (RHIB) has been used for sea trial tests [2, 3, 4]. A project for the development of intelligent unmanned surface vehicle for multipurpose mission of ocean observation and sea surveillance has been conducted under the financial support of The Ministry of Oceans and Fisheries since 2011. Now, it is the final eighth fiscal year of the project.

Because USV is controlled autonomously without human operator and it has the colliding accidental possibility with manned vehicle on the sea area, USV need to keep the convention on the international regulations for preventing collisions at sea, 1972 (COLREGs). The core technology of collision avoidance is to quantify the risk of colliding situation between USV and traffic ship and to decide the safe route for collision avoidance. To estimate the collision risk effectively, fuzzy algorithm has been used. Hasegawa inferred the collision risk using time to the closest point of approach (TCPA) and distance to the closest point of approach (DCPA) [5]. Rhee and Lee extended the algorithm of collision avoidance on a basis of Hasegawa's results [6]. Kijima and Furukawa designed automatic collision avoidance system using fuzzy inference [7]. Son estimate the directional collision risk around own-ship by using fuzzy algorithm [8]. In order to decide the safe route for collision avoidance, action space searching method has been used. Imazu and Koyama implemented collision avoidance by using the probability of collision and action space searching [9]. Rhee and Lee applied the estimation method of collision risk to

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the action space searching [10]. Kijima and Furukawa changed directional range of searching according to the level of collision risk [11]. Son has developed the autonomous collision avoidance system (ACAS) for USV by using the concept of changeable action space searching in which action space can change according to the level of collision risk [12] . In the previous study, ACAS has been validated on the first prototype of USV, ARAGON I by using AIS [13] . It is important to detect and track the obstacle for autonomous collision avoidance in USV. Pulse radar is used for the main sensor of obstacle detection and tracking. But because pulse radar has the blind zone, obstacle detection and tracking tests has been carried out by using multiple sensors such as pulse radar, electro-optical camera, infra-red camera and Lidar[14,15] .

In this paper, autonomous collision avoidance system (ACAS) is developed for USV, ARAGON II by using fuzzy algorithm and changeable action space. sea trial test is carried out in order to validate the ACAS on the second prototype of USV, ARAGON II. Test scenarios include the complicated colliding situations against multiple traffic ships of head-on, crossing and overtaking. Obstacle information are used on track data, which are calculated from sensor fusion among pulse radar, electro-optical camera, infra-red camera and Lidar[16]. Three power boats are used for moving obstacles together with two virtual ships, which is generated by using virtual simulation. Main features of ACAS and the results of sea trial test are described in this paper.

II. AUTONOMOUS COLLISION AVOIDANCE SYSTEM (ACAS)

A. Unmanned Surface Vehicle, ARAGON II

ARAGON II, the second prototype of Unmanned surface vehicle (USV) of KRISO has been built in 2016 and it is a kind of planning hull. Fig. 1 shows ARAGON II. The main dimensions are summarized in TABLE I. ARAGON has been developed for multiple missions of ocean observation and sea surveillance.

TABLE I. PRINCIPAL DIMENSION OF ARAGON II

Item	Dimension
LENGTH	8.0 m
BREADTH	2.5 m
MAXIMUM SPEED	Over 40 knots
ENGINE	400-hp Diesel Engine with single waterjet

Fig. 1. THE 2ND PROTOTYPE USV of KRISO, ARAGON II

B. Configuration of ACAS

ACAS consists of main three parts for collision avoidance. The first part is obstacle recognition part, in which navigational information of USV and obstacle information are collected. Navigational information of USV such as position, speed, course and attitude are acquired by using real-time kinematic (RTK) GPS and integrated navigation system (INS). Obstacle information are collected from data fusion among automatic identification system (AIS), pulse radar, light detection and ranging (Lidar) and electro-optical & infrared (EO/IR) camera[16]. The second part is collision avoidance algorithm part, in which the optimal route is estimated by using changeable action space searching and collision risk based fuzzy algorithm. The final part is auto-pilot, which is actuated for the following to the optimal route. Each part is real-timely conducted and time consumption of each step is shorter than one second.

C. Collision avoidance algorithm

To estimate the route for collision avoidance, A* searching method has been used but the size of action space such as node, branch and layer is fixed irrespective of the level of collision risk [10]. A searching method, in which the directional range of searching can be changed according to the collision risk, has been used but the action space in the future is not considered [5]. In this paper, in order to consider the change of the level of collision risk, a collision avoidance algorithm is designed by using the searching method of changeable action space (CAA). In the previous study, CAA has been tested on the 1st prototype USV, ARAGON I in the actual sea area [13]. Fig.2 shows the flow of collision avoidance algorithm by using CAA. In the configuration of action space during encountering obstacle, changeable action space is generated considering the collision risk which is estimated in each node by using fuzzy algorithm. The optimal route is decided out of alternative routes according to the cost function. TABLE II summarized the inference laws of collision risk.

TABLE II. INFERENCE LAWS OF COLLISION RISK [12]

TCPA or DCPA		**TCPA**							
		NB	**NM**	**NS**	**PS**	**PMS**	**PM**	**PMB**	**PB**
DCPA	PS	-0.2	-0.6	-1	1	0.8	0.6	0.4	0.2
	PMS	-0.2	-0.2	-0.6	0.8	0.6	0.4	0.2	0.2
	PM	-0.2	-0.2	-0.2	0.6	0.4	0.2	0.2	0.2
	PMB	-0.2	-0.2	-0.2	0.4	0.2	0.2	0.2	0.2
	PB	-0.2	-0.2	-0.2	0.2	0.2	0.2	0.2	0.2

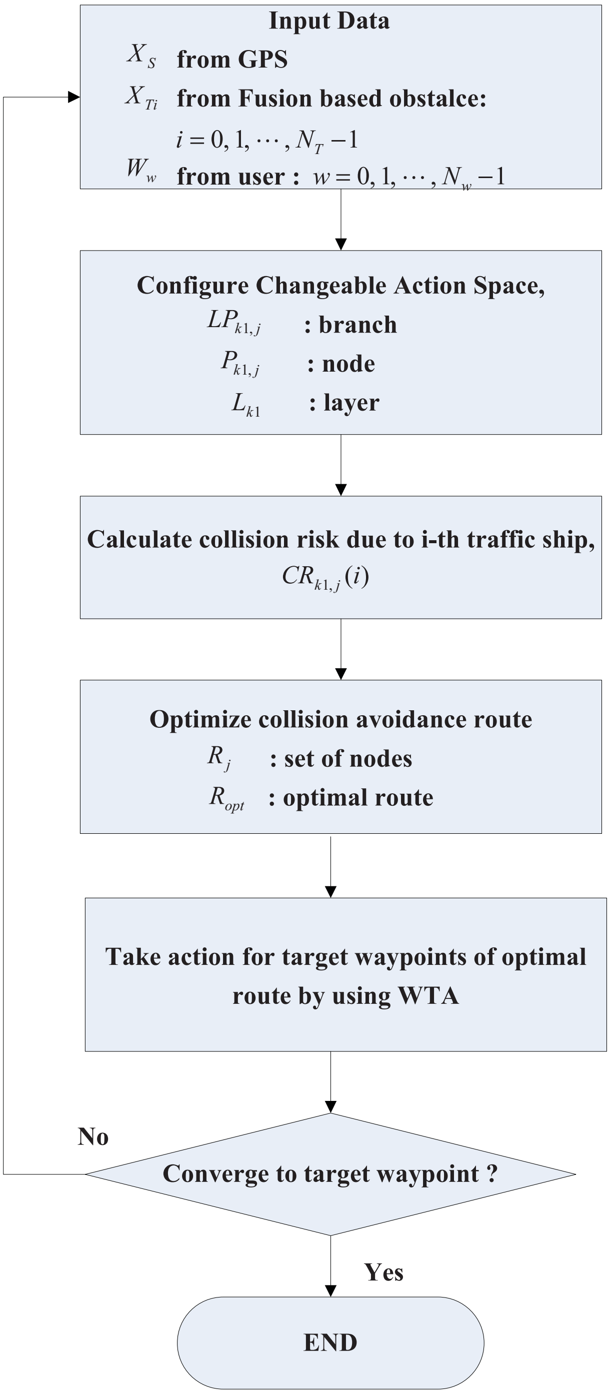

Fig. 2. Flowchart of collision avoidance algorithm

III. SEA TRIAL TEST AND RESULT

A. Scenario of sea trial test

Testbeds are established in order to validate the autonomous collision avoidance system (ACAS) of the USV, ARAGON II as shown in Fig. 3. To check into the performance of ACAS on the various encountering situation against traffic ships according to the COLREGs, the complicated colliding scenario is planned with five traffic ships of head-on, port-crossing, starboard-crossing, the 2nd head-on and overtaking as shown in Fig. 4. Two traffic ships of the 2nd head-on and overtaking are virtually generated. Three power boats are used as head-on vessel and two crossing vessels as shown in Fig. 5.

Fig. 3. USV ARAGON II in the Suyoung Bay of Busan

Fig. 4. Scenarios for collision avoidance

As shown in Fig. 4, the distance between the starting position of each traffic ship and the colliding position with

USV, ARAGON II is about 500 meters and the test speed of traffic ship and ARAGON II is 10 knots. In the scenario, because starboard-crossing vessel and overtaking vessel are stand-on vessels according to the COLREGs, they keep the course and the speed even in the colliding situation with ARAGON II which takes action of collision avoidance actively[16]. But because port-crossing vessel is give-way vessel according to the COLREGs, it takes action of collision avoidance against ARAGON II by using human operation.

B. *Results of sea trial test*

Fig. 5, Fig. 7 and Fig. 9 show the trajectory results of USV, ARAGON II and traffic ships. Black line means USV, ARAGON II and red line means track data, '900X' of traffic ships from sensor fusion. Blue line means trajectory of virtual traffic ship of overtaking or the 2nd head-on vessels. '123', '456' and '789' mean navigation data of AIS, which is installed in head on, starboard-crossing or port-crossing vessel for the reference of sensor fusion. In the collision avoidance, track data from sensor fusion are used as obstacle information. Fig. 6 and Fig. 8 show the photographs of collision avoidance taken from drone camera during sea trial test.

Fig. 5. Trajectory of collision avoidance of USV ARAGON II against virtually-overtaking, port-crossing and starboard-crossing vessels

Fig. 6. Photograph of collision avoidance of USV ARAGON II against virtually-overtaking, port-crossing and starboard-crossing vessels

ARAGON II is stand-on vessel against overtaking virtual vessel (ID:111) and port-crossing vessel (ID:456) according to COLREGs. As shown in Fig. 5 and Fig. 6, ARAGON II keep its course in the overtaken situation and even until port-crossing vessel passes by the stern of ARAGON II. ARAGON II is give-way vessel against starboard-crossing vessel (ID:123) and it takes avoidance action to starboard. As shown in Fig. 5 and Fig. 6, ARAGON II changes its course to starboard side for collision avoidance against starboard-crossing vessel.

After three obstacles of overtaking, port-crossing and starboard crossing vessel pass by, two obstacles of head-on and the 2nd head-on vessels continuously approach to ARAGON II. Fig. 7 and Fig. 9 show the trajectory of collision avoidance against head-on vessel (ID:789) and the 2nd virtual head-on vessel (ID:222), respectively. The track data from sensor fusion (ID:9007) is similar with the AIS data(ID:789). According to the COLREGs, ARAGON II is give-way vessel on the head-on vessels. As shown in Fig. 9, ARAGON II takes the continuous actions to the starboard-side for collision avoidance against the continuously approaching obstacles in head-on direction.

Fig. 7. Trajectory of collision avoidance of USV ARAGON II against head-on vessel

Fig. 8. Photograph of collision avoidance of USV ARAGON II against head-on vessel

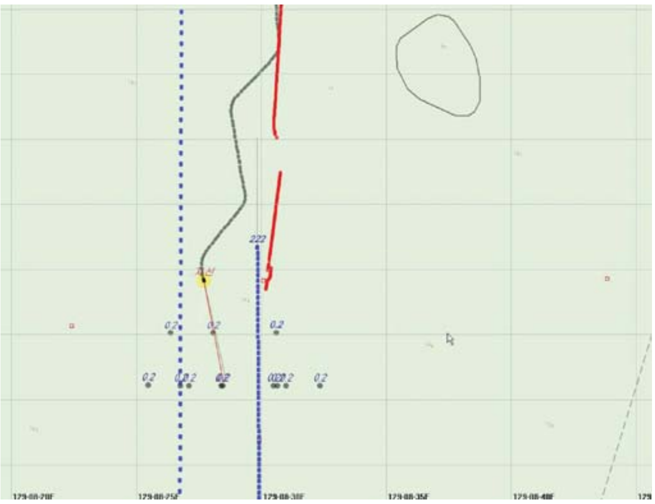

Fig. 9. Trajectory of collision avoidance of USV ARAGON II against head-on and virtual head-on vessel

IV. CONCLURIONS

Autonomous collision avoidance system (ACAS) is developed for USV, ARAGON II by using fuzzy algorithm and changeable action space. Sea trial test is carried out in order to validate ACAS according to the COLREGs. To evaluate the performance of ACAS on the five continuous colliding situations with overtaking, port-crossing, starboard-crossing, head-on and the 2nd head-on vessels, actual three powerboats and two virtual boats are used as traffic ships in the sea trial test. In collision avoidance, track data from sensor fusion are used as obstacle information. As a result of sea trial test, ARAGON II successfully takes avoidance actions in the all of colliding situation against the five approaching traffic ships by using ACAS. As stand-on vessel against overtaking and port-crossing vessel according to the COLREGs, ARAGON II successfully keep its course without any avoidance action during traffic ships' passing. As give-way vessel against starboard-crossing vessel and head-on vessel according to the COLREGs, ARAGON II successfully takes avoidance actions to starboard-side. In the future, it is necessary to validate ACAS on the various maritime traffic conditions in the actual sea fairway in order to check into the stability and robustness of ACAS.

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