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STUDY ON ADVANCED DEVELOPMENT AND APPLICATION OF MICRO MARINE ROBOT FOR MARITIME DOMAIN AWARENESS

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Abstract. *Recently, researches of the heterogeneous collaborative network composed of marine robots such as an underwater robot, a surface robot, and an aerial robot are gradually executed for maritime domain awareness (MDA). However, the development and application (D&A) of large-sized marine robots has many difficulties due to size and cost. As the micro marine robot (MMR) which is a kind of the marine robot has the superiority in terms of size and cost although it has some constraints due to small power, the D&A of MMR may be effective to develop the heterogeneous collaborative network. To study the D&A of MMR, an advanced D&A of MMR using the system engineering process (SEP) and the virtual marine robot (VMR) is considered. Study results show the overview of MMR, the advanced D&A of MMR and the need for additional studies.*
Keywords: Maritime domain awareness, Heterogeneous collaborative network, Micro marine robot, System engineering process, Virtual marine robot

1. **Introduction.** Recently, researches of the heterogeneous collaborative network [1] composed of marine robots such as an underwater robot, a surface robot, and an aerial robot are gradually executed for maritime domain awareness (MDA). However, the development and application (D&A) of large-sized marine robots has many difficulties due to size and cost, i.e., the large-sized marine robots have low mobility and high cost. This means that the large-sized marine robots have the ability of the wide area navigation and the high cost operating.

Among the future marine robot, the micro marine robot (MMR) has no difficulty due to size and cost, i.e., the MMR has high mobility and low cost. This means that the MMR has the ability of the narrow area navigation and the low cost operating. As the MMR has the superiority in terms of size and cost although it has some constraints in terms of operating time, detection range, disturbance rejection due to small power, the D&A of MMR may be effective to develop the heterogeneous collaborative network that has the application area of inspection, military, research, survey, work, port, etc.

To study the D&A of MMR, an advanced D&A of MMR using the system engineering process (SEP) as a global research and development (R&D) methodology and the virtual marine robot (VMR) as an information and communications technology (ICT)-based R&D methodology is considered.

2. **Overview of MMR.** Related to the overview of MMR, the studies of the heterogeneous collaborative network, the autonomous underwater vehicle (AUV) and the MMR are performed as follows.

The naval postgraduate school (NPS) in USA as the best practice of MDA has the heterogeneous collaborative network [2,3] that effectively connects the underwater, surface, and aerial systems for MDA.

According to the Douglas Westwood Ltd, the AUV which is a kind of the marine robot can be divided into the small ($<$ 100kg), medium (101-1000kg), large ($>$ 1000kg) in terms of its size. Although the small AUV which is a kind of MMR has the small number of models, it has the large number of units in the AUV market. This means the MMR has the best marketability in the AUV market. This is well shown in Table 1.

Table 1. The world AUV market report 2010-2019

Models	Hybrid	Inspection	Military	Research	Survey	Unknown	Work	Total
?				1		1		2
large	2	1	16	14	3		1	37
medium		1	13	13	2			29
small	1		7	14	1			23
Total Models	3	2	36	42	6	1	1	91
Units								
?				1		1		2
large	2	1	36	29	6		1	75
medium		2	79	38	19			138
small	1		30	152	231			414
Total Units	3	3	145	220	256	1	1	629

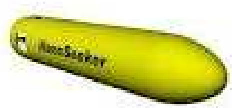
As a proof of the development of the MMR, the representative development cases of the MMR are summarized in Table 2.

The Research Institute of Marine Robot Education Technology (RIMRET) in Korea as the best practice of the education has the representative development cases of the MMR: a micro surface robot (MSR) which is named S-Shark I has the abilities of surface locomotion based on the 2-degree of freedom (DOF) motion of surge and yaw and obstacle avoidance based on the 3-channel obstacle avoidance sonar (OAS) detection of front, right and left. An MSR which is named S-Shark II has the abilities of surface locomotion based on the 2-DOF motion and obstacle avoidance based on the 4-channel OAS detection of front, right, left and bottom. An MSR which is named S-Shark III has the abilities of surface locomotion based on the 2-DOF motion and obstacle avoidance based on the rotating 4-channel OAS [4]. A micro underwater robot (MUR) which is named G-Shark I has the abilities of underwater locomotion based on the 3-DOF motion of surge, yaw and pitch and obstacle avoidance based on the 4-channel OAS [5]. An MUR which is named G-Shark II has the abilities of underwater locomotion based on the 4-DOF motion of surge, yaw, pitch and heave and obstacle avoidance based on the 4-channel OAS and image acquisition based on the side scan sonar (SSS). A micro aerial robot (MAR) which is named A-Shark I has the abilities of aerial locomotion based on the 3-DOF motion and remote control based on the radio frequency (RF) controller [6]. An MAR which is named A-Shark II has the abilities of aerial locomotion based on the 2-DOF motion and obstacle avoidance based on the rotating 1-channel infrared (IR) [7].

3. **Advanced D&A of MMR.** Related to the advanced D&A of MMR, the studies of the SEP and the VMR are performed as follows.

The SEP as a global R&D methodology is the activities of people that improve the efficiency in the development of the system which is a set of associated component for common purpose. The operating concept is established after the brainstorming process.

Table 2. Representative development cases of MMR

Year	MMR	Nation	Developer	Image
2006	Micro Hunter	USA	Nekton Research	
2008	Ranger	USA	Nekton Research	
2008	Transphibian	USA	Nekton Research	
2009	Nano Seeker	CANADA	Hylands Underwater Vehicles	
2011	S-Shark	Korea	RIMRET	
2012	G-Shark	Korea	RIMRET	
2012	A-Shark	Korea	RIMRET	

Based on this operating concept, the requirement analysis is performed and the requirements are derived consequently. Based on the requirement analysis, the functional analysis is performed and the functions are derived consequently. Based on the functional analysis, the design is implemented and the hardware and software family trees are acquired consequently. Based on the design, the manufacturing is executed and the prototype is acquired consequently. Based on the analyses, design, and manufacturing, the test and evaluation items are acquired. Through the test and evaluation, related requirements and functions may be satisfied. These processes are shown in Figure 1.

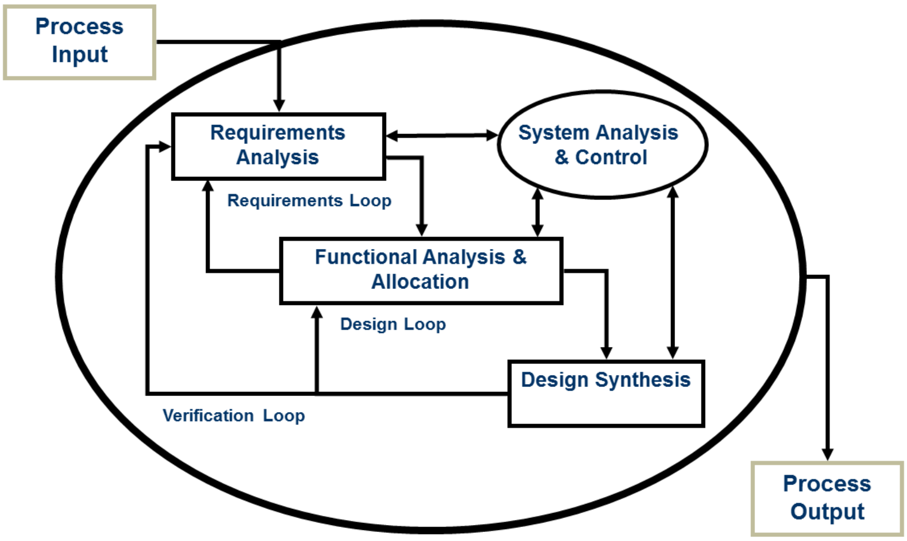


FIGURE 1. System engineering process

The VMR as an ICT-based R&D methodology is the technology of modeling and simulation (M&S) that analyzes the effectiveness by estimating the performance in the development of the system.

Recently, the design is implemented using the computer aided three dimensional interactive application (CATIA) program as a modeling tool and this modeling tool facilitates the easy development of the VMR by using compatible rendering tool. Also, mathematical modeling is necessary to reduce the performance estimation error. The general marine robot involves 6-DOF motions because six independent coordinates are required to define the position and orientation of a rigid body in three dimensions, i.e., it is described by the components of surge, sway, heave, roll, pitch, and yaw [8,9]:

$$\boldsymbol{Ma} = -\begin{bmatrix} \boldsymbol{F}_I \\ \boldsymbol{G}_I \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_R \\ \boldsymbol{G}_R \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_H \\ \boldsymbol{G}_H \end{bmatrix} + \begin{bmatrix} \boldsymbol{F}_P \\ \boldsymbol{G}_P \end{bmatrix} \tag{1}$$

where $\boldsymbol{M}$ is a mass matrix and $\boldsymbol{a}$ is an acceleration vector. Respectively, $\boldsymbol{F}_I$ and $\boldsymbol{G}_I$ are inertia force and moment vectors, $\boldsymbol{F}_R$ and $\boldsymbol{G}_R$ are restoring force and moment vectors, $\boldsymbol{F}_H$ and $\boldsymbol{G}_H$ are hull force and moment vectors and $\boldsymbol{F}_P$ and $\boldsymbol{G}_P$ are propulsion force and moment vectors. The representative development cases of the MMR are summarized in Table 3.

The RIMRET in Korea as the best practice of VMR has the representative development cases: a surface robot assembly/disassembly visualization simulator (SRAVsim), an underwater robot interaction visualization simulator (URIVsim), an aerial robot assembly/disassembly visualization simulator (ARAVsim), an underwater robot assembly/disassembly visualization simulator (URAVsim).

As a proof of the marketable application of the MMR, the educational and military cases are representative. These are shown in Figure 2.

From these results, the advanced D&A of MMR is proven to have meaningful methodologies such as SEP and VMR. In the future, additional studies such as path planning [10] and navigation will be conducted for the concrete D&A of MMR.

4. **Conclusions.** In this paper, an advanced D&A of MMR using the SEP and the VMR has been well studied. The advanced D&A of MMR is summarized as follows: it requires the SEP such as the brainstorming, the operating concept establishment, the requirement analysis, the functional analysis, the design, the manufacturing, the test and evaluation to improve the efficiency; it requires the VMR such as the assembly/disassembly visualization simulator, the interaction visualization simulator to analyze the effectiveness; it has the

Table 3. Representative development cases of VMR

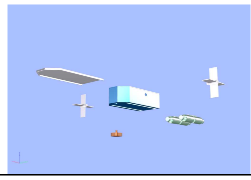
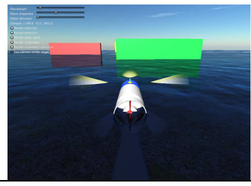
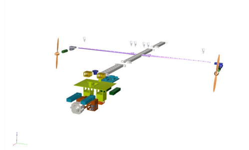
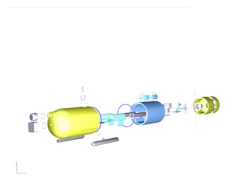
Year	VMR	Nation	Developer	Image
2014	SRAVSim	Korea	RIMRET	
2014	URIVSim	Korea	RIMRET	
2015	ARAVSim	Korea	RIMRET	
2015	URAVSim	Korea	RIMRET	

Figure 2. Representative application cases of MMR

best marketability of both civil and military application areas. The study results showed the overview of MMR, the advanced D&A of MMR and the need for additional studies. Through this, a basic D&A of MMR for MDA has been established.

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