Journal of Computer and Communications, 2017, 5, 83-91
http://www.scirp.org/journal/jcc
ISSN Online: 2327-5227
ISSN Print: 2327-5219

Case Analysis for USV Integrated Mission Planning System

Jinyeong Heo[1], Yongjun You[2], Yongjin Kwon[1*]

[1]Department of Industrial Engineering, Ajou University, Suwon, South Korea
[2]The 6th R&D Institute, Agency for Defense Development, Jinhae, South Korea
Email: *yk73@ajou.ac.kr

How to cite this paper: Heo, J., You, Y.J. and Kwon, Y.J. (2017) Case Analysis for USV Integrated Mission Planning System. *Journal of Computer and Communications*, **5**, 83-91.
https://doi.org/10.4236/jcc.2017.57009

Received: April 17, 2017
Accepted: May 19, 2017
Published: May 22, 2017

Abstract

Advanced countries around the world are spurring the development of Unmanned Surface Vehicles (USVs) that can operate autonomously at marine environment. The key enabling technology for such USVs is the mission planning system (MPS) that can autonomously navigate through the harsh waters. The MPS not only has the functions for the navigation, but also has the capabilities, such as obstacle avoidance, malfunction corrections, dealing with unexpected events, return home functions, and many other eventualities that cannot be programmed in advance. The autonomy levels are increasingly moving higher and it is foreseeable that the trend will continue in the future. The main purpose of this paper is the analysis of the MPS onboard the USVs, in terms of the categories, functions, and technological details. Also, we analyze the case study of autonomous mission planning control systems in various fields and introduce the features that constitute the critical functionalities of the mission planning systems.

Keywords

Unmanned Surface Vehicle (USV), Integrated Mission Planning System, Mission Planning System, Mission Re-Planning System, Path Planning

1. Introduction

According to the development of advanced science technology and along with the changes of increasingly complicated maritime environment, the level of autonomy required for USVs is getting higher and higher. The autonomous mission planning system (MPS) has been studied not only in the marine field but also in the fields of ground-based robotics and aerospace domains. While the demand for the effective MPS is increasing at a rapid pace, the actual construction requires a very high level of domain knowledge as well as investment. One can easily note that the development of autonomous vehicles is advancing fast in the laboratory environment, yet the actual deployment is very slow due to many concerns, such as unexpected accidents or undetected shortcomings in the control algorithms. With all the technological development, the current level of global autonomous technology is staying at levels 3 or 4 [1] [2] [3]. This means that only limited autonomous operations are possible under restricted conditions. The autonomy level is divided into 11 categories, the zero level being remote control operations, while the level 10 representing a complete autonomy for the self-driving vehicles. The level 4 means that the vehicle can autonomously avoid obstacles in real-time, detect/sense the changing environment, and change the mission plan in accordance with the changing environment. Therefore, moving onto the level 10 means decades of further research at this time [3] [4].

In order to reach this level, a system that can judge, plan, execute, and effectively respond to all planned as well as unforeseen events occurring in real-time should be required. Depending on the situations, USVs will be able to react to the abnormal conditions, system malfunctions, and re-plan the original plans, while making a judgement in accordance with the priorities within the mission goals [4] [5] [6]. In this sense, the MPS can be the most important component of any USV systems, if the USVs should be intelligent and self-operating at waters that are far beyond the reach of remote human operators [7]. For this purpose, we closely analyze the cases of autonomous mission planning systems and the corresponding characteristics. We have studied the most advanced forms of MPS that have been adopted in the space program. We also looked into the most current MPS that is being developed for the USV. By examining those current and previously successful MPS, one can identify the critical elements and the operating principles of the mission planning system. Such studies have not been adequately conducted in the past. In addition, we suggest the essential technological functions of integrated mission planning systems that are onboard the various autonomous mission planning platforms [8].

2. Review of Related Literature

The autonomous navigation system is an operational system that establishes a voyage plan for navigation, identifies the status of USV, anticipates and responds to changes in surrounding conditions [8] [9] [10]. These technologies have been studied in many developed countries. There are many examples that have actually been applied. The US Navy developed CARACaS. This is for the unmanned underwater vehicle and ground robot applications, which has been developed by MIT and Oxford. In space applications, the first AI (artificial intelligence) system was installed in the space exploration robot, NMRA and ASPEN. These systems have autonomous mission plan/re-plan, and also CARACaS is originally a technology developed by space exploration robots. Below are the key features analyzed for the MPS technology.

2.1. CARACaS

CARACaS, which stands for control architecture for robotic agent command and sensing, has been developed by the US Naval laboratory for unmanned swarming boats. It consists of software, radar, and various surveillance sensors. The CARACaS system integrates a number of USVs, assigns each mission to USVs, and assists in joint operations. The system structure consists of 1) Behavior Engine, 2) Dynamic Planner Engine, 3) Perception Engine, and 4) World Model. In particular, Dynamic Planner Engine continually updates the status of USV. Within, the CASPER (continuous activity scheduling planning execution and re-planning) creates the best possible plan within the resources available as well as within the constraint limits [11] [12] [13]. **Figure 1** shows the CARACaS onboard the USV.

■ Main functions and features of CARACaS

- Detection and avoidance of high-performance static threats (buoys, reefs, mines)
- Mission collaboration with other weapon systems
- Adaptive mission planning based on load resources (fuel, ammunition)
- Navigation in accordance with COLREGS regulations
- Adaptive behavior based on threat detection

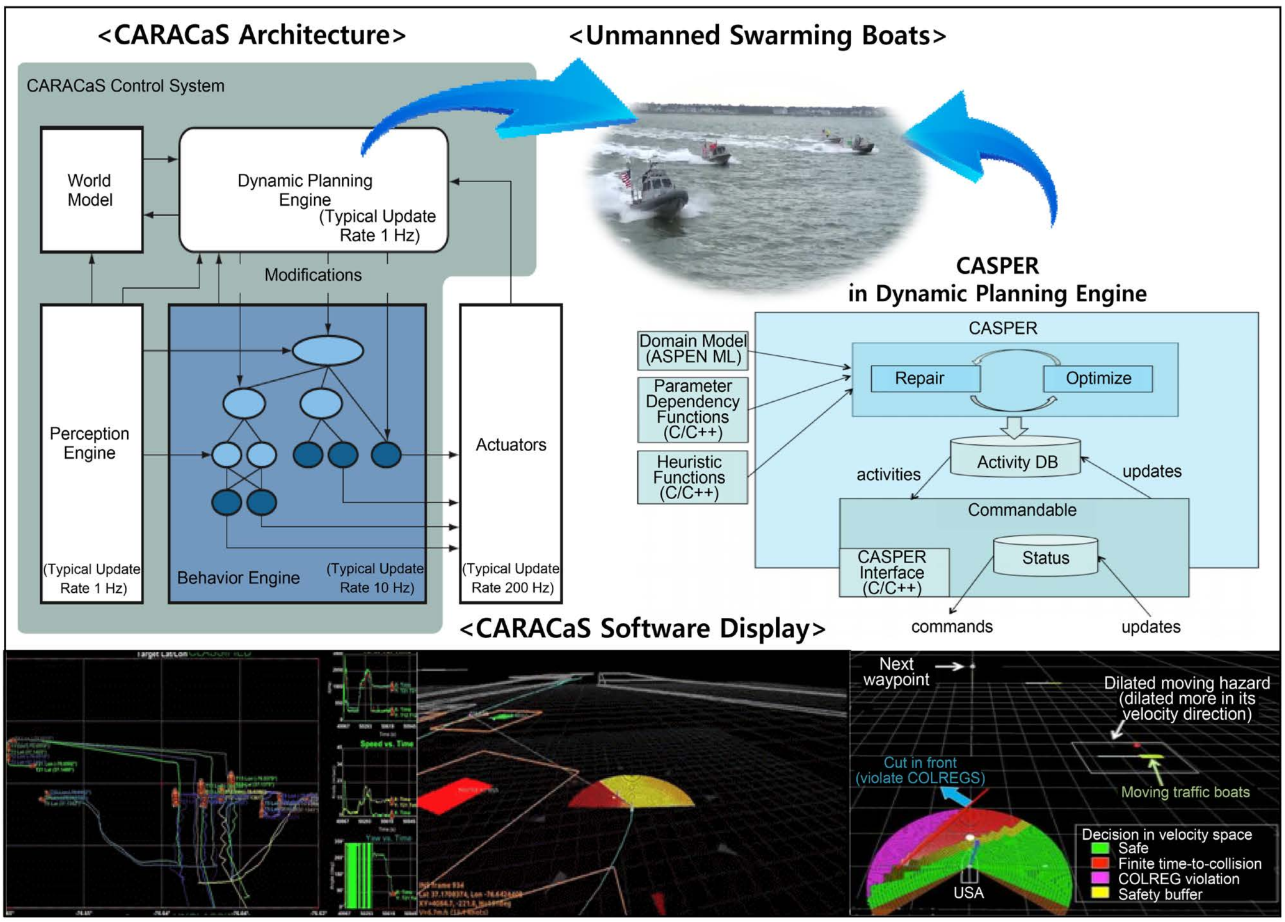

Figure 1. CARACaS control system.

2.2. MOOS-IvP

MOOS-IvP is the MPS software with an application called IvP Helm that is added on MOOS. The MOOS part was jointly developed by researchers at MIT and Oxford University and provides middleware capabilities for building ubiquitous environments of unmanned underwater vehicle and unmanned ground robot applications [14] [15]. The IvP is an application developed by Naval Undersea Warfare Center (NUWC). It is a multi-purpose optimization algorithm applied for arbitration in a behavior-based architecture. Figure 2 shows the architecture of MOOS-IvP.

As shown in Figure 2, MOOS is connected with various function applications and IvP Helm around MOOSDB. It transmits real-time position and direction of unmanned submersible, sensors information about surrounding environment and obstacles, control commands through publish-subscribe method. In addition, IvP Helm has a star-topology structure in which many behavior modules are connected in the same manner as the MOOS structure, and the behavior is a module defined in advance for operations related to mission planning and actions.

■ Main functions and features of MOOS-IvP

- A Publish-Subscribe middleware function that enables smooth communication between applications and the operation environment
- Provides Marine-Viewer function that can check the simulation process by rendering information about position, direction and speed of UUV in real time

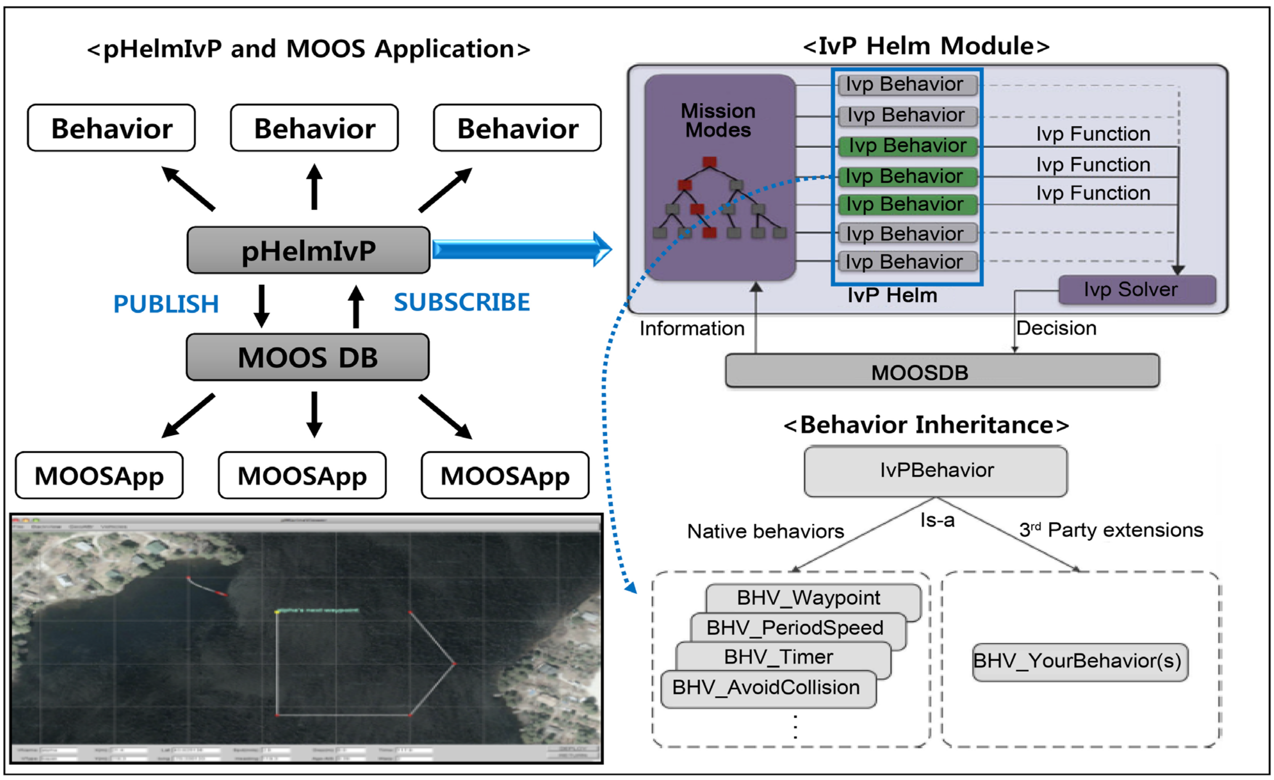

Figure 2. MOOS-IvP system.

- Easy to expand and reusable modules
- A multi-objective optimization algorithm using architecture based behavior
- The IvP autonomous module is called pHelm IvP and determines the direction, speed, and depth of UUV
- Independent operation of the configuration module enables fast response and excellent scalability

2.3. NMRA

NMRA (new millennium remote agent) architecture is an autonomous exploratory robot control system onboard the Deep Space One platform. This system is the first AI system boarded in a space exploration robot that integrates the existing real-time monitoring control method, constraint-based on planning/scheduling, multiple processing methods, and model-based situation judgment and reconstruction functions [16] [17].

In Figure 3, the NMRA architecture consists of five components: 1) Planning, 2) Scheduling, 3) Executive, 4) Model-based mode identification, and 5) Real-time control system. Among them, the monitoring and control system follows the conventional structure. The explanation of each component is described below.

■ Main functions and features of NMRA

- Mission planning is accomplished through the collaboration of Executive, Mode-Identification and lower-level monitoring and control systems
- Mode-Identification (MI) transmits the abstract information to Executive, and the Executive judges the state of the exploration robot with the information provided
- MI inputs the observed information provided from the sensor to identify the command sequence for mission execution and the current mode of the robot configuration module
- Monitoring receives the sensor data stream and distinguishes the stream information into the required abstract levels for the MI
- Real-time Control System receives the commands from Executive, and conducts the actual control of the low-level state of the exploration robot

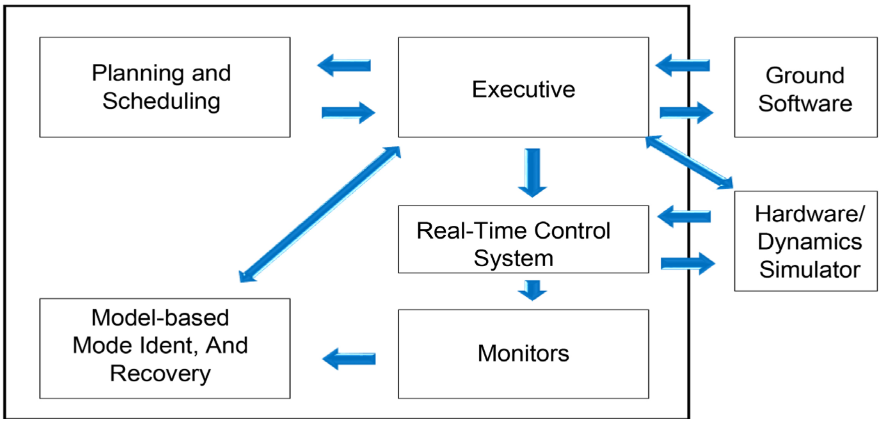

Figure 3. NMRA architecture.

- Planner/Scheduler is a "Batch Process" type of sequential module

2.4. ASPEN

ASPEN (Automated Scheduling and Planning Environment) was developed by the Artificial Intelligence Group at JPL (see Figure 4). Based on AI techniques, ASPEN is a modular, reconfigurable application framework which is capable of supporting a wide variety of planning and scheduling applications [18] [19] [20].

Key features include that operators in ground control station can check the available resources of the exploratory robot and the mission plan in operation through the ASPEN software. In Figure 4, since the resources available in the ASPEN interface appear in various colors in the form of time horizon, operators can understand the robot status easily. As such, the ASPEN performs the Iterative Repair algorithm for mission re-planning in real time when any event occurs.

3. Analysis of Autonomous MPS

The common features of technologies described above indicate that they require a variety of decision-making processes, such as assigning missions and targets with regard to the available resources, responding to unexpected situations (mission planning/re-planning), and mission path planning and re-planning to achieve the intended goals. It is necessary to estimate the state of USV according

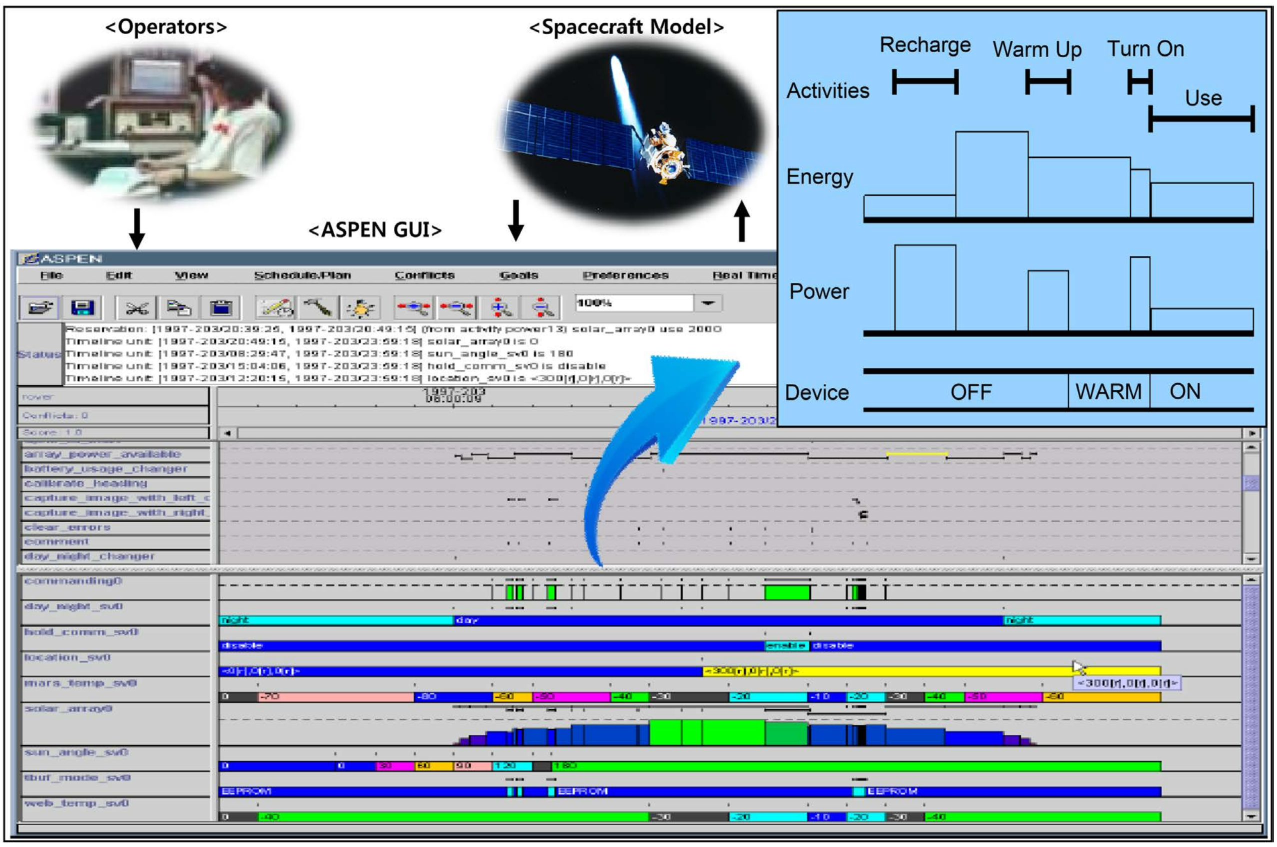

Figure 4. ASPEN software.

to the environmental changes that are occurring in real time, while detect and identify the unidentified vehicle or recognize the situations in order to make a necessary judgement. For spacecraft operations, since those vehicles are far away from the Earth and cannot receive any maintenance or resupplies, the consideration of onboard resources in terms of how to assign the priority becomes really crucial. For example, the spacecraft needs to decide when to use the RAM (onboard memory), and how much to use at a given time. This is due to the fact that the onboard RAM capacity is limited and it can perform so much computation at a given time. Therefore, the MPS has to consider using the available resources very carefully with the priority. The use of electric energy (which is stored in the onboard battery) also needs to be scrutinized, especially during the night-time operations. During the daytime (when the Sun is within the sight, so the spacecraft can recharge its batteries), the use of battery is less critical than during the night time. For batteries, they can be recharged and be used many times. However, the use of onboard rocket fuel is much more restricted, because the fuel cannot be replenished once used. All those issues need to be scrutinized and resolved without jeopardizing the mission. Monitoring and making a judgement for the spacecraft become very expensive, since the vehicles are too far away from the Earth, and due to time lag, sometimes it takes more than 20 minutes to make it respond to the control signals. Therefore, the onboard MPS that can make intelligent decisions become a very important component, if any long-distance missions need to be successful. The overall concept is illustrated in Figure 5.

In short, the effective MPS should contain the following functions: 1) be able to set up a new mission goal based on the sensor information and through the monitoring system, 2) a mission profile system should be capable of setting a mission plan as well as conducting re-planning tasks, and 3) while at the same time, capable of creating path planning and path points. All those should happen simultaneously along with the consideration of a) current mission goals, b) altered, new mission goals, if necessary, c) equipment status, and d) the current

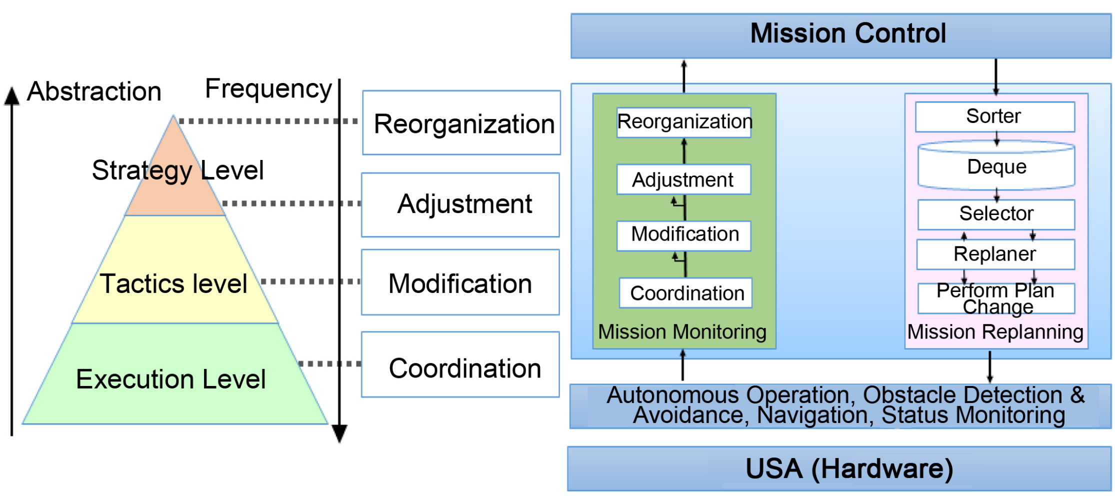

Figure 5. Integrated mission planning process suggested in this paper.

resource constraints. Doing all those while navigating in rough seas or through the deep space is by no means an easy task. On top of all those illustrated technological components, with the introduction of artificial intelligence, the MPS will continue to evolve and advance in the future.

4. Conclusion

In this paper, we analyzed various cases of MPS systems related to the integrated mission planning that can plan and execute missions autonomously. Looking at previously developed examples, they are similar in terms of 1) receiving environmental information through various onboard sensors, 2) recognizing the situation, 3) re-planning the missions according to the changing environment, and 4) while considering the important restrictions. In its current form, the MPS is at the level 4 of autonomy. In order to carry out the missions autonomously, the level 4 is still lacking many judgmental capabilities. The advanced sensors need to be developed, and the artificial intelligence (AI) needs to be further evolved, for the combination of advanced sensors (which can precisely detect the changing environment) and AI (which can make a judgement in accordance with the sensory inputs). Up until very near future, one can easily predict that the USVs will be jointly controlled both by the remote human operators and by the advanced mission planning systems. However, in the long-term, it is anticipated that the USVs equipped with more advanced integrated mission planning systems will be able to judge like human beings and carry out the missions autonomously.

Acknowledgements

This work was supported by the Agency for Defense Development (ADD) under the Contract No. UD160008DD.

References

[1] Suh, J., Kim, D. and Lee, H. (2011) Development Trend of Autonomous Unmanned Underwater Vehicle Navigation Technology. *Journal of Control, Robotics and Systems*, **17**, 36-46.

[2] Lee, W., Kim, C., Choi, J. and Kim, Y. (2003) A Ship Motion Control System for Autonomous Navigation. *Information Science Society*, **9**, 674-682.

[3] Huntsberger, T. and Woodward, G. (2011) Intelligent Autonomy for Unmanned Surface and Underwater Vehicles. *OCEANS* 2011, Waikoloa, HI, 19-22 September 2011, 1-10.

[4] Benjamin, M.R., Schmidt, H., Newman, P.M. and Leonard, J.J. (2010) Nested Autonomy for Unmanned Marine Vehicles with MOOS-IvP. *Journal of Field Robotics*, **27**, 834-875. https://doi.org/10.1002/rob.20370

[5] Pell, B., *et al.* (1998) An Autonomous Spacecraft Agent Prototype. In: Bekey, G.A., Ed., *Autonomous Agents*, Springer, US, 29-52. https://doi.org/10.1007/978-1-4615-5735-7_4

[6] Sherwood, R., Govindjee, A., Yan, D., Rabideau, G., Chien, S. and Fukunaga, A. (1998) Using Aspen to Automate EO-1 Activity Planning. 1998 *IEEE Aerospace*

Conference, **3**, 145-152. https://doi.org/10.1109/aero.1998.685789

[7] Kitowski, Z. (2012) Architecture of the Control System of an Unmanned Surface Vehicle in the Process of Harbor Protection. *Solid State Phenomena*, **180**, 20-26.

[8] Glotzbach, T., Schneider, M. and Otto, P. (2008) Multi System Mission Control for Teams of Unmanned Marine Vehicles—Software Structure for Online Replanning of Mission Plans. *7th International Conference on Computer Applications and Information Technology in the Maritime Industries* (*COMPIT*), Lüttich, Belgium.

[9] Pascarella, D., Venticinque, S. and Aversa, R. (2013) Agent-Based Design for UAV Mission Planning. 2013 *8th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing* (*3PGCIC*), Compiegne, 28-30 October 2013, 76-83.

[10] Steele, M.J. (2004) Agent-Based Simulation of Unmanned Surface Vehicles: A Force in the Fleet. Naval Postgraduate School, Monterey, CA.

[11] Bibuli, M., *et al.* (2014) Unmanned Surface Vehicles for Automatic Bathymetry Mapping and Shores' Maintenance. *OCEANS* 2014, Taipei, 7-10 April 2014, 1-7. https://doi.org/10.1109/oceans-taipei.2014.6964440

[12] Bays, M.J., Tatum, R.D., Cofer, L. and Perkins, J.R. (2015) Automated Scheduling and Mission Visualization for Mine Countermeasure Operations. *OCEANS* 2015/*MTS/IEEE Washington*, Washington DC, 19-22 October 2015, 1-7. https://doi.org/10.23919/oceans.2015.7401849

[13] Miskovic, N., Bogdan, S., Petrovic, I. and Vukic, Z. (2014) Cooperative Control of Heterogeneous Robotic Systems. *37th International Convention on Information and Communication Technology, Electronics and Microelectronics* (*MIPRO*), Opatija, 26-30 May 2014, 982-986. https://doi.org/10.1109/mipro.2014.6859711

[14] Bian, X., Chen, T., Yan, Z. and Qin, Z. (2009) Autonomous Mission Management and Intelligent Decision for AUV. *International Conference on Mechatronics and Automation*, Changchun, 9-12 August 2009, 2101-2106. https://doi.org/10.1109/ICMA.2009.5246027

[15] Zhang, Q., *et al.* (2010) An Improved Heuristic Algorithm for UAV Path Planning in 3D Environment. *Proceedings of the* 2010 *2nd International Conference on Intelligent Human-Machine Systems and Cybernetics* (*IHMSC*), **2**, 258-261.

[16] Sun, Q., Yu, W., Kochurov, N., Hao, Q. and Hu, F. (2013) A Multi-Agent-Based Intelligent Sensor and Actuator Network Design for Smart House and Home Automation. *Journal of Sensor and Actuator Networks*, **2**, 557-588. https://doi.org/10.3390/jsan2030557

[17] Raboin, E., Švec, P., Nau, D. and Gupta, S.K. (2013) Model-Predictive Target Defense by Team of Unmanned Surface Vehicles Operating in Uncertain Environments. 2013 *IEEE International Conference on Robotics and Automation* (*ICRA*), Karlsruhe, 6-10 May 2013, 3517-3522. https://doi.org/10.1109/icra.2013.6631069

[18] Clare, A.S., *et al.* (2012) Operator Object Function Guidance for a Real-Time Unmanned Vehicle Scheduling Algorithm. *Journal of Aerospace Computing, Information, and Communication*, **9**, 161-173. https://doi.org/10.2514/1.I010019

[19] Gernert, B., *et al.* (2014) An Interdisciplinary Approach to Autonomous Team-Based Exploration in Disaster Scenarios. 2014 *IEEE International Symposium on Safety, Security, and Rescue Robotics* (2014), Hokkaido, 27-30 October 2014, 1-8. https://doi.org/10.1109/SSRR.2014.7017655

[20] Smith, S.F., Lassila, O. and Becker, M. (1996) Configurable Mixed-Initiative Systems for Planning and Scheduling. *Advanced Planning Technology*, AAAI Press.