HUMAN-MACHINE INTERACTION FOR UNMANNED SURFACE SYSTEMS

BY

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THESIS

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Abstract

This research investigated the human-machine interaction (HMI) technologies for human-robot teams operating as unmanned surface systems (USS). An *pilot* role was found to be the most prevalent in the USS-related literature but additional human roles were determined to likely be necessary (e.g., *Mission Specialist)* though were not documented; interface needs have not yet been determined for any role. The human interfaces used by 67 Micro and Small X, Intermediate, Harbor, Fleet, and E,F,G-Class platforms were examined and it was determined that: i) the research literature does not well characterize the human roles present in unmanned surface systems, ii) domain complexity may necessitate increased automation of the robot platform for the human team, and iii) that unmanned surface vehicles likely lay on the human-machine interaction spectrum between unmanned ground vehicles and unmanned aerial vehicles. This work is expected to serve as a reference for future design and refinement of human interfaces for USSs and as a foundation for better understanding HMI in USSs.

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CHAPTER 1

INTRODUCTION

This research surveys the current state of understanding and technological accessibility of human-machine interaction (HMI) of the human roles for Unmanned Surface Systems (USSs).

1.1 Research Question

Unmanned Surface Vehicles (USVs) have become a part of a core branch of Unmanned Systems in the globe due to their stability, robust communication, and potential for future development. But in order for USVs to be successful, the lack of detailed information of the Unmanned Surface Systems (USVs) and its solutions are needed to be identified.

The primary research question of this thesis work is
What is a current state of Human-Machine Interaction (HMI) for small unmanned surface systems?

HMI in general but specifically for small USVs has not been discussed or mentioned in many studies. The identification of HMI can potentially improve the control mode and especially the level of automation so that the variety of mission applications can be expanded. The USVs seems to have a potential to be a leading devices in many different field of applications due to advantages discussed below.

The majority of the platforms are in the smaller size group that are not developed by military. Reasons behind the void of information is caused by the simplicity of the platforms and single operator system. Smaller systems have restricted limitations in payloads, range, and endurance and these limitations influence each other. Especially primary missions for smaller USVs are single missions in environmental monitoring so that risk of human operators are low, and in disaster recovery & rescue that require urgent human decisions. The main interest of the operation tends to be simplicity and efficiency instead of depending on automation with less human in loop operation. The level of HMI are not considered in terms of automation or the level of dependence in computer, but the level of ease for the human operators.

1.2 Why focus on USV

Unmanned systems are dramatically becoming popular due to following points: the cost of manned systems are the significantly more expensive than unmanned system even with human operators; the coverage and awareness of environment situation for Unmanned systems are improved due to advanced technology of sensors and, localization systems; productivity of missions as a whole will be more efficient due to operator specific mission (human operator can concentrate on manned missions); Unmanned systems keep human presence away from dangerous environment [1]. Addition to USVs, Unmanned systems consist of Unmanned Ground Vehicles (UGVs), Unmanned Ariel Vehicles (UAVs), Unmanned Underwater Vehicles (UUVs), and Unmanned Space Vehicles. Especially USVs are given a recent popularity due to effective utilization for not only wartime missions, but also peacetime missions [1].

The reasons behind this popularity are tied to accessibility and communication. For environmental monitoring mission, air regulation and land ownership can cause limitation in accessibility. Surface water such as watercourses, lake and wetland are public water. For deep water mission, UUVs have difficulty communicating with the ground control station due to a limitation of signal transmission under water. USVs belongs to the border of air and under water, so that for heterogeneous mission, USVs can act as the link between ground station or other unmanned and manned systems.

1.3 Understanding Unmanned Surface Vehicles

USVs have been developed and utilized for many of decades, *Unmanned* implies removing human presence from the targeted area [2]. They are either remotely operated or pre-programmed to be auto-piloted through radio, WiFi, cellular network, satellite, etc. Due to drastic improvement of global positioning systems in terms of compactness, effectiveness and affordability, USVs started to show their strength in Unmanned System field [2]. USVs especially take advantage of their air-sea interface to serve as a bridge in the networks of heterogeneous manned/unmanned air, ground, and marine platforms to introduce new and advanced understandings in environmental monitoring, disaster rescue, surveillance, warfare, and defence applications [3].

1.4 Importance to Civil Engineering

UAVs, UGVs and UUVs have been popularly used for a variety of civil applications. For example: UAVs have been utilized for land surveying and monitoring, construction management, and disaster response; UUVs have been used for underwater monitoring, underwater inspection and maintenance and repair for marine infrastructure or vehicles; UGVs are popularly used for military, and explosives & bomb disabling missions.

Despite high popularity and prestigious technology of these systems, the existing problems and application difficulties prohibit researchers from finding complete solutions. In particular, UAVs and UUVs share the same restriction of signal communication range. Especially for the team (multi-vehicle) missions, their environment becomes obstacle between these platforms. USVs are considered to fill this void and with additional factors such as long endurance, high payload capacity, user friendly interfaces and mostly reliable signal communication. USVs have a potential to be powerful additional tool or team-player tool for civil applications such as disaster rescue, offshore & onshore infrastructure inspection, and environmental monitoring. For instance, bridge inspection after Hurricane WILMA and IKE were conducted by the Center for Robot-Assisted Search and Rescue (CRASAR) with USVs and Underwater ROV. This case study led post disaster recovery inspection economically feasible by reduction of time, cost, and risk of human presence [4].

1.5 Contributions

There are two distinct contributions that are presented in this thesis regarding to HMI for USVs. In the existing literature, specific identifications of human roles for USVs are not always stated for both research and commercial systems. Especially for smaller platforms, number of team members, human roles, or interfaces are barely found in contrast of growing numbers of smaller platforms.

1.5.1 Contribution 1

Filling the void of HMI information provides better accessibility to match high demand and supply of multi-mission smaller USVs by large range of users. Especially this void can provide solution to key components when level of autonomy increases.

1.5.2 Contribution 2

Identifying specific human roles provides efficacy in number of crew member needed and on the other hand, shared crew can be analyzed and reevaluated depending on risk and safety of the mission.

1.6 Organization of this Thesis

This thesis is organized as follows:

- Chapter 2 begins with a review of the research and industrial literature associated with categories and characteristics of USVs, Human Robot Team roles and HMI for existing USVs platforms. Actively operating USVs are identified and surveyed in Table 1.
- Chapter 3 analyzes identified HMI and its trend according to the NAVY classification scale of USV of Micro and Small X-Class, Intermediate-Class, Harbor-Class, Fleet-Class and E,F,G-Class. Hardware and Software based Human-Machine interfaces are analyzed by the surveyed data in Table 2 and Table 3.
- Chapter 4 introduces 3 findings of Human-Machine Interaction for Operator role and its limitation.
- Chapter 5 finally presents conclusions regarding to each findings and limitations, and then future work and recommendation.

CHAPTER 2

RELATED WORK

This section provides a comprehensive review of the research and industrial literature, identifying 67 existing Unmanned Surface Vehicles (USVs). The USVs are categorized into four different groups based on size, weight, range, endurance, and types of the mission. The present human roles and human machine interaction (HMI) relationships are also presented including hardware and software interfaces for each USV.

2.1 Categories of Unmanned Surface Vehicles

Currently, there is not an official classification system for USVs [5]; however, the most common descriptions for USVs follow the 2007 U.S. Navy Master Plan standards that include four classes of vehicles organized by length (the distance between the forward-most and after-most parts of the vehicle): X-Class, Harbor, Snorkeler, and Fleet [1]. The National Defense Research Institute (NDRI) provides an additional class, EFG, for USVs that are greater in length than the Fleet-Class [6]. This survey combines the U.S. Navy, NDRI category structures and, additional adjustment classes which are created for this survey.

Additional category modifications are included in the survey: (1) The Snorkeler-Class (submersible) is not described in this survey due to the similarity with Harbor-Class as well as this class of SUV is outside the scope of the thesis. (2) The Intermediate-Class has been added to cover USVs with lengths between 3 m and 7 m. Currently, USVs with lengths between 3 m 0 7 m not classified in the literature. The vehicles that fall into this size range have been found to be show unique characteristics and a large number of USVs are available in this class. (3) The X-Class is divided into two sub-groups: Micro X-Class defined as a length under 1.5 m and Small X-Class defined with a length of 3 m. These sub-classifications are used to distinguished the X-Class USVs by concept and operational system.

A total of 6 classifications are use to described the state-of-the-art for USVs: Micro X-Class, Small X-Class, Intermediate-Class, Harbor-Class, Fleet-Class, and E,F,G-Class.

Three vehicles are described for each classification type in the section below.

2.1.1 X-Class

The X-Class category is defined as vehicles that are under 3 m in length and can operate on the open water in choppy sea-surface conditions. However, a majority of the USVs in this class are more fitted for shallow water use.

These vehicles are considered to provide "low-end" Intelligence, Surveillance and Reconnaissance (ISR) and also have ability to support manned or other unmanned missions [1]. Several different types of missions are supported with the most common use for observation and data collection for non-military purposes [6]. The missions range from environmental studies to search & rescue to surveillance. This class tends to be more cost effective and user friendly due to the simpler platforms than larger systems. These advantages encourage use in academic and civilian operations.

The X-Class is divided into 2 sub-categories by sizes to describe the differences in geometries, mission types, and advantages.

2.1.2 Micro X-Class

Micro X-Class is a sub-category of the X-Class with the length of the vehicles under 1.5 m. While smaller platforms have limited payloads, their small size and simplicity allow ease in accessibility and deployment. This class tends to be low-cost and operate on very simple control and sensing systems. The restrictions of the payload limit the variety of sensors that can be equipped. The small platform also has a higher risks of damage by environmental conditions. Missions are dominated by environmental monitoring, infrastructure inspection, flood study and search & rescue. One advantage is the ability to operate in narrow channels and shallow water depths. Due to the small range of communication, the distance to targets and operational endurance are very limited.

The Ziphius [7] is the smallest app-controlled platform among existing USVs in the industry. It is made for recreational usages but can potentially be utilized for different applications such as environmental monitoring or infrastructure inspection due to customizable body and open source programmable systems. It's small hull draft allows operation in shallow to deep water as long as it is in within the limited communication range.

The Lutra [8] is an air-boat type Cooperative Robot Watercraft (CRW) developed by

Platypus LLC., which was industrialised after many experiments conducted by Carnegie Mellon University. It is also small and used for environmental monitoring and flood studies. The Lutra has a very durable control system for its size and the ability to be operated as a multi-vehicle team by a single operator. An Android smart-phone interface and piloting interface allows multi-vehicle operations.

Finally, the Pioneer [9] is a twin pontoon type platform that are especially suitable for shallow water and it is usually controlled remotely with RC-controller by an operator though his or her line of sight (LOS). The Pioneer can also be semi-autonomous if additional control systems are equipped. A live stream video feedback is recorded by its gimbal camera as well as piloted by LOS. It is used for filming, environmental clean up, and infrastructure inspections.

2.1.3 Small X-Class

The Small X-Class is another sub-category wit the length of the vehicles are between 1.5 m and 3 m. It is the larger end of the X-Class and it has a diverse range of characteristics. One of the main differences from Micro X-Class is wider range of the endurance due to communication and payload improvements. While the mission types stays within environmental monitoring and search & rescue, the increase in their endurance and communication range allows these platform to obtain larger scale of data such as climate and hurricane monitoring instead of short term point monitoring such as water sampling or inspection.

The Hurricane Tracker [10, 11, 12] is a buoy system similar to the Emergency Integrated Lifesaving Lanyard (EMILY) platform implemented for hurricane tracking. The Hurriacane Tracker is dropped to the target area by other vessels and controlled remotely. Preprogrammed operations can be activated via text message from a smart-phone. This system allows close and detailed study of the eye of hurricane.

The CNR-ISSA Charlie [13] is also controlled with a smart-phone but more directly and hands-on. A smart-phone is utilized as a controller instead of just an activator. Its catamaran platform is especially well-fitted for shallow water environmental monitoring. The control system was experimented to improve user's "easy-to-use" feeling. The operator is not required to have special training to use this system.

The Wave Glider [14] is the first hybrid water and solar propelled USV. It is used for long term environmental and climate monitoring, and also for the surveillance patrol. Their stored solar energy and wave-powered energy allow this platform to conduct a long endurance missions without increasing the cost of operation. It is monitored from a base station onshore with open source software developed by Liquid Robotics.

2.1.4 Intermediate-Class

The Intermediate-Class was added specifically for this survey and includes the vehicles that are between 3 m and 7 m in length. Some can be on the shallow water but majority of others are well-fitted for choppy open water due to the size, weight, and payloads of the vehicle. Many inflatable type of vehicles are commonly utilized as the platform for this class. The mission for this class includes environmental monitoring, long term ocean monitoring, rescue, and port surveillance.

the Intermediate-Class seems to be still have a site specific domain even though complex sensing and control systems can be equipped. The payload is chosen based on the environmental condition or types of mission the VSU will conduct.

The smaller end of the Intermediate-Class is utilized for surveillance missions and Jet-ski or inflatable boats with high speed engines are favorable. On the other hand, the larger end of this class is utilized for long endurance environmental missions. The fast mono-hull vehicles are used to reached to target position quickly and turn off to float while collecting data. They also be solar powered depending on the needs of the operating conditions. The accuracy of the positioning and sensing is improved for this class due to allowance of the higher payload to equip complex sensing systems.

The VaCAS [15] group used a laser line scanner to real-time map and identify the river pathway. It also maps the bottom of the river with sonar to determine underwater obstacles. The data collected allows for accurate navigation and path planning for autonomous control of the USV.

The WAM-V [16, 17] is the another inflatable vehicle in this class. They are ultra lightweight and can be operated in choppy water conditions allowing for real time sensing. Its unique light weight platform also sustains the maximum payload capacity allowing extra sensing devices to be equipped. Inflatable platforms become very beneficial for maximization of payload and portability. The ability to be disassembled and inflatable the platform are one some of the advantages of these USVs.

The Ocean Atmosphere Sensor Integration System (OASIS) [18] is a floating type platform rather than a moving boat used for climate monitoring, water quality monitoring, and military operations. It is piloted to target location and floats to collect data while saving power. It intended to be low-cost, long duration, and has a reusable battery platform so that it utilizes the solar power and recharges as it run out the power. For these reasons, this platform requires open water locations with minimal overhead obstacles.

2.1.5 Harbor-Class

The Harbor-Class is defined for vehicles that are 7 m in length and fitted for open sea-surface. For this size and larger, the platforms can be both manned or unmanned. This class can conduct major missions in maritime security with robust ISR and it is expected to have mature autonomy, launch and recovery, and weapons & payloads technologies [1]. The X-Class had wide variety of level in autonomy but for vehicles that are the Harbor-Class and larger, adaptive planning/group behavior, obstacle avoidance, and communication become necessities to achieve the robust autonomy level that are required [1]. The Harbor-Class includes both warfare and environmental monitoring missions [19].

2.1.6 Fleet-Class

The Fleet Class categorizes vehicles that are 11 m in length. The fleet-class also includes both warfare and environmental monitoring missions. This class support ”high-end” surface mission for military operations [1]. This class can be operated to be very fast or moderate speed when it is supporting other missions such as towing other manned vehicles or USVs. Occasionally, they are used as support vehicles for other missions [19].

One of advantages of this class and larger USVs are that their vehicles can also hold manned missions. From this size class, the numbers of the vehicles drastically decrease due to the high cost of vessels and operations. To overcome this limit,in 2014, US NAVY created retro fitting projects for fleet class vehicle for full automation update. The system is described in detail in the next section. This retrofitting will allow the old manned vehicles to be retrofitted to unmanned vehicles with low cost.

2.1.7 EFG-Class

The E and F-Class is 26 m in length but they have a variety of widths. The G-Class is 41 m in length. Since there are no platforms that are larger than 26 m or 41 m [6], in this survey, E,F and G-Classes are all combined in the same group. Commonly, these size vehicles are utilized for the manned mission due to the cost of vehicles and the range of complexity of the mission. Their missions are dominated by warfare and surveillance. They tend to have large of cost and are not an economical solution due to their size and required accessibility. Due to large payloads and the cost of system and operation, this class vehicle completes multiple missions with manned and unmanned situations.

2.2 Human-Machine Interaction Literature on USV

The government states in USV master plan 2007 [1] that USVs need major improvements in the level of autonomy to reduce data inflow and outflow to and from the operator[20]. Most of the time, USVs are semi-autonomy and this level of autonomy can be adjusted during the mission. There are some tele-operated systems(non-autonomy), and there is no full autonomy system running even though it has a technological potential to be fully autonomy.

Huang [21] developed a framework to characterize and articulate the autonomy of unmanned systems. He introduced a visual framework for the relationship between the level of HMI and the level of autonomy with the factors of mission and environment complexities. In his framework, the level of autonomy is quantified and shown with correlations with the level of HMI that are measured by the situation awareness of unmanned systems and human. This correlation is described as higher the level of HMI is lower the level of autonomy and vice versa. The level of HMI is controlled to be higher when the complexities are higher.

Adams [22] identified the relationship between unmanned vehicles (UV) and situation awareness(SA) using her interpretation of the definition of SA by Endsley [23]. She explained 3 levels of unmanned system SA with comparison with Endsleys' 3 levels of human SA such as perception, comprehension, and projection. The perception is sensed by visual, sound, smell, and so on for the human SA. Human also senses the consequence and relationship with the perception instead of only searching to sense for a programmed perception target like UV's SA does. But UV can overcome the physical limitation that human experience such as diminished focus to cause failure to obtain perceptions and if sensors are available and can be equipped, it can overcome human skills of perception. The perception with the UV systems are commonly obtained visually for human. Particularly the USVs obtain it by live streaming video or data are converted to visual form on the screen. The comprehension is understanding of the obtained data by processing and integrating with the mission and related information. This accuracy rate can vary by the level of experience or training the human operator had.

UV's SA for the comprehension is controlled by the human comprehension or not being obtained. The projection is obtained by the perception and comprehension. Human could be obtaining the projection under severe stress of the mission environment. The UV's SA for the projection can be used to support by utilizing its programmed mission planning or the decision making tools. Those UV's SA skills can be improved by better understanding of human cognitive system. More human cognitive data, more options can be provided by UV.

The vehicles which are larger than Intermediate-Class are often used for military missions and usually have more than a single operator. This is because larger the vehicle is larger the payloads are. These systems can be equipped and can operate multiple missions at the same time and it will be actually cost-efficient to operate multi-missions than a single mission. This is simply because the operation cost for the larger vehicles are more expensive and it will not worth to have a single mission. One the other hand, smaller vehicles are limited to equip several sensors. They also face larger impacts and damages when they are on the water, so their sensors are better to be cheaper. But it does still require a threshold of the optimum balance that vehicle can be useful [24]. This characteristics for the difference in sizes can be improved by the quality, size, and price of sensors. But currently, it is more beneficial to make low-cost single mission small USVs and high-cost multi-complex mission large USVs.

Then, the goal of HMI for both vehicle types are observed to be different. The HMI goal for the smaller vehicles are multi-agent team, ease in communication and operation. The HMI goal for the larger vehicles are full autonomy. This difference is also supported by the types of missions that each groups deals with. The larger vehicles conduct more complex mission, and the smaller vehicles conduct more simple missions. Then simple mission has low level of HMI, so that autonomy for the smaller vehicles can be less problem. On the other hand, the complex mission requires high HMI followed by more problems to be autonomous. These supporting factors are due to payload, and accessibility and tolerance of the environment conditions.

2.3 Human Roles

Although specific human roles for USVs do not necessary appear in each individual literature, but there are 2 trends categories of roles that a majority of platforms fall into. Huang [21] identified the human roles for unmanned systems in general such as *Supervisor,* *Teammate, Pilot (Operator), Mechanic/Developer, and Bystander*. For UAVs, Peschel et al suggested the core human role called *Misson Specialist* addition to *Pilot*, and it seems also to apply for some USVs. Hence with literature reviews of USVs and reviews of UASs by Peschel et al. [25], followings are the 2 categories for human roles for USVs: *Pilot* and *Mission Specialist*.

2.3.1 Pilot

The *Pilot* for USVs is a role that is a combination of *Operator*, *Teammate*, and the *Supervisor* can be added for some cases such as for smaller and simpler platforms. Huang [21] described the *Operator* role as the person performing remote control or tele-operation, semi-autonomous operations, or other man-in-the-loop types of operations. The *Operator* determines the condition of the mission status, and makes decision whether to continue the mission or need to make some changes. The *Teammate* assist the *Operator* the overall mission. Finally the *Supervisor* is a person monitors one or more robots with respect to progress on the mission, can task the robot(s) at the mission level, monitors mission progress, provides mission level directions, coordinates missions, and can assign an operator to assist a robot if needed [21]. If this role separately exists for the platform, this role will receive collected and processed information from the *Operator* and *Teammate* and will make a decision and command the mission.

The *Pilots* for both sub-groups of X-Class and the Intermediate-Class might have to conduct multi-tasks to control, make a decision, and operate without presence of the *Supervisor*. Their missions, control system, and mission environment are simple enough for a *Pilot* to conduct the multi-task. The Lutra [24] has a human operator interface called the *Agent* that acts as a *Teammate* to process data and provides necessary information for a *Pilot* to gain proper SA to conduct and complete their mission. The Hurricane Tracker [26] is auto-piloted and missions can be programmed such that an *Operator* might only do a few minutes work for a day or two of mission time. In case of change in mission that are announced by human interface, the *Operator* will make a decision and conduct a change via smartphone text message. The Smart-phone Charlie utilizes its human computer interface, so that an *Operator* is allowed to perform fine maneuvering operations needed for instance to deploy the vehicle at sea, docking, taking the control of the robot in case of dangerous situations, etc [13].

Usually smaller classes requires a single person or 2, this number can increase or additional roles will be added when severity of the environmental condition or complexity of the mission increases.

The X-Class follows *Shared Roles Model* dominantly, it is a mixture of the Taskable Agent Model and the Remote Tool Model for describing human-robot teaming [27]. Majority of semi-auto platform in this class requires human supervision or remote control if it is necessary in the any moments. The *Pilot* will control the vehicle through live stream video or LOS while the vehicle by itself is monitoring or collecting data as it was programmed. On the other hand, the operator can be looking for some targets through the monitor and make decision while the vehicle is auto piloted for programmed pathway. For example, Valada [28] calls his interface *end-user interface and centralized operator interface* that falls into the shared roles model category. Valada [28] states this interface provides a single *Pilot* with an overview of the boat's condition or situation and provides high and low level commands for interacting with them. For example, a centralized *Pilot* provides the highest situation awareness but in the case of lost connection from human operator, the boat will make decision and adjustments depending on the programmed tasks or a priority.

On the other hand, for a larger platform with complex and multi-missions, the *Pilot* is dedicated to a single complicated task with other human team members. The *Pilot* is dedicated to the operation of the vehicles and additional human roles such as *Teammate* and *Mission Specialist* are added to the human team. Especially for the combat mission, the *Pilot* controls the vehicle and identify the target, then additional human role such as *Mission Specialist* either give an order as a *Commander* or conduct the order on its own. The balance of the *Pilot*'s task level can apply, influence, and optimize its mission and purpose.

2.3.2 Mission Specialist

The *Mission Specialist* role is a combination of a *Supervisor* and *Teammate*. Peschel [25] describes this role for UAVs as the team member responsible for visual investigation and recording and, in more advanced vehicle systems, delivery of an on-board pay-load. For this survey, the *Mission Specialist* is a person who is dedicated to process and analyze data or purely conducting supervision to make decisions without piloting the platform.

This role does not necessary shows up to every platform if this role is conducted by the *Pilot*. The X-Class and some of Intermediate-Class seems to have a single human role system, so that the *Mission Specialist* role is included as a part of the *Pilot* role. The Mariner 560 calls its *Mission Specialist* as an *USV Operator* and it monitors the Mariner 560 and its installed payload from the Vehicle Control Station (VCS) which features electronic charts, engine and navigation info [29]. For the larger classes, this role presence might be a critical.

This role also does not necessary has to be at the same site as a *Pilot* as long as a *Mission Specialist* has a robust and fast communication system. But usually a *Mission Specialist* stands next to a *Pilot*. For Harbor-Class, ivind [30] calls it as *Observer* and is responsible for fusing sensor data to provide a good estimate of the vessel state, as well as creating an image of the surrounding environment. Then this processed data becomes an input for their *Pilot* to make an order and conduct the mission. The *Mission Specialist* appearance depends on the type and complexity of mission and numbers of ongoing tasks at the missions.

Table 2.1: Classifications of Selected Unmanned Surface Vehicles (USVs) Currently in Operation[1]

Group	**USV Platform Name**	**Size[2] [meters]**	**Weight[3] [kilograms]**	**Range [kilometers]**	**Endu -rance [hours]**	**Mission type**
Micro	Ziphius	0.35 × 0.25	1.5	0.09	1	Recreational use (Shallow/Open Water)
	Lutra	0.81 × 0.47	6.92	2.4	4-8	Environmental/Water Monitoring, Flood Study (Shallow Water)
	Pioneer	1.07 × 0.64	7.0	0.3	0.2-1	Environment Cleanup, Infrastructure Inspection, Filming (Shallow Water)
Small	Hurricane Tracker	1.65 × 0.38	57.0	Satellite	120-240	Hurricane/Sea-Level Research (Open/Choppy Water)
	Smartphone Charlie	2.4 × 1.7	300	WIFI	N/A	Environmental Monitoring (Shallow Water)
	Wave Glider SV3	2.9 × 0.67	122	WIFI	8760	Patrol, Monitoring (Open/Choppy Water)
Intermediate	Wam-V	3.6 × 1.8	68.0	80	N/A	Surveillance, Research (Open/Choppy Water)
	VaCas	4.79 × 2.0	181	WIFI	72	River Traffic/Navigation (Shallow Water)
	OASIS	5.48 × 2.4	1,360	Satellite	2160-4320	Weather Faorescasting, Hurricane Study (Open Water)
Harbor	Kan-chan	7.99 × 2.8	3,500	N/A	N/A	Environmental/Ocean Study (Shallow Water)
	Viknes	8.52 × 2.97	3,300	N/A		Mine Sweeping, Weapon Attack Training (Open/Choppy Water)
	Protector	9.5 × 3.5	4,000	10-20	8	Armed Combat (Open/Choppy Water)
Fleet	Seastar	11.0 × 3.5	6,000	555	10	Home Land Security/Naval Application (Open/Choppy Water)
	Protector	11.0 ×	7,800	N/A	12	Armed Combat (Open/Choppy Water)
	SCOAP	11.0 × 5.0	N/A	Satellite	720	Oceanographic Observation & Data Collection (Shallow/Open Water)
EFG	Vigilant	16.0 × 3.6	6,000	2778	720	Surveillance, Search & Rescue (Open/Choppy Water)
	Piranha	16.5 × 3.2	3,630	32	4023	Surveillance (Open/Choppy Water)
	Poseidon	20.0 × 5.5	40,000	3704	168	Surveillance (Open/Choppy Water)

[1] Maximum operational parameters are reported and referenced from manufacturer specification sheets - normal operational parameter values will usually be lower and domain dependent. [2] Dimensions given are (length × width) [3] The maximum payload weight the vehicle can carry are proportional to the vehicle weight

Table 2.2: Hardware Based HMI of Selected Unmanned Surface Vehicles (USVs) Currently in Operation

Vehicle	**Joystick**	**RC - Controller**	**Key -board**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
Ziphius					[7]		[7]	[7]	[7]	
Lutra						[8]	[8]		[8]	
Pioneer		[9]							[9]	
Hurricane Tracker						[12]	[10, 12]	[10]		
Smart-phone Charlie	[13]		[13]	[13]	[13]	[13]	[13]		[13]	[13]
Wave Glider SV3						[14]			[14]	
WAM-V	[16]					[16]				
VaCas						[31, 15]			[31, 15]	
OASIS			[32]			[18]			[18]	
Kan-chan						[33]				
Viknes						[30]				
Protector (9m)	[34]		[34]		[34]	[35]			[34]	[35]
Seastar	[36]			[36]					[36]	[36]
Protector (11m)	[34]		[34]		[34]	[35]			[34]	[35]
SCOAP	[37]					[37]				
Viglant			[38]			[38]			[38]	
Piranha										
Poseidon			[39]			[39]			[39]	

Table 2.3: Software Based HMI of Selected Unmanned Surface Vehicles (USVs) Currently in Operation

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
Ziphius	[7]	[7]	[7]	[7]	
Lutra	[8]	[8]	[8]	[8]	
Pioneer	[9]				
Hurricane Tracker	[10]	[10]			
Smart-phone Charlie	[13]	[13]	[13]	[13]	
Wave Glider SV3		[14]	[14]		[14]
WAM-V	[16, 17]				
VaCas		[15]			
OASIS		[32]	[40]		[40]
Kan-chan	[41, 33, 42]	[41, 33, 42]			[41, 33, 42]
Viknes	[30]	[30]			
Protector (9m)	[35, 34]		[35, 34]		[35, 34]
Seastar	[36]		[36]		
Protector (11m)	[34, 35]		[34, 35]		[34, 35]
SCOAP		[37]			
Vigilant	[38]		[38]		[38]
Piranha	[43]				
Poseidon	[39]				[39]

CHAPTER 3

HUMAN-MACHINE INTERACTION ANALYSIS

In this section, hardware and software based HMI are identified and analyzed by each classes. Most classes have real time video streaming for human in loop operation. Many platforms throughout the classes fall to the category of semi-autonomous which can be conducted remotely (tele-operated) or have some autonomy. The following terms are defined for SUV control systems: Fully autonomous is when USVs accomplish the entire mission without human assistance while adapting to operational and environmental conditions; semi-autonomous is when USVs conduct the mission with various level of human-machine interaction, but it is also have capability of autonomous operation; manual or remote control is when USVs are operating under human supervision and human control, when operating in this state, the HMI is considered to be the maximum level [21, 1].

The relationship between the level of HMI and the level of autonomy has an optimized balance for each environmental situation or the mission type. This is also supported with the relationship for the level of SA for human and machine influencing the level automation [22] as discussed in Chapter 2. Human roles are mainly defined as a *Pilot* and a *Mission Specialist.* For the smaller platforms, single or few operators are identified but their actual tasks are not clearly stated. Smaller USVs typically conduct environmental monitoring and surveying missions that are programmable under human operator's remote vehicle control, or completely programmed operations without human control. Chapter 2 summarized human roles as tasks during the mission for the human role have direct influences when the automation level is discussed. The X-Class *pilots* might have to conduct multi-tasks during operations including operating and control the SUV and making mission critical decisions. As the size of the vehicle increases, the complexity of its missions can also increase. The operation requires a larger number of human roles and typically this additional role is considered to be the *mission specialists.* Then their control system shifts toward semi-auto and remote full-autonomy while human roles are dedicated to a single complicated task with other human team members. The balance of operator's task level seems to apply, influence, and optimize its mission and purpose while the size of vehicles and human roles are adjusted depending on the complexity and types of their missions.

In addition to this factor, larger vehicle classes tend to receive a human control from the base station or other vessels. This is because the larger vehicles have an ability to be equipped with a wider range of signal communication systems compare to X-Class. Vehicle controls are conducted through software rather than handset remote controller that are commonly used by the operator for X-Class vehicles. Software used for larger system uses more complex control system due to number of on-going mission at once and this fact shows a correlation to higher number of human roles that are required for larger systems. Complex human tasks require full attention by human (high human SA). In order to complete a multi-mission, the number of human increases. Hence, human roles depends highly on the type of missions, target locations or environmental conditions, size, and complexity of platforms.

3.1 Human-Machine Interaction for X-Class

Types of the human role for the X-Class are not necessary identified or specified due to simplicity and user-friendliness of X-Class as its advantages. With the information, the operator might be the most commonly used term for this class and they tend to be required to conduct multi-tasks during their mission. X-Class follows *Shared Roles Model* dominantly, it is a mixture of the Taskable Agent Model and the Remote Tool Model for describing human-robot teaming [27]. The Majority of semi-auto platform in this class requires human supervision or remote control if it is necessary in the any moments. The *pilot* controls the vehicle through live stream video or line of sight while the vehicle by itself is monitoring or collecting data as it was programmed. On the other hand, the operator can be looking for some targets through the monitor and make decision while the vehicle is auto piloted for programmed pathway. For example, Valada [28] calls his interface *end-user interface and centralized operator interface* that falls into the shared roles model category. He says this interface provides a single operator with an overview of the boat's condition or situation and provides high and low level commands for interacting with them. For example, a centralized operator provides the highest situation awareness but in the case of lost connection from human operator, the boat will make decision and adjustments depending on the programmed tasks or a priority.

In X-Class, the majority of vessels are controlled with laptop or computer manually, semi-auto or combination of both. Then rests are either controlled manually with RC remote control system or special consoles made for the vehicle. The majority of system are mixture of remote and semi-auto for simplicity of deployment and recovery. Also depends on the mission, this level of the mixture of control system varies due to the dependence level of humans' SA for decision making. Osga [44] claimed as "Human Factors Issues" for HMI challenge: attention management and allocation explains about user's requirement to adjust USVs control to their environment condition such as wave speed, surface traffic, and mission tempo; mental model of robot and state explain that users are required to maintain their situation awareness of USVs mission status and USVs condition; and lastly, users are required to perform emergency maneuvers for sudden change in mission or accident during programmed operation of USVs. For example, a complex mission such as military mission and rescue mission requires high level of human situation awareness since the mission is not programmable with their software interface. EMILY [45] is controlled remotely for rescue mission which is the second part of the Osga's [44] claim but the same platform of EMILY that is used for hurricane research NOAA's Hurricane Tracker [12] is both semi-control and remotely controlled to collect the data in the eye of the hurricane. Their missions can be operated through cell phone at the base station to make an adjustment on the hardware on-board. On the other hand, a simple mission such as environmental monitoring or sensing does not require high human SA.

Except the time of manual control, most of the vehicles are monitored and controlled through a monitor with live stream with LOS or software utilizing way-point location by GPS or satellite. This class vessels are usually operated by a one person conducting *pilot* and *mission specialist* role. Such multi-tasks are enable since their missions are tend to be less complex and in smaller range.

As the software point of view, there is a mixture of complex and simple menus for the operator. Most of platforms use real time video stream for the visual control for human in-loop operation and these software are API customizable. Another observation of this class is that vehicle control is usually human in-loop, but actual missions to obtain and store the data can be conducted fully autonomy such as water sampling, temperature sensor,depth measurements features.

3.1.1 Micro X-Class

The majority of the Micro X-Class includes both RC-controller and laptop or computer as the operation system. Depending on the mission or environmental condition, this operation method can be adjusted that will cause the difference in automation. Others are controlled through laptop or computer system. Hardware control is utilized more often rather than software while their missions are usually software based and programmable.

The Ziphius [7] is the smallest, and the first app-controlled aquatic USV in the industry. Its application on the tablet is utilized as a device by an operator with synthetic overlay on the live stream video. This application creates a simple synthetic overlay console on the touch screen tablet display to provide user-friendly operation. Their application is developed using the YVision of the Unity platform that allows visual based platform based on Natural User Interface (NUI) [46]. On the other hand, the Pioneer [9] uses RC controller on the LOS for direct piloting or through the live video stream. The Lutra [24, 8] is controlled visually with a laptop interfaced with Arduino micro-controller system linked with cell phone and its video on board. It can be controlled autonomy by path planning but since the Lutra is used for flood situation, the obstacle avoidance and decision making become the critical role. Additionally the Lutra is a team player, the multi-vehicle mission is allowed for this platform. An operator can link up and monitor several platforms on the one shared laptop screen.

3.1.2 Small X-Class

The majority of the Small X-Class also has laptop or computer as their operation system. Addition to the RC-controller, there are unique consoles for each platforms including joysticks, keyboard, and buttons. Real time video or GPS positioning are used for the most of platforms to control the vehicles. The Wave Glider [14] is controlled by base station though WIFI. Their operation is web-based open source application and the glider is remotely controlled with position on the screen over aerial image. This platform is solar powered and it is more like floating (Glider) than a boat.

For some platforms, smart phones are used to command the decision or pilot the vehicles while the mission. The smart phone allows the wider range of communication due to the development of 3G, 4G network. Some of the cell phone applications are following. The Hurricane Tracker uses an autopilot system connected to line of sight digital radio or Short Burst Iridium Satellite link [26]. It can be controlled through a ground station laptop or Internet software site operated by NOAA. The Hurricane Tracker also can receive the urgent change in mission through text message from the cell phone to control the hardware on the vehicle [12]. The Smart phone charlie [13] can be piloted by using applications on the smart-phone touch screen for ad hock adjustment while the large console stays at base station. It uses Google's Android open source platform, a touch screen and attitude sensor on the Android's OS system. Then a smart-phone become a compact controller for the Charlie. There are 2 applications developed for the control system: the first one uses Google map to remote or semi-control by using a smart-phone as a joystick to change the direction by utilizing the attitude sensor though LOS, then touch screen will allows the user to command a decision such as speed; the second one uses geo-referenced map and the user will decide the direction by touching a position on the smart-phone screen and the vehicle will follow to the route. This human interface improved the operator's difficulty for the mission control. Their smart-phone operation was tested not to require special training for the operator. Addition to these following platforms, long endurance environmental monitoring glider uses cell phone modem and satellite as the communication tool from base station computers.

3.2 Human-Machine Interaction for Intermediate-Class

The majority of Intermediate-Class has semi-autonomous system and it is remotely controlled by special console or laptop at the base station or other following vessels. The consoles are consisting of joystick, buttons, keyboard, and display. Then once is located in target spot, it can conduct the mission following path planning or way-point. For long endurance mission, the mission is thoroughly conducted by non-human and human will be notify if urgent situation occurs. This long endurance data collection can be robust due to improvement of communication systems and fast processing time. On the other hand, for short endurance mission, human is always in loop.

The mission type have direct impacts on human roles and the level of HMI. In this class, there are more than one human roles can be expected due to possibilities of the complexity of control and expanded range of missions.

The control system for the WAM-V became the challenge topic for 2014 Martime RobotX competition. The OASIS is semi-autonomous control and it is remotely controlled with portable remote control unit or game controller then once it is deployed to the targeted area, it is controlled by autonomous guidance navigation and control (GNC) for course tracking and station keeping [18]. Additionally OASIS states "Additionally at the ground control station, a graphical control station application provides an interface for an operator to monitor platform telemetry via strip chart and tabular display as well as view images received from the on-board camera [18]". The *pilot* is allowed to process, sort, and make decision with the control station that can also be interfaced with Google Earth. Then the control station "interfaces with a charting application to facilitate planning and situational awareness[18]".

The VaCAS [31] group developed the guidance and control system for river-line operation. Its underwater sonar and laser-scanner collect the data and process then create a real-time mapping for path-planning for the mission. The VaCAS experiment succeed fully-autonomous control for their targeted river-line area. From this class, the transition of hardware based control to software based control became more obvious.

In Intermediate-Class, the vehicles are controlled semi-autonomy. As a experimental stage, VaCAS group succeed full-autonomy control for limited region. Due to the size of the vehicles, many platforms are controlled remotely though LOS or though LOS on real time video until target area and then it conduct the missions for long endurance. If the mission is short endurance, it is usually remotely controlled with higher speed by an operator.

3.3 Human-Machine Interaction for Harbor-Class

Human roles for Harbor class is mixtures of dependence in software and hardware based control. Human is still in the center of the circle of for the decision making or remotely operated through live video stream. Most of the system uses laptop or computer at the base station as a control devices. This computer or laptop is operated as a part of console that includes joystick for piloting through live video on the display. Software side of the systems are very complex and utilize synthetic overlay for positioning assistance and sensing data visualization.

Harbor-Class, the vehicles are controlled through RC controller with lines of sight, laptop and computer, or consoles with joysticks, keyboards, and buttons through real time videos. The software systems are complex and majorities of systems are made for the specific mission. Due to the complexity of the control and the accuracy requirement, multiple operators are present at the base station. Each person will have individual task to make decisions. Humans are heavily in loop during the missions.

3.4 Human-Machine Interaction for Fleet-Class

Fleet class is very similar to Harbor class. Complex menus are used for software based control and there are at least two operators to control the vehicle.

In 2014, Office of Naval Research (ONR) announced the retrofitting projects for Fleet-Class Unmanned Surface Vehicles to perform "Swarm", multi-vehicle team mission. This system allows existing manned or unmanned boat to perform "Swarm" mission with low-cost of installation [47]. This projects utilizes the technology developed by ONR called Control Architecture for Robotic Agent Command and Sensing (CARACaS). This technology is still under development but in the future, CARACaS is expected to be retrofitted not only to Fleet-Class USVs, but other sizes. Also it is considered to be adapted for UAVs [48]. The CARACAs will allow existing manned vehicles to be retrofitted to be utilized as unmanned surface vehicles. Advantageously, CARACAs requires low cost of device and installation. Hence, this technology can lead further development and can expand the mission types to be wider ranges and more variety for Fleet-Class vehicles.

In Fleet-Class, all of the platforms have a joystick for its control either with console or the laptop. For the military mission platforms, their software were not customizable but made for the specific complex missions that are interchangeable for each mission. Seastar [49] uses a software called UMAS multi-application command and control system allows the the human team to control and operate from base station and also it allows Seastar's integration into any C4I network. For the oceanographic monitoring mission of SCOAP [37], the software is customizable. This class is very similar to the Harbor-Class platforms. The level of HMI for this class is considered to be low due the remote-operation control and human team has the full insight on decision making. Two people team is appeared to be a common in this class, and each of the member are dedicated to their operation or decision making roles.

3.5 Human-Machine Interaction for EFG-Class

Human roles for E,F,G-Class are not specifically identified due to the limited mission of warfare. There seemed to be more than one person as an operator. The mission specialist stays besides them to analyze the situation, support and make decision.

In EFG-Class, they are either controlled by computer or special console from the base station or other vessels. All are controlled remotely through live stream video and have complex menus are missions that require multiple human roles but they are not specifically stated since their missions are all military warfare or surveillance. Each vehicle costs over million US dollars and the amount of damage and risk that could cause to human, environment and politics show the hesitation or impossibility of full automation. This class requires full situation awareness from human.

CHAPTER 4

HUMAN-MACHINE INTERACTION FINDINGS

An analysis of the human-machine interaction for six categories of unmanned surface vehicles was conducted and resulted in three findings. The first finding determined that the research literature does not well characterize the human roles present in unmanned surface systems. The second finding suggested that the domain complexity may necessitate increased automation of the robot platform for the human team. The third finding showed that unmanned surface vehicles likely lay on the human-machine interaction spectrum between unmanned ground vehicles and unmanned aerial vehicles.

4.1 Finding 1

Human roles are not explicitly defined or reported in the research literature; at best an Operator role is assumed.

Human roles are not always identified in the unmanned surface system literature. Especially for X-Class, human roles are identified in the context of user-friendly control systems or operations and by the actual names of the roles. Systems presented tend to have simple software based menus and control systems that would usually imply a single operator or at most two or three people. An operator typically conducts piloting and decision making. For smaller platforms, automation and remote controls are usually combined for the *ad hoc* control. For example: (1) piloting can be automated by following planned path while the operator conducts the core mission; (2) piloting can be conducted under supervision of the human operator while the vehicle is programmed to do missions and collect data; (3) or both piloting and the mission are conducted under supervision of a human. Usually, simpler roles/tasks in each cases are automated or programmed as machines roles. For larger platforms, the cost and risk of the failures tend to be higher than for smaller platforms. Due to these reasons, the number of the human roles may be expected to be higher when compared to the smaller platforms as the size of vehicles increase.

4.2 Finding 2

Domain variability (e.g., open water versus debris-filled waterway) and intended tasks necessitate increased automation or other human roles with dedicated interfaces.

Obstacle avoidance can vary based on the level of HMI and also heavily limited by the environmental conditions. The level of HMI should correlate with the level of human situation awareness similar to the relationship between the level of autonomy and the level of human machine situation awareness stated in Adams [22]. In a slow stream or open water, in order for the vehicles to be floating and moving can be controlled without human in loop. In this situation, the level of situation awareness is low and it does not require high speed processing time. On the other hand, high level of situation awareness is required for fast stream or choppy water with debris and it does require full supervision by human to avoid the obstacles quickly.

The risks and types of the tasks have also direct impact on the variability of the level of the autonomy. High intensity tasks require the highest level of situation awareness, this causes the increase of the number of human roles and human will be in-loop operation. Low intensity tasks require the lowest level of situation awareness that enable the operator to multi-task with an assist from software based machine's situation awareness. For this situation, human does not necessary have to be in loop most of the time but they cannot be completely absence. Even though there are nearly or completely full-automation with artificial intelligence (non-human in loop), there is no USS with this level of HMI due to policies, ethics, and risks. Especially in the cases of warfare/combat missions, a potential to take away a human life by artificial intelligence can cause controversy. These human feelings could hold back this improvement for certain types of missions but also there is no ethical answer for the potential risk of the failure.

4.3 Finding 3

The human-machine interaction for unmanned surface systems falls on the spectrum between unmanned ground systems and unmanned aerial systems.

Given the operational intent of USVs, they typically do not have a appropriate HMI besides pilot-centric. The pilot controls and makes decisions under full supervision by the same pilot especially for smaller platforms. Software interfaces for the pilots for the small platforms are simpler, and prepared for the ad-hock use. For larger platforms, the pilots and mission specialists can either share the one interface or have duplicated systems. Sometime the pilots can be the link between the USV and base station. The operators on the chase vehicle can control and conduct the decision after mission specialist analyze the situation from the base station onshore.

Types of missions also can affect this level of HMI. Rescue or military missions that require high level of situation awareness at the decision making during the mission, their HMI have to me human in loop with current level of automation. But for programmed data collection mission like environmental monitoring can expect less human in loop due to absence of decision making. For time of emergency such as obstacle avoidance or lost in communication, they can either manually operated or pre-programmed to return to the shore.

While other unmanned systems have proper HMI for each systems, HMI for the USVs adjusted to the most fitted version and it seems to be among HMI for UGVs, UAVs, and UUVs.

CHAPTER 5

CONCLUSIONS

This research investigation determined that detailed information for HMI and human roles needed to be documented for unmanned surface systems. Without proper documentation, the problems involving HMI are difficult to be identified for the future improvement or potential mission applications.

There are technologies that allow vehicles to be fully automated without human in loop. Vehicles can be programmed with the moving path, mission, and decision making. Although there exists this level of technology, human situation awareness cannot be avoided due to ethical view of the mission. If the level of HMI indicates the level of autonomy, then this level should be adjustable for USVs in order to make ethical decisions along with the most optimized and safe mission activity.

The *pilot* role exists for every category of USV, but the actual operation of the entire tasks can be differ by size and especially mission types and domains. Even though human tasks are similar throughout USVs such as piloting, data acquisition and process, and decision making, the level of intensity and number of tasks that can be conducted by each individual at the mission can be different. From an environmental perspective, if the ocean is high traffic or severe condition by the waves, high current, or debris, higher human SA is required and this person should be dedicated to this task rather than multi-tasking to conduct other part of mission such as data collection. As socioeconomic view, a simple environmental data collection can be done without maximum usage of human SA. Then human could also do other task at the same time while programmed software is conducting the mission. But for warfare mission like a high intensity combat mission, the critical decision should not be made by the computer since it has high potential to impact human lives and be against human ethics. Then this task should be carefully reviewed by human roles and the additional roles like *mission specialist* or additional number of human roles for this task can be utilized. Especially those complex tasks usually have complex software based controls compare to simple mission vehicles. Additional number of human tasks are expected in order for each human role to conduct their tasks under full supervision.

Moreover, the cost of the platform can influence the level of autonomy. Trade off between level of HMI and the risk regarding cost can also be influenced by type and complexity of mission. Smaller low-cost platforms can be less necessary to be concerned even it is lost or broken. With Huang's approach [21] of visualization of autonomy and HMI. Additional cost and risk aspects into Huang's diagram can lead to better understanding of the future USV development.

Currently, site condition and the complexity of the mission controls the level of HMI in order to avoid or minimize the failure. For the future, the ideal platform should be able to minimize the level of HMI with independence of the complexity of the mission or environmental condition.

APPENDIX A

TABLE FOR ALL EXISTING USV

Table A.1: Summary of X-Class Unmanned Surface Vehicles Currently in Operation

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Ziphius [7]	0.35 x 0.25	1.5	0.09(WiFi 802.11)	1	Shoe-shaped shell for recreational use for shallow to deep water.
Minnow [50, 51]	0.66 x 0.21	- 2	WiFi 802.11	N/A	Catmaran for joint action with UAV or other larger USV to monitor and survey environment for shallow to open water. Especially tolerable to choppy water.
Lutra [52, 53, 54, 28, 8]	0.81 x 0.47	6.92	2.4(WiFi, 3G or EDGE)	4 - 8	Airboat for multi-boat team mission for environmental monitoring, water quality monitoring, depth buoy verification, flood study for shallow water.
MAKARA-02 [55, 56]	0.83 x 0.53	3	WiFi	1	Small Waterplane Area Twin Hull (SWATH) for Indonesian Goverment defense purposes for shallow to open water. Especially tolerable to choppy water.

Table A.1: Table A.1 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Pioneer [9]	1.07 x 0.64	7	0.3(Radio)	0.2 - 1	Twin pontoon for Survey, film production, environmental cleanup, infrastructure inspection for shallow water.
Malaysia USV [57]	1.1 x 0.87	14.79	25(RF modem)	N/A	Catamaran for water quality monitoring for littoral.
ESM30 [58]	1.15 x 0.75	26	2(Handset) - 10(Base station)	6	Catamaran for water sampling monitoring for shallow to open water.
SURF 20F [59]	1.28 x 0.45	9	2	1	Monohull for Eutrophication and ater Quality Monitoring for shallow to open water.
Kingfisher [60]	1.3 x 0.94	29	0.25(WiFi 2.4GHz)	1.5 - 3	Catamaran hull pontoon for multi-boat mission for environmental monitoring, mapping underwater topography, bridge scour and sediment loss study for shallow water.
Kaizu USV [61, 62]	1.42 x 1.2	22	0.5	6	Airboat for water quality monitoring for shallow water.

Table A.1: Table A.1 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
EMILY [63, 45]	1.37 x 0.4	11.3	1.6	0.5	Buoy for Emergency Integrated Life Saving for shallow to open water(ocean, river, flood). Especially tolerable for choppy water.
ME70 MM70 [64, 65]	1.47 x 0.9	58	2(Handset) - 10(Base station)	10	Catamaran for ocean survey, pollution tracking and supervision technology for open water.
CatONE [66, 67]	1.6 x 1.0	12	N/A	8	Catamaran for multi-boat team mission for Hydrographic Measurement and Environmental Monitoring for shallow water basin, seepage detection in cannals for shallow water.
Hurricane Tracker [10, 11, 12]	1.65 x 0.38	57	Short Burst Iridium Satellite link	120 - 240	Buoy for hurricane research, collect sea-level data for NOAA for open water. Especially tolerable for choppy water.

Table A.1: Table A.1 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Surfsense [68, 69]	1.65 x 1.22	68	Sight digital radio, SATCOM	N/A	Catamaran for Mapping and survey mission for very shallow water.
AutoCat [70]	1.8 x 1.0	10	Radio	N/A	Catamaran for Sub-bottom survey, AUV telemetry link, or marine life tracking for open water.
GSV ”Rocky” [71, 72]	1.9 x 1.2	34	3.2(WiFi 802.11G)	2	Catamaran T-shaped chassis for environmental Monitoring tool, and mapping for Open water.
Roboduck 2 [73]	2.13 x 0.71	43	N/A	6 - 8	Monohull for collecting data used by a team of researchers, study the effect of harmful algal bloom for shallow to open water.

Table A.1: Table A.1 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
AMB/ASMV [74, 75, 76]	2.13 x 0.91	176	32	5 - 7.5	NOMAD buoy for Surveying and monitoring the lagoon or coastal environment with respect to geological, biological, physical and chemical phenomenon in a cost-effective manner for Open water (deep water)
C-Cat2 [77]	2.4 x 1.2	80	28 - 37	5.8	Catamaran rugged hull for water quality sampling, environmental assessments and in-shore survey for shallow water.
C-Stat [78]	2.4 x 1.2	450	463	96	Buoy for surface to underwater communications node, port, harbour and ship security, oceanographic data collection, subsea asset positioning for Open water.
CNR-ISSIA Smartphone Charlie [13]	2.4 x 1.7	300	WiFi	N/A	Catamaran for environmental monitoring for shallow water.

Table A.1: Table A.1 (Cont.)

Vehicle	Dimensions [meters]	Weight [kilograms]	Range [kilometers]	Endurance [hours]	Design Use
SESAMO [79, 80]	2.4 x 1.8	360	0.55	20	Catamaran for sea water sampling for open water(deep water.
Shanghai Maritime University USV [81]	2.7 x 1.48	60	1.8	2	Catamaran for harbor surveillance, water quality sampling, hydrologic survey, maritime search and rescue for open water(ocean, littoral).
Wave Glider SV3 [14]	2.9 x 0.67	122	WiFi 802.11g, Cellphone Modem	8760	Glider for Patrol and monitoring for open water(deep water).
Malaysia Patrol Model [82]	2.96 x 1.07	267	0.25(WiFi 2.4 GHz)	N/A	Jet Ski for sea patrol and environmental monitoring for open water. Especially tolerable for choppy water.

Table A.2: Summary of Intermediate-Class Unmanned Surface Vehicles Currently in Operation

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
SCOUT [83, 84]	3.05 x 0.55	81.6	0.25(WiFi 802.11b, Radio 2.4 GHz)	8	Kayak for milti-boat tem mission for oceanographic and undersea testing for open water.
Stingray [85, 86]	3.2 x 1.2	800	Wireless LOS	8	Jet ski for Coast Guard application, patrol, clearing shipping lanes and underwater search missions for open water. Especially tolerable for choppy water.
Blackfish [87, 88, 89]	3.22 x 1.2	470	1	1	Jet Ski for Maritime security, naval special warfare and tactical intelligence, surveillance and reconnaissance missions for shallow to open water. Especially tolerable for choppy water.
MESSIN [90, 91]	3.3 x 1.8	350	0.25(WiFi 2.4 GHz)	3 - 10	Catamaran for scientific marine research, tracking dolphins for shallow to open water. Especially tolerable for choppy water.

Table A.2: Table A.2 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
SCU SWATH [92]	3.4 x 1.3	360	0.25(WiFi 2.4 GHz)	8	Small Waterplane Area Twin Hull for bathymetric mapping for shallow to open water.
BASIL [93]	3.4 x 1.5	380	6	8	Buoy for multi-boat team mission for accurately track underwater vehicles for open water.
AutoNaut [94]	3.5 x 0.43	120	45	2160	Mono hull for surveillance and data gathering for open water.
DELFIM [95, 96]	3.5 x 2.0	320	80	N/A	Catamaran for automatic marine data acquisition and to serve as an acoustic relay between submerged craft and a support vessel for open water. Especially tolerable for choppy water.
WAM-V [16, 17]	3.6 x 1.8	68	80	N/A	Inflatable twin hulls suspension system for harbor, port surveillance, research, ISR, defence, networking.
Pungo Kayak [97]	3.7 x 0.74	N/A	0.5	1.72	Kayak for depth survey for shallow water.

Table A.2: Table A.2 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
SeaOWL [98]	3.8 x 0.22	672	N/A	10 - 35	Patented, multi-channel hull for surveillance, data gathering, port harbor and coastal security,MCM, ASW, serach and rescue.
Piraya [99]	4.0 x 1.4	400	112(LAN/WLAN, cellphone based links and Iridium satellite)		Deep V mono hull for multi-boat team mission for patrolling coastal waters, a requirement accentuated by the increased terror threat from the seas for open water.
Springer [100, 101]	4.0 x 2.3	544	N/A	N/A	Catamaran for undertaking pollutant tracking, and environmental and hydrographic surveys for shallow water and NGC testing for shallow to open water.
C-Enduro [102]	4.2 x 2.4	350	9260 - 13890	2160	Rugged Catamaran for collection of offshore data with the freedom to customise for challenging climatic environments for open water.

Table A.2: Table A.2 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Roaz [103, 104]	4.5 x 2.2	200	2 - 3(WiFi802.11E)	N/A	Catamaran for Risk assessment for shallow water environments and water land interface zones as the near surf zone in marine coast for shallow to open water.
ALANIS [105, 3, 106]	4.5 x 2.2	800	WLAN, Radio	12	Rubber aluminum boat for environmental monitoring for open water.
VaCas USV [107, 31, 15]	4.79 x 2.0	181	WiFi 2.4 GHz with 8.5 dBi antenna; emergency stop over 900 Mhz radio link	72	Inflatable boat for river support of looka-head capability, river traffic, river navigation for shallow water.
The Lake Wivenhoe ASV [108, 109]	4.88 x			24	Catamaran for water sampling for open water.
SARPAL [110]	4.9 x 2.1	1088	N/A	24	Inflatable boat for ocean rescue for open water. Especially tolerable for choppy water.

Table A.2: Table A.2 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
ZhengHe 101 [111]	5.0 x 1.9	945	9.26	8	Workboat for monitoring inshore marine topography, hydrology, water quality, and meteorological data for shallow to open water.
C-Cat5 [112]	5.0 x 2.2	650	10	12	Rugged catamaran for water quality sampling, environmental assessments and in-shore, coastal survey for shallow to open water.
SeaFOX [113]	5.1 x 2.1	1088	9.65 -	N/A	Inflatable boat for anti-terrorism force protection (ATFP), and maritime interdiction operations (MIO) for shallow to open water.
OASIS [32, 114, 18]	5.48 x 2.4	1360	900 MHz Freewave spread-spectrum radios, Iridium satellite modem	2160 - 4320	Observations off conventional shipping routes, routine transects, dynamic feature mapping, support for weather forecasting, and hurricane research for open water.

Table A.2: Table A.2 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Kaasbll 19 [115]	5.75 x 2.12	450	N/A	N/A	Center console boat for oil search and other offshore activities for open water. Espacially tolerable to choppy water.
C-Worker [116]	5.85 x 2.2	3500	40	240 - 720	Mono hull for subsea positioning, surveying and environmental monitoring for open water. Espacially tolerable with choppy water.
Mariner 560 [29]	5.85 x 2.05	1700	15	50	Workboat for maritime data acquisition for open water.Especially tolerable for choppy water.
C-Hunter [117]	6.3 x 0.6	10	2000	50 - 96	Rugged mono hull for MCM, ASW, Environmental mannng,hydrographic survey for open water.

Table A.3: Summary of Harbor-Class Unmanned Surface Vehicles Currently in Operation

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Spartan [118, 119, 120]	7 x	2000	N/A	8 - 48	Rigid Inflatable boat for protection for surface combatants, noncombatants, and other national and strategic assets for open water. Especially tolerable with choppy water.
Inspector MK-1 [121]	7.1 x 2.5	2100	18.52 ¿	15	Inflatable boat for small weapon attack training,mine sweeping for open water. Especially tolerable for choppy water.
Kan-chan [122, 41, 33, 42]	7.99 x 2.8	3500	N/A	N/A	Sailboat for ... for open water. Especially tolerable with choppy water.
Viknes [30]	8.3 x 2.97	3300	N/A	N/A	Yacht for nnmanned follower vessel(manned vehicle) for open water.
Protector (9m) [34, 123, 124, 120, 35]	9.5 x 3.5	4000	10 - 20	8	Rigid Inflatable Boat for armed combat mission for open water. Espacially tolerable to choppy water.

Table A.3: Table A.3 (Cont.)

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Silver Marlin [85]	10.67 x	4000	936	24	Mono hull for ISR missions, force protection/anti-terror missions, anti-surface and anti-mine warfare, search and rescue missions, port and waterway patrol and electronic warfare for open water. Especially tolerable to choppy water.
C-Sweep [125]	10.8 x 3.5	9000	370	N/A	mono hull for mine sweeping, hunting, deployment, tracking, and recovery of ROVs, remote sensing surveillance for open water. Especially tolerable to choppy water.

Table A.4: Summary of Fleet-Class Unmanned Surface Vehicles Currently in Operation

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Seastar [36, 49]	11 x 3.5	6000	555	10	Boat for the entire array of Home-Land Security and Naval applications for open water. Especially tolerable to choppy water.
Protector (11m) [34, 123, 124, 120, 35]	11 x	7800	N/A	12	Rigid Inflatable Boat for armed combat mission for open water. Espacially tolerable to choppy water.
SCOAP [37]	11 x 5	N/A	Satellite communications (Iridium)	720	Catamaran for coastal oceanographers to collect field observations with sampling coverage and resolution for shallow to open water.

Table A.5: Summary of E, F, G-Class Unmanned Surface Vehicles Currently in Operation

Vehicle	**Dimensions [meters]**	**Weight [kilograms]**	**Range [kilometers]**	**Endurance [hours]**	**Design Use**
Katana [126]	12 x 2.8	N/A	648	N/A	Mono hull for harbor security, patrol of shallow coastal and territorial waters, surface and electronic warfare and offshore platform protection for open water. Espacially tolerable to choppy water.
Vigilant [127, 128, 38]	16 x 3.6	6000	2778	720	Boat for surveillance, serch and resucue for open water. Espacially tolerable to choppy water.
Piranha [43, 129]	16.5 x 3.2	3630	4023	32	Boat for anit-submarine, anti-piracy, mine countermeasures, surveilance, recon, and patrol for open water. Especially tolerable to choppy water.
Poseidon [39]	20 x 5.5	40000	3704	168	Boat for patrol and protection of EEZ and territorial waters for open water. Especially tolerable to choppy water.

Table A.6: Summary of X-Class Unmanned Surface Vehicles Hadrware Based HMI

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
Ziphius					[7]		[7]	[7]	[7]	
Minnow										
Lutra						[8]	[8]		[8]	
MAKARA-02						[56]				
Pioneer		[9]							[9]	
Malaysia USV	[57]		[57]			[57]				
ESM30		[58]			[58]	[58]				
SURF 20F		[59]								
Kingfisher	[60]	[60]				[60]				
Kaizu USV [61, 62]										
EMILY		[45]								
ME70 MM70		[64, 65]			[64, 65]	[64, 65]				
CatONE		[66]				[66]				
Hurricane Tracker						[12]	[10, 12]	[10]		
Surfsense						[69]	[69]	[69]		
AutoCat						[70]				

Table A.6: Table A.6 (Cont.)

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
GSV ”Rocky”	[71]	[71]				[71]			[71]	
Roboduck 2	[73]	[73]								
AMB/ASMV	[74]	[74]				[75]			[74]	
C-Cat2	[77]		[77]	[77]					[77]	[77]
C-Stat	[78]		[78]	[78]					[78]	[78]
Smart-phone Charlie	[13]		[13]	[13]	[13]	[13]	[13]		[13]	[13]
SESAMO						[79]				
Shanghai Maritime University									[81]	[81]
Wave Glider SV3						[14]			[14]	
Malaysia Patrol	[82]		[82]			[82]			[82]	

Table A.7: Summary of Intermediate-Class Unmanned Surface Vehicles Hadrware Based HMI

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
SCOUT		[83]				[83]			[83]	
Stingray	[85]		[85]						[85]	[85]
Blackfish			[87]	[87]					[87]	[87]
MESSIN	[91]	[91]				[91]				
SCU SWATH	[92]					[92]				
BASIL										[93]
AutoNaut						[94]				
DELFIM						[96]				
WAM-V										
Pungo Kayak						[97]				
SeaOWL			[98]						[98]	[98]
Piraya		[99]								
Springer						[100]				
C-Enduro	[102]		[102]	[102]					[102]	[102]
Roaz	[103]		[103, 104]			[103, 104]				
ALANIS									[105, 106]	
VaCas						[31, 15]			[31, 15]	
The Lake Wivenhoe					[108]		[108]			

Table A.7: Table A.7 (Cont.)

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
SARPAL	[110]								[110]	[110]
ZhengHe						[111]				
C-Cat5	[112]		[112]	[112]					[112]	[112]
SeaFOX	[113]					[113]			[113]	
OASIS			[32]			[18]			[18]	
Kaasbll 19						[115]				
C-Worker	[116]		[116]	[116]		[116]			[116]	[116]
Mariner 560	[130]			[130]	[29]				[29]	[130]
C-Hunter	[117]		[117]	[117]					[117]	[117]

Table A.8: Summary of Harbor-Class Unmanned Surface Vehicles hardware Based HMI

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
Spartan		[119]								
Inspector MK-2	[121]			[121]					[121]	[121]
Kan-chan						[33]				
Viknes						[30]				
Protector (9m)	[34]		[34]		[34]	[35]			[34]	[35]
Silver Marlin	[85]		[85]						[85]	[85]
C-Sweep	[125]		[125]	[125]		[125]		[125]	[125]	

Table A.9: Summary of Fleet-Class Unmanned Surface Vehicles Hardware Based HMI

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
Seastar	[36]			[36]					[36]	[36]
Protector (11m)	[34]		[34]		[34]	[35]			[34]	[35]
SCOAP	[37]					[37]				

Table A.10: Summary of E,F,G-Class Unmanned Surface Vehicles Hardware Based HMI

Vehicle	**Joystick**	**RC - Controller**	**Keyboard**	**Buttons**	**Touch -screen**	**Laptop or PC7**	**Smart -phone**	**Tablet**	**Dislplay**	**Console**
Katana	[131]		[131]	[131]		[131]			[131]	[131]
Viglant			[38]			[38]			[38]	
Piranha										
Poseidon			[39]			[39]			[39]	

Table A.11: Summary of X-Class Unmanned Surface Vehicles Software HMI

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
Ziphius	[7]	[7]	[7]	[7]	
Minnow	[50]	[50, 51]			
Lutra	[8]	[8]	[8]	[8]	
MAKARA-02	[55, 56]	[55, 56]			[55, 56]
Pioneer	[9]				
Malaysia USV	[57]				
ESM30	[58]	[58]	[58]		[58]
SURF 20F					
Kingfisher	[60]	[60]			
Kaizu USV	[61, 62]	[61, 62]			[61, 62]
EMILY	[45]				
ME70 MM70	[64, 65]	[64, 65]	[64, 65]		[64, 65]
CatONE	[66, 67]	[66, 67]	[66, 67]		
Hurricane Tracker	[10]	[10]			
Surfsense	[69]	[69]			
AutoCat					
GSV ”Rocky”	[71, 132]	[71, 132]	[71, 132]		
Roboduck 2	[73]	[73]	[73]		[73]
AMB/ASMV	[75, 76]	[75, 76]		[75, 76]	
C-Cat2	[77]		[77]		[77]

Table A.11: Table A.11 (Cont.)

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
C-Stat	[78]		[78]		[78]
Smart-phone Charlie	[13]	[13]	[13]	[13]	
SESAMO	[79, 133, 80]	[79, 133, 80]			[79, 133, 80]
Shanghai Maritime University	[81]				
Wave Glider SV3		[14]	[14]		[14]
Malaysia Patrol	[82]	[82]	[82]	[82]	

Table A.12: Summary of Intermediate-Class Unmanned Surface Vehicles Software HMI

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
SCOUT		[83, 84]			[83, 84]
Stingray	[85]		[85]		[85]
Blackfish	[87]			[87]	
MESSIN					
SCU SWATH	[92]	[92]	[92]		[92]
BASIL					[93]
AutoNaut		[94]			[94]
DELFIM		[96]			[96]
WAM-V	[16, 17]				
Pungo Kayak		[97]			[97]
SeaOWL	[98]				[98]
Piraya	[99]	[99]			
Springer		[100]		[100]	
C-Enduro	[102]		[102]		[102]
Roaz	[103, 104]	[103, 104]	[103, 104]		[103, 104]
ALANIS	[105, 106]	[105, 106]			[105, 106]
VaCas		[15]			
The Lake Wivenhoe		[108]	[108]	[108]	
SARPAL	[110]				
ZhengHe	[111]	[111]		[111]	

Table A.12: Table A.12 (Cont.)

Vehicle	Real Time Video	API Customization	Synthetic Overlay	Menus(Simple)	Menus(Complex)
C-Cat5	[112]		[112]		[112]
SeaFOX	[113]	[113]			
OASIS		[32]	[40]		[40]
Kaasbll 19		[115]		[115]	
C-Worker	[116]		[116]		[116]
Mariner	[130, 29]		[130, 29]		[130, 29]
C-Hunter	[117]		[117]		[117]

Table A.13: Summary of Harbor-Class Unmanned Surface Vehicles Software based HMI

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
Spartan	[119]				
Inspector MK-2	[121]		[121]		[121]
Kan-chan	[41, 33, 42]	[41, 33, 42]			[41, 33, 42]
Viknes	[30]	[30]			
Protector (9m)	[35, 34]		[35, 34]		[35, 34]
Silver Marlin	[85]		[85]		[85]
C-Sweep	[125]		[125]		

Table A.14: Summary of Fleet-Class Unmanned Surface Vehicles Software Based HMI

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
Seastar	[36]		[36]		
Protector (11m)	[34, 35]		[34, 35]		[34, 35]
SCOAP		[37]			

Table A.15: Summary of E,F,G-Class Unmanned Surface Vehicles Software Based HMI

Vehicle	**Real Time Video**	**API Customization**	**Synthetic Overlay**	**Menus(Simple)**	**Menus(Complex)**
Katana	[131]		[131]	[131]	[131]
Vigilant	[38]		[38]		[38]
Piranha	[43]				
Poseidon	[39]				[39]

REFERENCES

[1] United States of America Department of NAVY, "The navy unmanned surface the navy unmanned surface vehicle (usv) master plan," United States of America Department of NAVY, Tech. Rep., 2007. [Online]. Available: http://www.navy.mil/navydata/technology/usvmppr.pdf

[2] J. E. Manley, "Unmanned surface vehicles, 15 years of development," in *OCEANS 2008*. IEEE, 2008, pp. 1–4.

[3] M. Bibuli, M. Caccia, L. Lapierre, and G. Bruzzone, "Guidance of unmanned surface vehicles: Experiments in vehicle following," *Robotics & Automation Magazine, IEEE*, vol. 19, no. 3, pp. 92–102, 2012.

[4] R. R. Murphy, E. Steimle, M. Hall, M. Lindemuth, D. Trejo, S. Hurlebaus, Z. Medina-Cetina, and D. Slocum, "Robot-assisted bridge inspection," *Journal of Intelligent & Robotic Systems*, vol. 64, no. 1, pp. 77–95, 2011.

[5] R. R. Murphy, *Disaster robotics.* MIT Press, 2014.

[6] S. Savitz, I. Blickstein, P. Buryk, R. W. Button, P. DeLuca, J. Dryden, J. Mastbaum, J. Osburg, P. Padilla, and A. Potter, "Us navy employment options for unmanned surface vehicles (usvs)," DTIC Document, Tech. Rep., 2013.

[7] Azorean Aquatic Techinologies, "Ziphius," 2013. [Online]. Available: http://myziphius.com

[8] Platypus LLC. (2013) Lutra 1.1. [Online]. Available: http://senseplatypus.com/Solutions/hardware.html

[9] NjordWorks Inc., "Pioneer," 2014. [Online]. Available: http://www.njordworks.com/pioneer/

[10] Emily Emergency Integrated Lifesaving Lanyard, "Hurricane tracker," 2012. [Online]. Available: http://emilyrobot.com/hurricane-tracker/

[11] N. Oceanic and A. A. (NOAA). (2012, May) Introducing emily and other innovations to improve hurricane forecasts. [Online]. Available: http://uas.noaa.gov/news/emily.html

[12] D. Wichner, “Tucson tech: Storm-tracking craft test waters here,” February 2013. [Online]. Available: http://azstarnet.com/business/local/tucson-tech-storm-tracking-craft-test-waters-here/article_0531f0a3-3834-59f3-a506-6f0f1eae819b.html?cid=print

[13] F. Ferreira, M. Bibuli, M. Caccia, and G. Bruzzone, “Enhancing autonomous capabilities and human-robot interaction for unmanned surface vehicles,” in *Control & Automation (MED), 2012 20th Mediterranean Conference on.* IEEE, 2012, pp. 1359–1364.

[14] Liquid Robotics Inc. (2014) Wave glider sv3. [Online]. Available: http://liquidr.com/technology/waveglider/sv3.html

[15] Autonomous Systems and Controls Laboratory at the Virginia Polytechnic Institute and State University, “Autonomour surface vehicle,” 2008. [Online]. Available: http://www.ascl.ece.vt.edu/ASV.html

[16] M. R. Dhanak, P. Ananthakrishnan, J. Frankenfield, and K. von Ellenrieder, “Seakeeping characteristics of a wave-adaptive modular unmanned surface vehicle,” in *ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering.* American Society of Mechanical Engineers, 2013, pp. V009T12A053–V009T12A053.

[17] Marine Advanced Reasearch Inc. (2009) Unmanned wam-v®. [Online]. Available: http://wam-v.com/unmanned.html

[18] J. R. Higinbotham, P. Kitchener, and J. R. Moisan, *Development of a new long duration solar powered autonomous surface vehicle.* IEEE, 2006.

[19] GCAPTAIN, “Unmanned surface vehicles- the future of robotic pirate hunters,” Blog, October 2011. [Online]. Available: http://gcaptain.com/forget-uavs-usvs-option/

[20] S. Campbell, W. Naeem, and G. W. Irwin, “A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres,” *Annual Reviews in Control*, vol. 36, no. 2, pp. 267–283, 2012.

[21] H. Huang, “Autonomy levels for unmanned systems (alfus) framework. vol. i: Terminology, version 2.0. contributed by the ad hoc alfus working group participants,” *NIST special publication*, 2008.

[22] J. A. Adams, “Unmanned vehicle situation awareness: A path forward,” in *Human systems integration symposium.* Citeseer, 2007, pp. 31–89.

[23] M. R. Endsley, “Toward a theory of situation awareness in dynamic systems,” *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 37, no. 1, pp. 32–64, 1995.

[24] P. Scerri, B. Kannan, P. Velagapudi, K. Macarthur, P. Stone, M. Taylor, J. Dolan, A. Farinelli, A. Chapman, B. Dias *et al.*, "Flood disaster mitigation: A real-world challenge problem for multi-agent unmanned surface vehicles," in *Advanced Agent Technology.* Springer, 2012, pp. 252–269.

[25] J. M. Peschel and R. R. Murphy, "On the human–machine interaction of unmanned aerial system mission specialists," *Human-Machine Systems, IEEE Transactions on*, vol. 43, no. 1, pp. 53–62, 2013.

[26] T. Mulligan, "Control system for hurricane tracker telephone interview," June 2014.

[27] J. M. Peschel, "Mission specialist human-robot interaction in micro unmanned aerial systems," Ph.D. dissertation, Texas AM University, August 2012.

[28] A. Valada, P. Velagapudi, B. Kannan, C. Tomaszewski, G. Kantor, and P. Scerri, "Development of a low cost multi-robot autonomous marine surface platform," in *Field and Service Robotics.* Springer, 2014, pp. 643–658.

[29] M. Robotics, "Mariner unmanned surface vehicle (usv)," 2013. [Online]. Available: http://3cft7x47zqd51r4ueo226y9puhz.wpengine.netdna-cdn.com/wp-content/uploads/2013/11/1403_usv_brochure_WEB.pdf

[30] Ø. A. G. Loe, "Collision avoidance for unmanned surface vehicles," 2008.

[31] D. J. Stilwell and C. A. Woolsey, "Sensing and autonomy for riverine vessels," DTIC Document, Tech. Rep., 2011.

[32] School of Computer Science at Carnegie Mellon University. (2012, February) Telesupervised adaptive ocean sensor fleet. [Online]. Available: http://www.cs.cmu.edu/~gwp/TAOSF/

[33] Yamaha Motor Co. (2001, February) Kan-chan remote navigational control by satellite. the world's first unmanned ocean atmospheric observation boat. [Online]. Available: http://global.yamaha-motor.com/news/2001/0209/boatshow-03.html

[34] Naval Drones, "Protector usv," 2012. [Online]. Available: http://www.navaldrones.com/protector.html

[35] Israel Weapons.com. (2007) Protector unmanned naval patrol vehicle. [Online]. Available: http://web.archive.org/web/20070329024450/http://www.israeli-weapons.com/weapons/naval/protector/Protector.html

[36] Naval Drones. (2006) Seastar. [Online]. Available: http://www.navaldrones.com/Seastar.html

[37] The Graduate School of Oceanography at the University of Rhode Island. (2013) Scoap. [Online]. Available: http://www.po.gso.uri.edu/~codiga/scoap/howitworks.htm

[38] E. Lundquist. (2013, July) Speed, payload, endurance. [Online]. Available: http://www.zycraft.com/ZycraftAUVSI.pdf

[39] Israel Aerospace Industries RAMTA Division . (2013) Poseidon ausv. [Online]. Available: http://www.iai.co.il/Sip_Storage//FILES/5/39945.pdf

[40] J. M. Dolan, G. Podnar, S. Stancliff, E. Lin, J. Hosler, T. Ames, J. Moisan, T. Moisan, J. Higinbotham, and A. Elfes, "Harmful algal bloom characterization via the telesupervised adaptive ocean sensor fleet," *Robotics Institute*, p. 187, 2007.

[41] Yamaha Motor Co. (2000, April) World's first unmanned ocean atmosphere observation boat kan-chan designed and built using sailing cruiser hull. [Online]. Available: http://global.yamaha-motor.com/news/2000/0413/observation.html

[42] Y. Hattori, "Kan-chan," 2003. [Online]. Available: http://mits10.aori.u-tokyo.ac.jp/hattori/ootuchi.html

[43] J. Holloway. (2012, April) Unmanned nanomaterial piranha threatens to redfine naval warfare. [Online]. Available: http://www.gizmag.com/zyvex-piranha-usv/22078/

[44] G. Osga, M. McWilliams, D. Powell, D. Kellmeyer, J. Kaiwi, and A. Ahumada, "Unmanned surface vehicle human-computer interface for amphibious operations," DTIC Document, Tech. Rep., 2013.

[45] Emily Emergency Integrated Lifesaving Lanyard. (2012) Emily emergency integrated lifesaving lanyard. [Online]. Available: http://emilyrobot.com

[46] YDreams, "yvision," 2012. [Online]. Available: http://www.yvision.com/

[47] P. Tucker, "Inside the navy's secret swarm robot experiment," October 2014. [Online]. Available: http://www.defenseone.com/technology/2014/10/inside-navys-secret-swarm-robot-experiment/95813/

[48] D. Smalley, "The future is now: Navy's autonomous swarmboats can overwhelm adversaries," 2014. [Online]. Available: http://www.onr.navy.mil/Media-Center/Press-Releases/2014/autonomous-swarm-boat-unmanned-caracas.aspx

[49] Aeronautics, "Seastar," 2007. [Online]. Available: http://www.aeronautics-sys.com/seastar_unmanned_surface_vehicle_usv

[50] A. Calce, P. M. Forooshani, A. Speers, K. Watters, T. Young, and M. Jenkin, "Roboboat-building unmanned surfaced vessels from rc motorboats."

[51] H. Hobby. (2014) Blackjack 26. [Online]. Available: http://www.horizonhobby.com/products/blackjack-26-brushless-catamaran-rtr-PRB3300

[52] T. El-Gaaly, C. Tomaszewski, A. Valada, P. Velagapudi, B. Kannan, and P. Scerri, "Visual obstacle avoidance for autonomous watercraft using smartphones," 2013.

[53] Carnegie Mellon Cooperative Robotic Watercraft. (2013, November) Carnegie mellon cooperative robotic watercraft. [Online]. Available: https://code.google.com/p/crw-cmu/

[54] A. Valada, C. Tomaszewski, B. Kannan, P. Velagapudi, G. Kantor, and P. Scerri, "An intelligent approach to hysteresis compensation while sampling using a fleet of autonomous watercraft," in *Intelligent Robotics and Applications*. Springer, 2012, pp. 472–485.

[55] UI Roboboat Team 2013. (2013, November) Makara 02 v.2. [Online]. Available: http://makara02v2.wordpress.com

[56] M. Mukti, A. Meisar, N. Ginanto, I. Elliika, and Y. Mahendra, "Makara-02 autonomousroboticboat 2013 competition," Universitas Indonesia, Project Report, 2013.

[57] N. A. A. Hussain, D. Sathyamoorthy, N. M. Nasuddin, N. M. Nawi, M. N. Mansor, N. E. S. Sulaiman, R. Yaacob, R. Ramli, M. R. M. Rashid, I. Ramli *et al.*, "Development of a prototype unmanned surface vessel (usv) platform," *Defence S&T Technical Bulletin*, vol. 6, no. 1, 2013.

[58] Zhuhai Yunzhou Intelligence Technology Ltd. (2010) ESM30. [Online]. Available: http://www.yunzhou-tech.com/?products=esm30

[59] ——. (2010) Surf 20f. [Online]. Available: http://www.yunzhou-tech.com/?products=surf-20f

[60] CLEARPATH Robotics. (2013, March) Kingfisher. [Online]. Available: http://www.clearpathrobotics.com/kingfisher/

[61] Car Mate MFG.CO., LTD. (2014) Float boat. [Online]. Available: http://www.innoracks.com/jp/products/fishing/floatboat.html

[62] Y. Kaizu, M. Iio, H. Yamada, and N. Noguchi, "Development of unmanned airboat for water-quality mapping," *Biosystems Engineering*, vol. 109, no. 4, pp. 338–347, 2011.

[63] B. Coxworth. (2010, December) Emily rescues swimmers when lifeguards can't. [Online]. Available: http://www.gizmag.com/emily-motorized-rescue-buoy/17297/

[64] Zhuhai Yunzhou Intelligence Technology Ltd. (2010) ME 70. [Online]. Available: http://www.yunzhou-tech.com/?products=me70

[65] ——. (2010) MM 70. [Online]. Available: http://www.yunzhou-tech.com/?products=mm70

[66] A. Romano and P. Duranti, "Autonomous unmanned surface vessels for hydrographic measurement and environmental monitoring," *TS04D - Hydrographic Technologies*, vol. 6118, 2012.

[67] aerRobotix. (2014) Catone. [Online]. Available: http://www.aerrobotix.com/video.html

[68] T. R. Clem, D. D. Sternlicht, J. E. Fernandez, J. L. Prater, R. Holtzapple, R. P. Gibson, J. P. Klose, and T. M. Marston, "Demonstration of advanced sensors for underwater unexploded ordnance (uxo) detection," in *Oceans, 2012*. IEEE, 2012, pp. 1–4.

[69] Emily Emergency Integrated Lifesaving Lanyard, "Surfsense," 2012. [Online]. Available: http://emilyrobot.com/surfsense/

[70] J. E. Manley, A. Marsh, W. Cornforth, and C. Wiseman, "Evolution of the autonomous surface craft autocat," in *Oceans 2000 MTS/IEEE Conference and Exhibition*, vol. 1. IEEE, 2000, pp. 403–408.

[71] E. T. Steimle and M. L. Hall, "Unmanned surface vehicles as environmental monitoring and assessment tools," in *OCEANS 2006*. IEEE, 2006, pp. 1–5.

[72] J. Andrews. (2004) Exploring uncharted waters. [Online]. Available: http://reports.research.usf.edu/publications/USF_fy03-04.pdf

[73] A. A. de Menezes Pereira, "Navigation and guidance of an autonomous surface vehicle," Ph.D. dissertation, University of Southern California, 2007.

[74] A. S. Outlaw, "Computerization of an autonomous mobile buoy," Ph.D. dissertation, Florida Institute of Technology, 2007.

[75] S. Wood, M. Rees, and Z. Pfeiffer, "An autonomous self-mooring vehicle for littoral & coastal observations," in *OCEANS 2007-Europe*. IEEE, 2007, pp. 1–6.

[76] S. L. Wood, "Application of an autonomous self-mooring vehicle," *Sea Technology*, vol. 50, no. 1, pp. 38–40, 2009.

[77] Autonomous Surface Vehicles Ltd, "C-Cat 2," 2014. [Online]. Available: http://www.asvglobal.com/science-and-survey/c-cat-2

[78] ——. (2014) C-Stat Mobile Buoy Systems. [Online]. Available: http://www.asvglobal.com/military-and-security/c-stat

[79] M. Caccia, R. Bono, G. Bruzzone, E. Spirandelli, G. Veruggio, A. Stortini, and G. Capodaglio, "Sampling sea surfaces with sesamo: an autonomous craft for the study of sea-air interactions," *Robotics & Automation Magazine, IEEE*, vol. 12, no. 3, pp. 95–105, 2005.

[80] M. Caccia, R. Bono, G. Bruzzone, G. Bruzzone, E. Spirandelli, G. Veruggio, and A. M. Stortini, "Design and exploitation of an autonomous surface vessel for the study of sea-air interactions," in *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*. IEEE, 2005, pp. 3582–3587.

[81] J. Wang, W. Gu, J. Zhu, and J. Zhang, "An unmanned surface vehicle for multi-mission applications," in *Proc. 2009 International Conference on Electronic Computer Technology*, 2009, pp. 20–22.

[82] O. Yaakob, Z. Mohamed, M. Hanafiah, D. Suprayogi, M. A. Ghani, F. Adnan, M. Mukti, and J. Din, "Development of unmanned surface vehicle (usv) for sea patrol and environmental monitoring."

[83] J. Curcio, J. Leonard, and A. Patrikalakis, "Scout-a low cost autonomous surface platform for research in cooperative autonomy," in *OCEANS, 2005. Proceedings of MTS/IEEE.* IEEE, 2005, pp. 725–729.

[84] J. Curcio, T. Schneider, M. Benjamin, and A. Patrikalakis, "Autonomous surface craft provide flexibility to remote adaptive oceanographic sampling and modeling," in *OCEANS 2008.* IEEE, 2008, pp. 1–7.

[85] Elbit Systems Ltd. (2009) New tools for new rules. [Online]. Available: http://elbitsystems.com/Elbitmain/files/USV.pdf

[86] Defence Update. (2006, November) Stingray unmanned surface vehicle (usv). [Online]. Available: http://defense-update.com/products/s/stingray.htm

[87] QuinetiQ North America. (2014) Blackfish. [Online]. Available: https://www.qinetiq-na.com/products/pscs/blackfish/

[88] P. Science. (2014) Qinetiq blackfish. [Online]. Available: http://www.popsci.com/bown/2011/product/qinetiq-blackfish

[89] FindTheBest.com, Inc. (2014) 2014 yamaha waverunner fzs. [Online]. Available: http://jet-skis.findthebest.com/l/106/2014-Yamaha-Waverunner-FZS

[90] T. Buch and M. Kurowski. (2013) Messin – an autonomously operating unmanned surface vehicle messin – an autonomously operating unmanned surface vehicle messin-an autonomously operating unmanned surface vehicle. [Online]. Available: http://www.innomar.com/wssa2013/2013-wssa-Buch.pdf

[91] J. Majohr and T. Buch, "Modelling, simulation and control of an autonomous surface marine vehicle for surveying applications measuring dolphin messin," *IEE Control Engineering Series*, vol. 69, p. 329, 2006.

[92] K. Rasal, "Navigation & control of an automated swath surface vessel for bathymetric mapping," Ph.D. dissertation, SANTA CLARA UNIVERSITY, 2013.

[93] ACSA Alcen. (2013) Basil. [Online]. Available: http://www.acsa-alcen.com/robotics/basil

[94] The AutoNaut USV from MOST (Autonomous Vessels) Ltd. , “Autonaut specification,” 2014. [Online]. Available: http://www.autonautusv.com/specifications

[95] J. Alves, P. Oliveira, R. Oliveira, A. Pascoal, M. Rufino, L. Sebastiao, and C. Silvestre, “Vehicle and mission control of the delfim autonomous surface craft,” in *Control and Automation, 2006. MED’06. 14th Mediterranean Conference on.* IEEE, 2006, pp. 1–6.

[96] Dynamical Systems and Ocean Robotics Lab at nstituto Superior Técnico. (2001) Delfim. [Online]. Available: http://dsor.isr.ist.utl.pt/Projects/Delfim/trials.html

[97] E. A. Karlik, “Remote depth survey of the charles river basin,” Ph.D. dissertation, Massachusetts Institute of Technology, 2007.

[98] DRS Technologies Inc., “Seaowl mk vi unmanned surface vehicle,” 2013. [Online]. Available: http://www.drs.com/Products/UAS/Seaowl.aspx

[99] ThyssenKrupp Marine Systems-Kockums. (2010, March) Piraya usv. [Online]. Available: http://www.kockums.se/en/products-services/naval-surface-ships/coast-guard-security/piraya-usv/

[100] W. Naeem, T. Xu, R. Sutton, and A. Tiano, “The design of a navigation, guidance, and control system for an unmanned surface vehicle for environmental monitoring,” *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, vol. 222, no. 2, pp. 67–79, 2008.

[101] R. Sutton, S. Sharma, and T. Xao, “Adaptive navigation systems for an unmanned surface vehicle,” *Journal of Marine Engineering and Technology*, vol. 10, no. 3, pp. 3–20, 2011.

[102] Autonomous Surface Vehicles Ltd, “C-Enduro,” 2014. [Online]. Available: http://www.asvglobal.com/science-survey/c-enduro

[103] C. Almeida, T. Franco, H. Ferreira, A. Martins, R. Santos, J. M. Almeida, J. Carvalho, and E. Silva, “Radar based collision detection developments on usv roaz ii,” in *Oceans 2009-Europe.* IEEE, 2009, pp. 1–6.

[104] H. Ferreira, C. Almeida, A. Martins, J. Almeida, N. Dias, A. Dias, and E. Silva, “Autonomous bathymetry for risk assessment with roaz robotic surface vehicle,” in *OCEANS 2009-EUROPE.* IEEE, 2009, pp. 1–6.

[105] M. Bibuli, M. Caccia, R. Bono, G. Bruzzone, G. Bruzzone, and E. Spirandelli. The alanis usv: Aluminum autonomous navigator for intelligent sampling: Aluminum autonomous navigator for intelligent sampling. [Online]. Available: http://202.114.89.60/resource/pdf/5077.pdf

[106] M. Caccia, M. Bibuli, R. Bono, G. Bruzzone, and E. Spirandelli, "Aluminum hull usv for coastal water and seafloor monitoring," in *OCEANS 2009-EUROPE.* IEEE, 2009, pp. 1–5.

[107] A. S. Gadre, C. Sonnenburg, S. Du, D. J. Stilwell, and C. Woolsey, "Guidance and control of an unmanned surface vehicle exhibiting sternward motion," in *Oceans, 2012.* IEEE, 2012, pp. 1–9.

[108] M. Dunbabin, A. Grinham, and J. Udy, "An autonomous surface vehicle for water quality monitoring," in *Australasian Conference on Robotics and Automation (ACRA)*, 2009, pp. 2–4.

[109] M. Dunbabin, B. Lang, and B. Wood, "Towards coordinated vision-based docking using an autonomous surface vehicle," in *Proc. Australian Conf. Robotics and Automation.* Citeseer, 2007.

[110] International Submarine Engineering, "Sarpal," 2013. [Online]. Available: http://www.ise.bc.ca/sarpal.html

[111] W.-R. Yang, C.-Y. Chen, C.-M. Hsu, C.-J. Tseng, and W.-C. Yang, "Multifunctional inshore survey platform with unmanned surface vehicles," *International Journal of Automation and Smart Technology*, vol. 1, no. 2, pp. 19–25, 2011.

[112] Autonomous Surface Vehicles Ltd. (2014) C-Cat 5. [Online]. Available: http://www.asvglobal.com/science-survey/c-cat-5

[113] M. Crowley. (2005, January) Northwin marine displays two boats at seattle show. [Online]. Available: http://www.workboat.com/newsdetail.aspx?id=16064

[114] J. M. Dolan, G. W. Podnar, A. Elfes, S. Stancliff, E. Lin, J. Higinbotham, J. C. Hosler, J. Moisan, and T. A. Moisan, "Smart ocean sensing using the telesupervised adaptive ocean sensor fleet," 2008.

[115] G. Beinset and J. S. Blomhoff, "Controller design for an unmanned surface vessel: Design of a heading autopilot and way-point navigation system for an underactuated usv." 2007.

[116] Autonomous Surface Vehicles Ltd. (2014) C-Worker. [Online]. Available: http://www.asvglobal.com/oil-and-gas/c-worker

[117] ——. (2014) C-Hunter. [Online]. Available: http://www.asvglobal.com/oil-and-gas/asv-6300c

[118] G. Martinic. (2014, July) Unmanned maritime surveillance and weapons systems. [Online]. Available: http://navalinstitute.com.au/unmanned-maritime-surveillance-and-weapons-systems/

[119] United States of America Department of NAVY. (2003, December) Spartan deployed on gettysburg. [Online]. Available: http://www.navy.mil/submit/display.asp?story_id=10964

[120] StrategyWorld.com. (2013, April) Surface forces: Roboships getting bigger and more numerous. [Online]. Available: https://www.strategypage.com/htmw/htsurf/articles/20130404.aspx

[121] ECA Robotics, "U.s.v. inspector mk2 - imagery bathymetric survey," 2008. [Online]. Available: http://www.eca-robotics.com/en/detail-produit.htm?_ref=68

[122] M. Uematsu, M. Toratani, M. Kajino, Y. Narita, Y. Senga, and T. Kimoto, "Enhancement of primary productivity in the western north pacific caused by the eruption of the miyake-jima volcano," *Geophysical research letters*, vol. 31, no. 6, 2004.

[123] naval-technology.com. (2014) Protector unmanned surface vehicle (usv), israel. [Online]. Available: http://www.naval-technology.com/projects/protector-unmanned-surface-vehicle/

[124] Rafael Advanced Defence Systems Ltd. (2010) Unmanned naval patrol vehicle. [Online]. Available: http://www.rafael.co.il/Marketing/351-1037-en/Marketing.aspx

[125] Autonomous Surface Vehicles Ltd, "C-Sweep," 2014. [Online]. Available: http://www.asvglobal.com/military-and-security/c-sweep

[126] M. Margalit. (2014, February) Video / made in israel: The new katana combat vessel. [Online]. Available: http://www.ynetnews.com/articles/0,7340,L-4484946,00.html

[127] naval-technology.com. (2014) Vigilant class independent unmanned surface vessel (iusv), singapore. [Online]. Available: http://www.naval-technology.com/projects/-vigilant-class-independent-unmanned-surface-vessel/

[128] ZyCraft. (2014) Iusv vigilant product overview. [Online]. Available: http://www.zycraft.com/Products/IUSV.html

[129] PR Newswire Association LLC. (2011) Super light-weight nano-carbon fiber boat piranha completes sea trials demonstrating record fuel efficiency. [Online]. Available: http://www.prnewswire.com

[130] Cavotec MSL Holdings Limited . (2010, December) Plain sailing for remote controlled unmanned vessel. [Online]. Available: http://blog.cavotec.com/ports-maritime/usv-rrc-dec-10/

[131] Israel Aerospace Industries ELTA Systems Ltd. . (2009, March) Advanced coastal surveillance radar family. [Online]. Available: http://www.iai.co.il/sip_storage/files/2/36842.pdf

[132] E. Steimle, “Project 8: Guided surface vehicles,” Center for Science Policy Application for the Coastal Environment, University of South Florida St. Petersberg, Final Report, 2009. [Online]. Available: http://www1.usfsp.edu/cspace/CSPACEMasterDocument20100301.pdf

[133] M. Caccia, R. Bono, G. Bruzzone, G. Bruzzone, E. Spirandelli, G. Veruggio, and A. Stortini, “Design and preliminary sea trials of sesamo: an autonomous surface vessel for the study and characterization of the air-sea interface,” Citeseer, Tech. Rep., 2003.