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Development and Missions of Unmanned Surface Vehicle

Ru-jian Yan, Shuo Pang, Han-bing Sun and Yong-jie Pang

Science and Technology on Underwater Vehicle Laboratory, Harbin Engineering University, Harbin 150001, China

Abstract: The navy and other Department of Defense organizations are increasingly interested in the use of unmanned surface vehicles (USVs) for a variety of missions and applications. The term USV refers to any vehicle that operates on the surface of the water without a crew. USVs have the potential, and in some cases the demonstrated ability, to reduce risk to manned forces, provide the necessary force multiplication to accomplish military missions, perform tasks which manned vehicles cannot, and do so in a way that is affordable for the navy. A survey of USV activities worldwide as well as the general technical challenges of USVs was presented below. A general description of USVs was provided along with their typical applications. The technical challenges of developing a USV include its intelligence level, control, high stability, and developmental cost reduction. Through the joint efforts of researchers around the world, it is believed that the development of USVs will enter a new phase in the near future, as USVs could soon be applied widely both in military and civilian service.
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1 Introduction

Unmanned vehicles are critical components of the future naval forces. Significant research and development has been performed on unmanned underwater vehicles (UUVs) and unmanned aerial vehicles (UAVs), yet little effort has gone into examining unmanned surface vehicles (USVs). With future conflicts taking place primarily in the littoral regions around the globe against adversaries who possess increasingly more effective weapon systems, placing people in harm's way may no longer be a viable option. USVs will provide the Fleet with additional military capabilities especially where loss of life is unacceptable. USVs can be deployed in waters where it's unacceptable to send a manned vessel, including high threat environments or areas contaminated by nuclear, biological, or chemical agents. They are reliable, fast, highly maneuverable, allowing them to conduct a wide range of missions, including patrols of the coast, without endangering navy personnel.

While USVs date back to World War II, it is only in the 1990s that a large proliferation of projects appeared (Corfield and Young, 2006). This is in part due to the technological progress, but also driven by a paradigm shift of the US Navy with a much stronger focus on littoral warfare and anti-terrorism missions. In 2001, the US Office of Naval Research (ONR) proposed the concept of the Littoral Combat Ship (LCS). The LCS was optimized for flexibility in the littorals as a mission reconfigurable system of systems, both manned and unmanned. The LCS achieves its joint force multiplier effect through the use of unmanned air, surface, and underwater vehicles. The intelligent high-speed unmanned surface vessel (USV) is mentioned clearly in the LCS, USV constitutes the unmanned combat system together with UUV and UAV. The unmanned combat system can address the Navy's need for affordable, efficient and technically sound multi-mission systems capable of worldwide deployment for littoral combat.

Successful missions of USVs in the second Gulf war have increased interest within the US Navy in USVs and several modern navies followed suit. USV have the potential, and in some cases the demonstrated ability, to reduce risk to manned forces, to perform tasks which manned vehicles cannot, to provide the force multiplication necessary to meet this threat and continue to accomplish our missions, and to do so in a way that is cost-effective. Potential USV missions could range from small torpedo-size data gatherers to large unmanned ships.

2 Description of USV

USV is based on innovations in high-payload, high-speed small craft design and unmanned systems technology to provide a highly capable unmanned surface vehicle meeting the strenuous demands of multiple missions. According to the United States magazine "Navy insider", U.S. Navy published an "unmanned surface vessel Master Plan" (hereinafter referred to noted as "Master Plan" lately) in 2007. The "Master Plan" reviewed various available USV types and characteristics, analyzed the attributes associated with USV missions and compared vehicle attributes to mission needs

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***Corresponding author Email:** yanrujian@hrbeu.edu.cn

(Program Executive Officer, 2007). It defines four classes of unmanned vessel: X-class, Harbor-class, Snorkeler-class and Fleet-class. The “Master Plan” led to the conclusion that smaller USVs, seven to 11 meters in length, should be the backbone of the USV fleet.

2.1 Craft types

Many hull and craft types were examined since a major design driver is the interface of the USV with the sea surface.

(1) Semi-submersible Craft;
(2) Conventional Planing Hull Craft;
(3) Semi-planing Hull Craft;
(4) Hydrofoils;
(5) Other Craft types.

Certain hull forms have specific characteristics that make them more suitable to certain operations. The requirements for a manned vehicle center around human limitations, such as motion, temperature, habitation space, etc. However, the requirements for an unmanned system are based solely on what the machinery can handle. Due to this shift in requirements, new and innovative hull forms, which may be unsuitable for manned operations, become prime candidates for USVs.

2.2 Applications

There are many applications for USV. The "Master Plan" describes seven high-priority unmanned vessel missions on the operational range. According to priority the order is: Mine Countermeasures, Anti-Submarine Warfare, Maritime Security, Surface Warfare, Special Operations Forces Support, Electronic Warfare, and Maritime Interdiction Operations Support. Here we list several typical applications for USV.

2.2.1 Mine Countermeasures (MCM)

MCM mission requirements are driven by the Fleet's need to rapidly establish large, safe operating areas, transit routes and transit lanes. The objective of the MCM capability is to find or create fleet operating areas that are clear of sea mines without requiring manned platforms to enter suspected mined areas, and to shorten MCM timelines. For the mission of MCM, a model was developed using a simple ladder pattern to search out randomly placed mines. It was assumed that each mine found was also neutralized using a mine-missile deployed from the USV. Further, this capability is required to operate within the near-term Navy force structure and to operate independently of other war fighting capabilities.

2.2.2 Anti-Terror

Operating by itself or integrated into a wider security network, the USV provides port, harbor and riverine security capability against covert or unconventional threats. The USV is unique in its ability to remotely conduct day and night port, harbor or riverine surveillance over extended hours, to interrogate potential threat platforms and to allow commanders to eliminate those threats if necessary. The USV is a force multiplier through its ability to conduct anti-terror protection without placing highly trained personnel at risk.

With integrated navigational sensors e.g. GPS, navigation radar and video cameras, the USV can conduct harbor surveillance even in busy waterways. The USV has the ability to provide remote detection, interrogation and engagement of potential threats to merchant vessels or naval ships.

2.2.3 Surveillance and Reconnaissance

The USV can successfully monitor waterways with general guidance from a commander and operator at sea or from shore - no matter how hazardous the condition is. The USV usually has an on-mount camera allowing for day and night operation and has a forward-looking infrared laser range finder with capability to detect and track targets in the near vicinity. The communications unit of the USV maintains a constant link between the USV and the control station. The navigation, surveillance and reconnaissance capabilities allow sailors to identify suspicious behavior, eliminate risks and safeguard high value maritime facilities and ships, especially in congested maritime traffic. Additionally, because the command control center crew can operate from a distance, the missions completed by the USV provide increased capability and flexibility to operational maritime forces.

2.2.4 Anti-Submarine Warfare (ASW)

It is vitally important that our navy be able to achieve and maintain access to all the world littorals at the times and places of its choosing. In view of the increasing submarine threat from our potential adversaries, it is critical to establish and maintain a highly effective ASW capability.

Operational concepts for the ASW Mission Capability include mono-static approaches (transmitter and receiver collocated on a single USV), bi-static and multi-static approaches (transmitter(s) and receiver(s) located on different platforms/USVs), and numerous variations on relative location of sensor and shooter in the prosecution phase. USVs will complement and extend existing ASW capabilities, with the specific USV employment scheme based on other available assets and their capabilities.

2.3 Vehicle class

The “Master plan” divides USV into three standard vehicle classes and one non-standard vehicle class.

1) The “X-Class” is a small, non-standard class of systems. It provides a “low-end” Intelligence, Surveillance, Reconnaissance (ISR) capability to support manned operations and is launched from small manned craft such as the 11m Rigid Inflatable Boat (RIB) or the Combat Rubber Raiding Craft (CRRC).

2) The “Harbor Class” is based on the Navy Standard 7m RIB and is focused on the maritime security mission, with a robust ISR capability and a mix of lethal and non-lethal armament. The “Harbor Class” USV can be supported by the majority of our Fleet, since it will use the standard 7m interfaces.

3) The “Snorkeler Class” is a 7m semi-submersible vehicle (SSV) which supports MCM towing (search) missions, ASW is also capable of supporting special missions that can take advantage of its relatively stealthy profile.

4) The “Fleet Class” will be a purpose-built USV, consistent with the handling equipment and weight limitations of the current 11m RIB. Variants of the Fleet Class will support MCM Sweep, Protected Passage ASW, and “high-end” surface warfare missions.

3 Development of USV

The use of unmanned vehicles in naval operations is not new, following World War II, USVs were developed and used for purposes such as minesweeping and Battle Damage Assessment (BDA). For example, in 1946, during Operation Crossroads, drone boats were used to obtain early samples of radioactive water after each of the Atomic Bomb Blasts. Later, in the late 1960’s, a 7-meter fiberglass hull, powered by a V-8 inboard gas engine, was modified to operate as a remotely controlled “chain drag” minesweeper.

In the 1990's, the Remote Mine-hunting Operational Prototype (RMOP) was operated from USS Cushing in the Persian Gulf. RMOP conducted 12 days of Mine-hunting operations in January/February of 1997 in participation with the SHAREM 119 exercise. There hasn’t been any large project on unmanned craft till 1990. This is because of the progress of science and technology, however, the further reason is that the U.S. Navy paid more attention to littoral warfare and counterterrorism. In the second Gulf War, unmanned vessels attracted the U.S. Navy attention because unmanned vessels accomplished the tasks successfully. Other European countries have introduced unmanned vessels into their modern navy from then on as well.

3.1 Development of USVs in U.S.

The Spartan Scout USV was created as an Advanced Concept Technology Demonstration (ACTD) in 2002 by the US Naval Undersea Warfare Center in Newport, Rhode Island, in conjunction with Radix Marine, Northrop Grumman, and Raytheon. The French navy and the Singapore navy joined the SPARTAN program of the US Navy in 2003. Its purpose was to protect troops against asymmetric threats; to enhance the early warning capabilities the networked ISR; to validate the USV effectiveness of unmanned sensors and weapons; to minimize human involvement, to reduce the risk of casualties.

The Spartan Scout USV is based on commercial off the shelf 7m rigid hull inflatable boat, which weighs two tons (Maguer *et al*., 2005). The craft can be equipped with modular payload packages for mine warfare, ISR/force protection, port protection, precision strike against surface and land targets, and possibly antisubmarine warfare.

A prototype Spartan Scout was successfully launched and remotely operated in the Persian Gulf from the USS Gettysburg in December 2003. In early April 2005，the Spartan Scout conducted the first live-fire test of a USV at Aberdeen Proving Grounds, Md. During the tests, it fired a remotely controlled, high-fidelity, electro-optically sighted .50-caliber machine gun while moving across the open water.

The only personnel required to handle the Spartan USV during operations is a two-man boat crew to launch and recover the USV. The Spartan is controlled via a data link with three laptop computers in the combat direction center of the cruiser. Fig.1 shows a demonstration of how a remote controller was used to steer a modified RIB Spartan USV. This USV has participated "Operation Enduring Freedom" and "Iraqi Freedom" and other combat missions in the Arab Gulf.

Fig.1 Spartan USV

The Navy sees the Spartan as a low-cost means of extending maritime patrol areas and providing anti-terrorism force protection for ships and other fleet assets against small, swarming enemy boats and mines. Spartan is one of the potential weapons systems for the Navy’s new LCS class ship that will use interchangeable mission modules to perform various tasks.

There are a number of companies in the United States who developed USV, they also made considerable progress. For example, Ghost Guardians, developed by U.S. Robotics Ship company, can accomplish the missions of force protection, delivery of goods (<150kg), collection of information, marine monitoring, etc. The robotics group at the US Space and Naval Warfare Systems Center in San Diego developed a USV test-bed as versatile platform for rapid prototyping and testing of new concepts (Ebken *et al*., 2005). The USV is based on the Bombardier SeaDoo Challenger 2000 powered by a Mercury 250-hp OptiMax fuel-injected V-6. A Florida based company SeaRobotics Corporation specializes in small, smart vessels that are remotely or autonomously-operated. Pricing starts at $35,000 USD, for a small, functional USV including hull, propulsion, batteries, OS, and computer. Many of the vessels are small, modular, and man-portable, allowing rapid deployment in remote areas or deployment by larger vessels. The command and control systems are user-friendly and compact, allowing backpack mobilization.

3.2 Developments of USVs outside U.S.

In 2003, Israel Raphael weapons design bureau delivered to Israeli Defense Forces the first batch of "Protector" high-speed autonomous unmanned surface vessel. Based on a 9m rigid-hulled inflatable boat, the Protector is stealthy, highly autonomous and can operate with general guidance from a commander in port, riverine, harbor and coastal waterways in a variety of roles, such as force protection, anti-terror, surveillance and reconnaissance, mine warfare and electronic warfare.

The hull of Protector is a deep V-shaped planing hull, with the inflatable section providing stability and endurance. A single diesel engine drives water jets, allowing speeds of 50 knots. The option modular systems of Protector include a highly accurate, stabilized mini-Typhoon weapon system with an excellent hit-and-kill probability, plus cameras, search radar and a Toplite electro-optical (EO) pod for detection, identification and targeting operations.

The Protector's anti-terror mission module includes advanced sub-systems that are already in military service in the U.S. and other countries. The surface search radar and the Toplite multi-sensor, electro-optical (EO) sensor enable detection, identification and targeting operations. The highly accurate Mk 49 Mod 0, 7.62-mm mini-Typhoon weapon system, with a stabilized gun platform and computerized fire control system, is integrated with the Toplight and can be used to eliminate threats.

Fig.2 Protector USV

Fig.2 shows the Protector USV in mission. Protector is an integrated, remotely controlled combat system ideally suited to meet force protection requirements in all maritime settings. By providing long range stand-off surveillance, identification and engagement capability Protector can be quickly deployed to defend high value assets including naval vessels, port operations, oil rigs and coastal power plants.

In 2005, Israel Elbit Systems Company came out with a small unmanned boat named "Stingray". Stingray attracted world wide attention for the maximum speed at 40 knots, the total laden weight of 150kg, and self-sustainability for more than 8 hours. Stingray can perform autonomously or be remotely controlled by a single operator located at the shore station or onboard the ship. Stingray is characterized by small hull and good stealth performance, and is able to complete many kinds of missions such as the coast objects identification, intelligence and reconnaissance and surveillance, electronic warfare and electronic surveillance and so on. The USV is designed for homeland security and coast guard applications including clearing shipping lanes and underwater search missions.

Fig.3 Stingray USV

The development is based on Elbit's extensive experience in the development and operation of unmanned air vehicles (UAV) and mini UAVs. It is equipped with autonomous navigation and positioning capability, cruise sensors, and a stabilization system which prevents capsizing. Stingray is equipped with day and night electro-optical stabilized payload. Fig.3 shows a Stingray USV.

Drawing on the successful experience of Spartan Scout, the British Defense Science and Technology Laboratory applied its modular advantages to produce the unmanned boat "Fenrir" cooperating with the U.S. Army. The "Fenrir" has replaced the traditional carrier-based rigid inflatable boats to implement high-risk tasks when completed in 2002. Since 1997, the German company Veers has been active in developing USVs. Initial work focuses on the development of a USV “STIPS” for the German ministry of fishery in two stages. In early 2005, Veers presented the Multi-Mission Surface Vehicle III (MMSV III) “See-Wiesel”, (Veers and Bertra, 2006). Due to participating in the development of the unmanned vessel Spartan Scout with the United States, Singapore has already made unmanned vessels in service to fight against international terrorist organizations and the pirates.

In 2010, Singagore Technologies Electronics launched Venus, a 9-meter USV at the Singapore Airshow 2010. To complement and meet the needs for users of USVs, the company is also demonstrating its in-house developed USV Simulator. The ST Electronics Venus USV is based on a composite 9m hull platform, integrated with Guidance Navigation Control (GNC), Electronics and Sensors Systems. ST Electronics has taken a modular design approach in the development of the Venus USV. The modular design concept envisages a common platform reconfigurable for multiple missions, through integrating different payload modules, offering a high level of mission autonomy. The Venus USV is intended to be adaptable in fulfilling the needs for a range of naval and security missions. The first prototype has already successfully completed its remote control and waypoint navigation trials and is now in its next development phase of mission payload integration.

In Japan, Yamaha developed two USVs, the Unmanned Marine Vehicle High-Speed UMV-H and the Unmanned Marine Vehicle Ocean type UMV-O (Enderle *et al*., 2004). The UMV-H is a reworked design based on a high-speed powerboat hull that enables it to move on the water and make mobile observations. Powered by a water jet, the UMV-H is 4.44m long and has a top speed of 40 knots. A GPS mapping navigation system enables the UMV-H to cruise a preset course operated either manually with a two-person crew, autonomously over a pre-programmed course with up to 100 navigational co-ordinates, or be driven by means of an extended underwater camera and sonar. The UMV-H can also learn from example and teach itself to follow a course once run on manual navigation.

At a length of 4.44 m, the craft is small enough to be loaded on a small cutter, but large enough to accommodate all necessary equipment and instruments such as under-water cameras and sonar equipment. The UMV-O is an ocean-going USV with displacement hull. It is used primarily in applications involving monitoring of bio-geo-chemical, physical parameters of the oceans and atmosphere that put the long-distance capabilities of the vehicle to effective use. The first UMV-O “Kan-Chan” was delivered in 2003 to the Japan Science and Technology Agency.

3.3 Research on USV in China

In China, USV technology is still in the conceptual design phase. Comparing with US and many other developed countries, China needs to pick up many key technologies in USV fields (Shang, 2009). According to some reports, Shenyang Shin Kong Corporation and Harbin Engineering University have done some research in this field.

Shenyang Shin Kong Corporation， a subsidiary of China Aviation Science and Industry Corporation, introduced the conceptional unmanned boat XG-2 in 2006. The XG-2 USV could be used for anti-submarine missions. The communication between the USV and control station on the ground is via satellite communication. The vehicle is equipped with missiles and could be used as search and rescue vessel or patrol vessel in gulf and lakes. By changing the onboard mission modules, the vehicle can serve for a wide range of applications.

In addition, the Corporation developed the China's first unmanned vessel "Tianxiang One" to provide meteorology services for sailing competition of the Beijing 2008 Olympic Games (Liu and Liu, 2008). It is the first world application of unmanned ship in meteorology. The unmanned vessel "Tianxiang One" has a self-stabilizing system to stabilize the vessel while working in the high wave ocean environment. The USV is also equipped with reliable power system, which enables the USV traveling hundreds of kilometers as a weather explorer as long as 20 days in the ocean. It significantly increases China’s ability of responding to marine incidents, environment monitoring in the oceans and large lakes, and disaster warning. The hull of Tianxiang One is a 6.5 meters long carbon fiber hull. It has many cutting-edge technologies including smart driving system, advanced radar system, satellite communication system, image processing and transmission system. The vehicle can perform autonomously or be remotely controlled by operators located at ground station. When performing autonomously, the vehicle could follow preprogrammed routes in the predefined search area while avoiding obstacles on the way. Fig. 4 shows Tianxiang One USV in mission.

Fig.4 Tianxiang One USV

Another major player of USV research in China is Harbin Engineering University. The Science and Technology on Underwater Vehicle Laboratory of Harbin Engineering University has accumulated rich experiences in the field of underwater robotics. Currently, the laboratory is doing the concept design of unmanned surface vessel and preliminary design of the hull of USV (Xu *et al*., 2006).

4 Challenges and Possibilities

Unmanned air, ground, and undersea vehicle programs provide an extensive (and growing) technology base available for USV development (Niu *et al*., 2008). This includes secure, wideband, line-of-sight communications, a variety of ISR sensors, and advanced command and control systems. Existing hydrodynamics, structural, propulsion, and electro-mechanical subsystem technologies are adequate to satisfy the requirements of the next generation of USVs. Despite having all this technology available, we still need to make improvements in the following four areas.

4.1 Intelligence

Since USVs need to navigate safely to complete certain tasks in a variety of marine environment, especially when it is beyond the sight and remote control does not work, the vehicle must be able to operate independently of constant operator supervision. The USVs must be able to detect environment, identify targets, avoid obstacles, autonomously plan paths, and autonomously accomplish the mission. The use of a USV presents potential risk to the safety of others and loss of property. The level of current USV technology requires constant supervision by operators to ensure avoidance of all obstacles. One of the more difficult issues related to autonomy is operating in a highly dynamic environment with other vehicles operated by humans. Humans are capable of generating some highly unpredictable behaviors. Therefore, an autonomous vehicle must be flexible enough to deal with unpredictable events or situations and also agile enough to respond quickly to changing conditions. So for the truly high-speed intelligent USVs, intelligence is the most basic feature as well as the greatest difficulty.

4.2 Control

One of the key technologies of the USV is control technology. We need to make more efforts in this field to seek a breakthrough in the control technology of USV (Zhang *et al*., 2009). In order to achieve a high level of autonomy, we need to resolve the control problems in stability, navigation, collision avoidance, and vehicle recovering. Effective launch and recovery systems (LARS) are necessary for unmanned vehicles to efficiently conduct operations at sea. Moreover, it must be easy and practical to operate the USV. The operator should be able to control more than one USV with a brief training. In the future, USVs and other unmanned platforms will carry through joint operations, so it is important to design a robust command and control system to ensure fault-free operation of USVs over long distances for extended periods of time.

4.3 High stability

Because USV is unmanned, the hull movement is difficult to be controlled by the automatic control system in ruff sea conditions. Therefore, stability and anti-capsizing are big issues for USVs. The stabilization system of USV should be able to stabilize the hull to prevent excessive deck motion or capsizing and determine the optimal course and speed for the given wave, wind, and current environment. In the worst case scenario, the vehicle may get upside down, a device for recovering the vehicle back to normal is essential.

4.4 Cost reduction

In order to make USV widely applied in many fields, we must minimize the cost of the development and maintenance. Israel has already done some work to reduce the cost of USV. When developing the USV Protector, a large number of civilian products and technologies were used to reduce costs. However, the current domestic civilian products in China are difficult to meet the technical requirements of USVs.

China's research in USV field has just started. It is still in the remote control boat phase. Many key technologies such as system integration, intelligent control, and high-speed vehicle design are still in the research phase. In the true sense of the autonomous high-speed intelligent unmanned surface vessel technology, China is way behind Europe and the United States. Additionally, because of the export control of high technology products of many foreign countries, it is necessary to do some basic research in the intelligent high-speed USV field.

5 Conclusions

The greatest feature of intelligent USVs is the capability of independent operation, so it is very important to research how to improve the intelligence level of USVs. In recent years, some researches did some work to improve USV's intelligence, including intelligent architecture design, mission planning, sensing and environmental monitoring. Despite some achievements, there are still many problems to be resolved.

With increasing speed of USVs, new and innovative hullforms may be required to take full advantage of the fact that the vehicle is unmanned. It is different from the traditional drainage-type vessel in movement. The dynamic lift, surface attack, and other issues that are only available to high speed movement, must be resolved.

Through the joint efforts of researchers around the world, it is believed that the development of the unmanned vessel (boat) will enter a new phase in the near future, the intelligence level of the unmanned vessel and the work it can be engaged in will go further, it can be applied widely both in military and civilian service.

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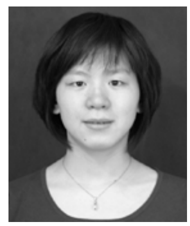
Ru-jian Yan was born in 1968. He is an associate professor at Harbin Engineering University. His current research interests include computer network, design of unmanned combat system. *etc*.

Shuo Pang received the M.S. and Ph.D. degrees in electrical engineering from University of California, Riverside, in 2001 and 2004, respectively. He is a professor at Harbin Engineering University and an associate professor in the Department of Electrical, Computer, Software, and System Engineering at Embry-Riddle Aeronautical University, Daytona Beach, FL. His current research interests include embedded control systems, robotics, and autonomous underwater vehicles.



Han-bing Sun was born in 1985. She is a student of Harbin Engineering University. Her current research interest is Unmanned Surface Vehicle design.

Yong-jie Pang was born in 1955. He is a professor at Harbin Engineering University. His current research interests include technology of naval architecture and ocean structure, autonomous underwater vehicle, etc.

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