NIX USV platform for precision track and trail of UUV platforms

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Abstract: This paper will discuss development work for a Navy unmanned surface vehicle called NIX for its use in multi-platform collaborative autonomy for S&T development efforts. The NIX platform is an 80" long by 40" wide M-Hull design. The M-Hull concept includes two full-length slats in its design which provides enhanced inherent tracking stability. Currently, the NIX is being outfitted with an optical imaging receiver to support high-resolution bottom imaging when paired with an unmanned underwater vehicle (UUV) that is outfitted with a laser illuminator. Together, the NIX and the UUV will form a complete bistatic laser imaging system. The bistatic imaging architecture is optimized for use in multi-platform collaborative autonomy. Precision tracking within a specific conical volume of the UUV is critical for optimal performance of the imaging system.

Keywords: USV, UUV, track and trail, bistatic, laser, optical, imaging

INTRODUCTION

USV, also known as Unmanned Surface Vessel, refers to any type of boat that operates on the surface of the water without a pilot and passengers on board. These types of vessels are remotely controlled by radio waves or autonomously controlled with pre-determined missions that are configured before the vessel is released. USVs are typically equipped with a wide variety of sensors for scientific research or ISR (Intelligence Surveillance Reconnaissance) missions. The NIX platform is a new state-of-art USV that offer exceptional stability, long durations, and a large payload compartment that can accommodate a wide variety of payloads. The platform is currently under development efforts and is being funded by NAVAIR/ONR SBIR.

NIX CONSTRUCTION

The NIX platform consists of five major systems:

1. Mechanical system
2. Propulsion system
3. Electrical system
4. Control system
5. Payload system

Mechanical system: The unique M-hull shape of the NIX USV platform provides enhanced inherent tracking ability. The hull consists of two long slats along each side and a flat transom that accommodates two pump assemblies. This type of design also provides higher efficiency. An M-hull vessel generates bow wave like any other boat. However, it recaptures this wave immediately with its rigid side skirts, forcing it to spiral through the hull's planing tunnels. There, it mixes with in-rushing air to create a cushion that pushes the hull higher out of the water, creating hydrodynamic and aerodynamic lift, which reduces drag and increases speed [1]. In addition, two sets of anodized aluminum rails are present in the design, one set in each of the slats. These aluminum rails provide a rigid base, which is necessary for installing equipment that requires precision mounting. The hull is manufactured using carbon fiber material to achieve two main goals: increase strength and reduce weight.

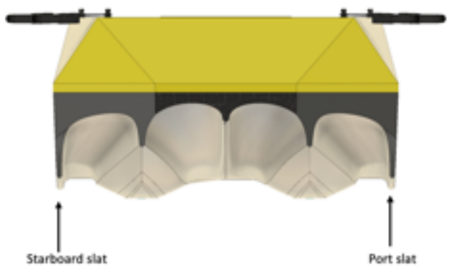

Figure 1. NIX USV Front View

Figure 2. NIX USV Side View

The top, or deck, consists of a squared-shaped design along the sides with a slight angle on the front to reduce air drag while the platform is navigating. Unlike the hull, the deck is manufactured using a slightly heavier fiberglass material. Due to the high conductivity properties of carbon fiber material, RF signals do not pass through it easily. Therefore, a fiberglass material was chosen for the top to enable wireless RF communications with the USV. Also, the deck has two waterproof access hatches, one located in the transom area that provides access to control electronics, propulsion system, and batteries and another one located in the front compartment that provides access to the payload section.

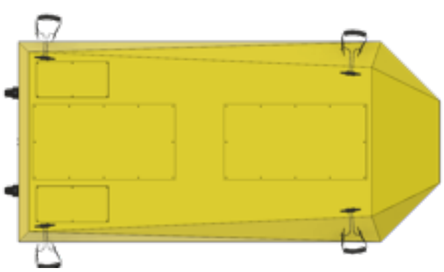

Figure 3. Top view of NIX USV

Propulsion system: Most electric high-performance unmanned vehicles such as drones utilize brushless motors due to their efficiency and high reliability. The use of brushless motors has allowed current platforms to outperform others by increasing operational time due to high efficiencies and lowering life cycle costs with higher reliability and lower maintenance requirements. The NIX platform utilizes two 10KW anodized brushless motors that can propel the platform at speeds of up to 30 knots. These motors are connected to a pump assembly through a stainless-steel shaft and coupler assembly. The platform's propulsion system is very similar to that of a jet ski.

1. Water enters a chamber located underneath the pump assembly
2. A high-efficiency brushless motor transfers the power to the pump utilizing a direct drive shaft
3. A propeller located inside the pump pushes the water through the nozzle at high pressure
4. The nozzle is attached to an arm that can be controlled when the platform requires to steer left or right

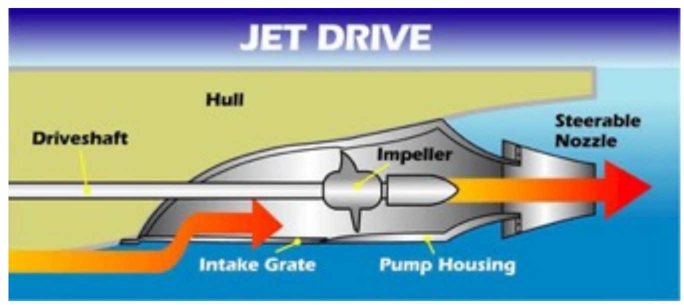

Figure 4. Jet drive propulsion system

All the components, with the exception of the brushless motor assembly, are manufactured from composite materials. By doing this, a substantial reduction in weight is accomplished and saltwater corrosion is avoided. Due to its size and M-Hull shape of the NIX platform, a dual propulsion system was installed, one in each of the two slats. This allows for quicker response, faster acceleration, and higher control when performing a tracking mission. The propulsion system can sustain high speeds for long durations when necessary, although when tracking UUV systems a speed of 6 knots or lower is most likely required. In addition, the use of this high-efficiency electric propulsion system reduces the amount of noise and vibrations experienced by other hardware installed in the aluminum rails.

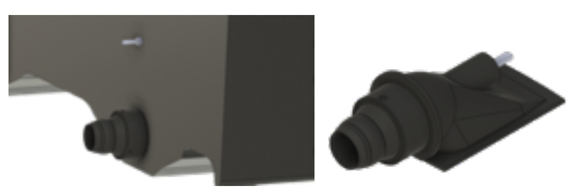

Figure 5. NIX Pump assembly and installation

Electrical system: The NIX platform is a fully electrical USV that utilizes LiPo (Lithium Polymer) batteries as the only energy source. These types of batteries are characterized by:

1. High energy density
2. High discharge rates
3. Fast charging
4. Small form factor
5. Low weight
6. Long life span

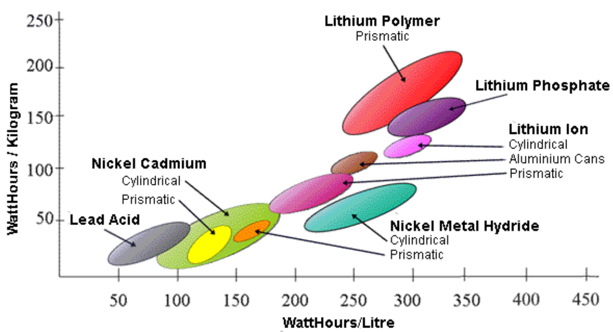

Figure 6. Battery chemistry comparison

The battery system used in the track and trail effort consists of a 3.3KWh configuration with a nominal voltage of 50V. The power system provides two 250W payload power rails with nominal voltages at 12V and 24V. One of the main advantages of a fully battery-powered electrical USV is that it provides a clean energy source to all payloads and doesn't generate electrical noise that can cause interference or poor measurements in the payload's ability to function.

Control system: The control and communication system in the NIX platform is responsible for commanding the motors to provide thrust in both exit nozzles and adjust the servos to allow the platform to maneuver and maintain or readjust its course. The control system consists of the following components:

1. Electronic Speed Controllers (ESCs) are the electronic components responsible for monitoring and varying the motor's RPM to maintain a desired speed. These are located in a dedicated module designed to handle high-currents, high-voltage, and has the ability to be water cooled to maintain high efficiency.
2. Servos are necessary to control the steering nozzle and provide left/right control. The vessel has two servos, one mounted by each pump assembly, secured along the aluminum rails.
3. The autopilot controller is the main motherboard of the platform and it is responsible for controlling the ESCs and servos when the USV engages in autopilot mode. It interprets inputs from multiple sensors such as GPS and an inertial measurement unit (IMU) as well as the main radio controller (RC) receiver to make its decisions. This system also has its own dedicated module which is located in the port side of the USV.
4. High bandwidth wireless ethernet radios provide a link between the user and all payloads located in the NIX. It also provides a line-of-sight connection between the autopilot and main ground station. This system's module is located in the center of the NIX, right next to the ESC's module.
5. The RC receiver provides the main control link to the user. It operates on a 2.4GHz commercial line and it takes priority over autopilot control. The receiver is located inside the main distribution board module.
6. The main distribution board takes commands from the autopilot motherboard and RC receiver and it routes the appropriate signals to the ESCs and servos. The main distribution board is located in the starboard side of the NIX, in-between the battery module and motor.

The individual modules communicate with each other utilizing a single harness that runs across the NIX's hull.

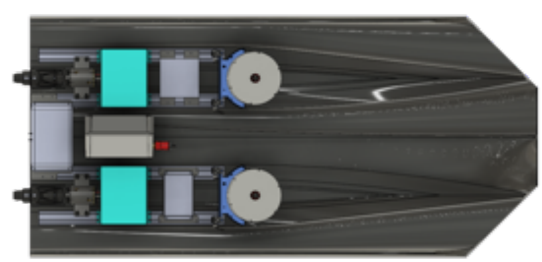

Figure 7. NIX modules arrangement

Payload system: The development of smarter sensors and new technology has introduced a higher need for high performance unmanned vehicles that can deploy these technologies in the field to perform specific tasks or gather data. The NIX platform is a vehicle designed specifically to be capable of carrying a wide variety of payloads, providing a full waterproof enclosure, low-dielectric top, and low-noise electric system as a base model. Depending on customer needs, additional capabilities can be added such as a long duration hybrid system, satellite connectivity, and basic echosounders for sonar mapping; none of which compromises the payload compartment. For the effort covered in the track and trail work, the NIX platform is being modified with a set of clear windows located on both sides of the USV, facing the water. These windows are specifically designed to capture a light reflection generated by an underwater vehicle. In addition, the platform carries the electronic equipment necessary to process these light signatures and send the data to the user utilizing the high-bandwidth wireless system installed in the platform.

UUV DATA COLLECTION

Unmanned underwater vehicle, or UUV, refers to a type of platform that operates underwater without a pilot or human occupant. In many occasions it is desired to have fast or ideally real-time transmission of data to the command and control station onshore or a mothership. Some examples of time-sensitive data are surveillance, inspection and monitoring missions where operator interaction is needed to analyze the data, get situation awareness, make decisions, and execute tasks based on analysis of the data [4].

When at the surface, UUVs often use radio links for command, control, and data transfer, but when underwater the radio links do not function, and the vehicle relies on its internal autopilot to guide it based on a preprogrammed mission. Typically, underwater vehicles are equipped with these communication payloads [4]:

- Radio frequency Wi-Fi: short range communication system used at-sea, on deck and in the lab.
- Iridium SATCOM: low data rate near global communication method
- Two-way acoustic telemetry/modem

This also means data collected by the UUV can only be accessed in three different ways [5]:

- Access the data by physically connecting to the UUV after recovery
- UUV resurfacing and broadcasting data via satellite, usually very slow process
- Data transmission via an underwater acoustic communication network of static and/or mobile nodes until it reaches a surface platform.

Often times, during a mission, a UUV will communicate with a surface platform using an acoustic link. This link is very low bandwidth and is used only to monitor basic UUV telemetry, although the user at the surface can use this link to send updates to the UUV to change the mission if necessary. Acoustic signals propagate as pressure waves, whose energy absorption limits the available bandwidth. Multipath propagation that causes frequency selectivity and random time variation, and Doppler effects that occur due to the low speed of sound (1500 m/s), create additional challenges. As a result, existing technology provides bit rates on the order of several kilobits per second for transmission over distances on the order of several kilometers [6]. In many cases, the acoustic link is deployed from a manned vessel that must maintain a certain distance from the UUV in order to establish a stable link or by utilizing a stationary buoy that can communicate with the UUV when within range.

HIGH PRECISION TRACK AND TRAIL NEED

A manned platform is a very capable way to track and trail a UUV, but it is not practical and does not scale well. A manned platform is expensive and being on the water puts human lives at risk. UUV missions can be very long, so shift work may be necessary, increasing the number of operators needed on that surface vessel, necessitating a larger vessel with facilities to support the people aboard. To alleviate the safety and cost issues with a manned platform, a stationary buoy, equipped to communicate with the UUV and relay information via satellite or radio links is one solution. Unfortunately, a buoy is stationary, and so it cannot adapt to any changes in the UUV mission. An unmanned surface vehicle is one solution that combines the mobility of a manned platform with the autonomy of a buoy. It removes the human element and remains capable of tracking and adapting to the UUV.

As part of the track and trail effort, the NIX platform incorporates an acoustic link system that it uses to communicate with the UUV. This includes telemetry updates from the UUV, which the NIX uses to adjust its own course and speed to match the behavior of the UUV. The NIX performs the acoustic transaction, which consists of sending the UUV a request for telemetry, receiving the telemetry from the UUV, interpreting the data, and adjusting its own control parameters, without any human interaction. The main benefit of using this approach is:

1. The NIX USV can follow the UUV autonomously
2. The USVs communication range is greatly expanded with the addition of a satellite radio
3. If the USV is within radio range of a manned vessel or shoreline, users can utilize the USV's high speed radio link to access sensor data in an almost real-time manner

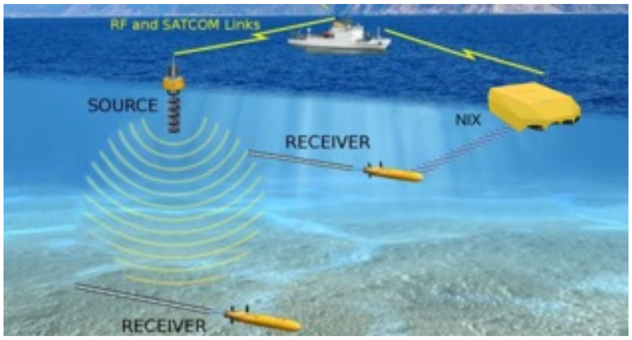

Figure 8. Underwater communication

BISTATIC LASER IMAGING

Imaging is an important technology in defense and commercial underwater applications for the task of object identification. Currently, SONAR systems dominate the maritime imaging technology sector since it is a mature technology and sound propagates for long ranges in water. The downside of SONAR is its inability to match the spatial resolution of optical systems, such as CCD cameras. Although cameras are capable of collecting very high-resolution imagery, their performance quickly deteriorates in degraded visual environments (DVEs) such as turbid coastal waters and harbors. This is because particulates in the water scatter the light, blurring and reducing the contrast of the collected imagery. Laser systems have been developed at NAWCAD Patuxent River, and at other institutions, to mitigate the scattering problem in DVEs [8]. Laser systems also add the advantage of producing three-dimensional imagery [10], which is very important when looking for low-contrast targets that are partially covered with sediment or biofouling.

In a conventional laser imaging system, the laser illuminator and optical receiver are constrained to being on the same platform. This usually leads to a sensor size, weight, and power (SWaP) that is not compatible with small autonomous vehicles. Additionally, if a conventional laser imaging sensor is used with a UUV, the data collected would also be stored on the UUV. Since the acoustic link does not have the bandwidth to transmit this kind of data in real-time, the data will not be recovered until the UUV surfaces and returns. Even after data recovery, typically a long post-processing step has to occur before getting a useable product. This delay from mission deployment to useable product is problematic in maritime environments that are constantly changing. An object found a few hours ago may have shifted by the time the data is processed, posing a problem for anyone who has to reacquire that object later. Having the ability to see the UUV's data in real time would shorten this turnaround time and improve the location accuracy of objects for downstream missions.

The bistatic laser imaging approach allows the user to view the sensor data in near real-time by removing the single platform constraint. The illuminator and receiver are placed on separate, independent platforms and each sensor subsystem's SWaP is individually optimized for the platform on which it is installed. The laser can be engineered to fit into small UUVs and the receiver can be placed on another platform [11][12]. As depicted in Figure 8, when the receiver is on a surface platform, like the NIX, the light reflected from the scene is collected at the surface and the resulting imaging data can be relayed via a high-speed radio link to a manned platform further away. This allows the data to be processed as it is received, increasing the speed at which it is available for use in subsequent decision-making.

Optical systems typically need very precise alignment to function well, but the bistatic system uses optical scattering to its advantage, decreasing the need for extremely precise alignment [9]. That being said, the bistatic system is still limited by optical absorption in water, and benefits from having the receiver in close proximity to the illuminator. The NIX's design lends itself to precise track and trail of a UUV, making it a good candidate to house the receiver portion of the bistatic laser imager.

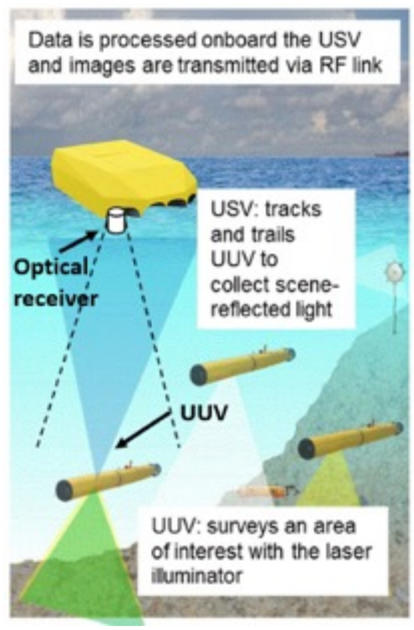

Figure 9. NIX capturing reflection from bistatic laser imager

SUMMARY

The current development of the NIX USV platform under NAVAIR/ONR SBIR funding will provide the ability to obtain real-time data acquisition of UUV systems outfitted with the emerging technology of bistatic laser imaging. The NIX is being outfitted with optically-clear, downwardfacing windows and the optical receiver subsystem of the bistatic laser imager this spring. The track and trail capabilities will be tested with a UUV in late summer this year, with the bistatic receiver hardware installed. Incorporating the laser illuminator into a UUV and testing with the NIX is scheduled for 2021.

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