

Article

Quantifying Efforts to Mitigate Interference between an Unmanned Surface Vessel and Starfish 990F for the Identification of Underwater Features in the Littoral Zone

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Abstract: Effective testing of new sensing technologies requires realistic yet deterministic test ranges. The advancements in customizable, adaptive unmanned surface vessels (USV) have contributed to the increasing presence of USVs completing maritime site characterizations of test ranges using commercial off-the-shelf (COTS) sensors such as the Tritech Starfish 990F side-scan sonar. This paper aims to present recommendations for the electromechanical integration of a COTS sonar system onto a capable USV through passive techniques such that underwater objects within the littoral zone of Sand Island, Hawaii, are characterized. Results demonstrated a 49% improvement in the sonar images. Therefore, designers are recommended to fully isolate the sensing system from the USV, physically separate the sonar and USV components, and to establish a baseline performance for the system prior to operation.

Keywords: side-scan sonar; unmanned surface vessel; interference; perceived brightness



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1. Introduction

The ethical detection, identification, and responsible handling of unexploded ordnance (UXO) affects a variety of coastal communities. In the State of Hawaii, UXOs pose environmental and social concerns to the public due to the risk of the UXO unexpectedly detonating or releasing harmful chemical compounds into the surrounding waters [1–3]. Finding UXOs in the real world is challenging [4]. Ocean life, biofouling, rocks, mud, sand, and coral (to name a few) obscure the UXOs characteristic silhouette. New locating and identifying technologies, which typically utilize optical or acoustical perception, that overcome these challenges are continuously being developed and improved [5–9]. These new technologies must be appropriately tested and validated. A munitions test range (MTR) provides a controlled environment to safely and fully test new technologies. “Successful” new technologies must locate and distinguish UXO from natural objects and other man-made, non-UXO objects in an actual ocean environment [10].

Testing at an MTR involves (1) the diverse deployment of inert objects at specified locations (i.e., setting up the range), (2) independent operation of the visiting technology (i.e., testing the new technology), and (3) post-test validation (i.e., decide if technology is ready for the detection of actual UXOs). The work presented here enables the setup of an MTR, which requires the accurate deployment of inert objects that include mock UXO items and man-made, non-UXO (i.e., clutter) items. A mock UXO, or seed, takes the form, weight, and material properties of a traditional UXO, without the potentially dangerous interior. Clutter items serve as a red herring for mock UXOs and aim to trick the technology being tested.

Although the MTR coordinator specifies the type and *desired* location of the deployed objects, due to wind, ocean currents, waves, and other factors existing, technology must be used to determine the *actual* deployed location of all objects. This setup verification step produces a ground truth map, which serves as a reference for evaluating the results

produced by the new technology being tested [11]. Unmanned surface vessels (USVs) provide an opportunity to improve both the efficiency and the accuracy of the MTR setup process [11–13]. However, leveraging USVs for this task requires that the existing sensing technology used to create the ground truth map be tolerant to potential interference from the components of the USV platform—particularly electric propulsion, which is more prevalent in USVs than manned combustion-based vessels [14].

The work described in this paper illustrates a method to quantify the interference in a side-scan sonar system towed by a USV platform by evaluating the average RGB luminosity of sections within the sonar image as captured and displayed by the sonar software. The luminosity value is then used to quantify various interference mitigation efforts.

2. Motivation

During initial testing, the direct integration, i.e., simply mounting the sonar to the USV, between a side-scan sonar and an existing USV did not yield a sonar image that allowed users to identify underwater features, as shown in Figure 1. A ladder-like group of four mock UXOs was deployed 5 m below the surface on a sandy bed. The side-scan sonar software was able to clearly display two objects. The other two mock UXOs in the ladder were obscured by bright bands of electrical interference that correlated with the energization of the USV's electric propulsion motors.

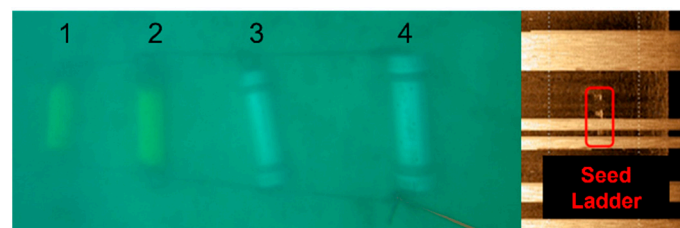


Figure 1. Left: photograph of a deployed ladder of mock UXOs comprised of two acrylonitrile butadiene styrene tubes (1 & 2) and two steel pipes (3 & 4). Right: the resulting image created by a side-scan sonar directly integrated onto an USV without any interference mitigation. The ladder structure is mostly obscured by interference in the sonar image.

The results of the initial testing suggested that the electrical interference produced by the thrusters of a common USV overwhelmed a common side-scan sonar system without further mitigation. This was discovered by an additional test that evaluated if the interference appeared due to the proximity of a strong electric motor or the electrical and electronic interoperability to a battery-powered USV as shown in Figure 2.

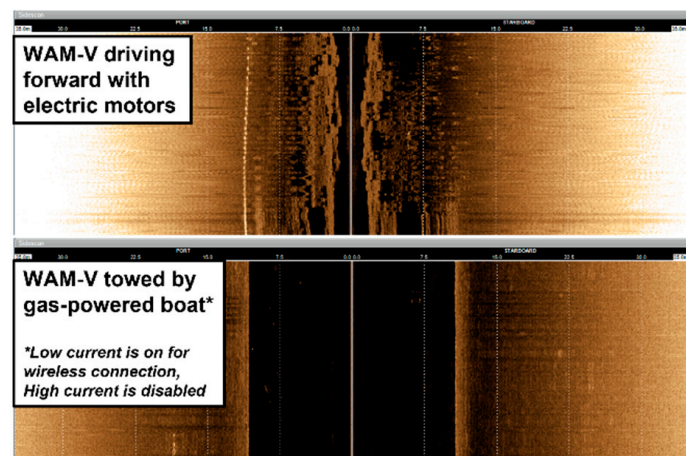


Figure 2. Comparison of the observed return of the side-scan sonar system aboard a USV operating under its own propulsion system and with the same USV being towed 25 ft behind a gasoline-powered research vessel.

The significant qualitative difference seen in Figure 2 was the driving motivation that prompted us to investigate quantitative approaches for determining the interference introduced by towing an electrically powered sonar system with an electrically propelled surface vessel.

3. Materials and Methods

The primary technologies being evaluated in this paper are the Tritech Starfish 990F side-scan sonar, the MRSUH USV, and the wave adaptive modular vessel (WAM-V) USV from Marine Advanced Robotics. Tests were conducted in one of two locations:

1. The littoral zone of Sand Island located on Oahu, Hawaii. This area features a coral and sand substrate at depths of 3–10 m. The testing area for these technologies is shown in Figure 3.
2. The ground floor foyer of Holmes Hall located on the University of Hawaii campus. This is a shaded area that allowed for in-air testing of the electric propulsion systems.

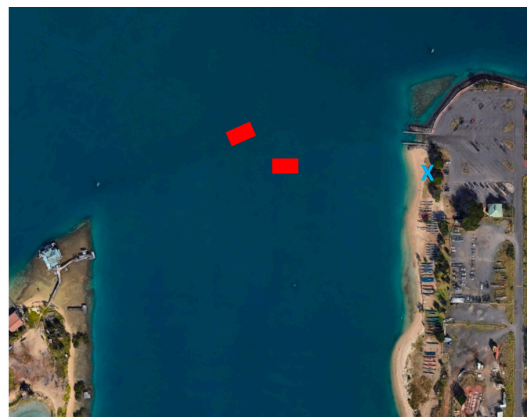


Figure 3. Satellite map of Sand Island. The red boxes represent the approximate locations where the mock UXO ladder was deployed. The blue X represents the approximate location of the ground station.

An overview of each technology and the methods for evaluation are presented in the following subsections.

3.1. Materials

Firstly, the Starfish 990F is a low-cost side-scan sonar that utilizes a 1 megahertz (MHz) acoustical compressed high-intensity radar pulse (CHIRP) to develop high-resolution images [15,16]. The sonar transducer is mounted to the underside of MRSUH or the WAM-V with an 80/20 aluminum frame. Sonar software allows operators to configure settings for the visualization of data, starting and stopping recordings, and exporting a comma-separated value file for postprocessing. One of the key features of this software is the plotter window. This window depicts the CHIRP returns as an instantaneous snapshot of the surface below the transducer as a function of time and may be altered to display data through a variety of color palettes. Due to the unmanned and remotely operated aspects of MRSUH and the WAM-V, Starfish 990F software was remotely configured, operated, and monitored remotely through a secure shell protocol.

Secondly, MRSUH is a small USV (~0.4 m) that was designed, manufactured, and is maintained and operated by the Renewable Energy, Industrial Automation, and Precision Engineering (RIP) Laboratory (Lab) at the University of Hawaii at Manoa. While it is limited in its payload-carrying capacity and maximum velocity, it allows for the rapid deployment and testing of various electromechanical techniques prior to fleetwide distribution. MRSUH is shown with the Starfish 990F in Figure 4.

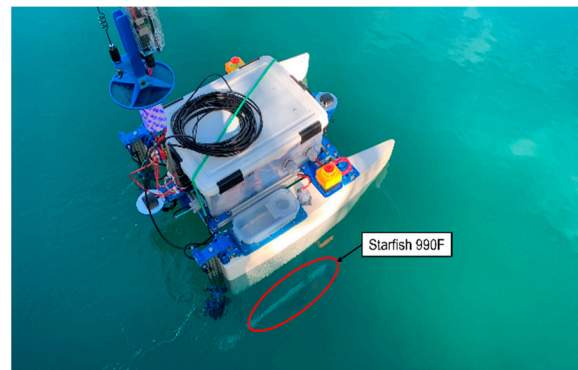


Figure 4. MRSUH equipped with the Starfish 990F under the vessel.

Thirdly, the WAM-V is a USV that is also maintained and operated by the RIP Lab. While the frame and hull were provided by Marine Advanced Robotics, the structural members, COTS electrical devices, and propulsion were implemented by members of the RIP Lab. The WAM-V is shown in a “fully loaded” configuration for MTR operations in Figure 5.



Figure 5. WAM-V equipped with Starfish 990F at the MTR.

3.2. Methods

A series of progressive efforts were applied to mitigate interference in the sonar. The efforts applied were as follows:

1. **Physical isolation:** The sonar transducer cable was physically routed away from the power and data-carrying cables of the MRSUH and WAM-V. The original placement of transducer cable was along pre-existing tie-down points—henceforth referred to as “cables near”. Mitigation efforts separated the tie-down points of the transducer and USV cables to be at least one cable-diameter of distance apart—henceforth referred to as “cables away”.
2. **Electrical isolation:** Power source and communications for the Starfish 990F were separated from the USV platform, and all physically connected paths between the systems were eliminated. The remaining interface was a wireless network that enabled remote operation.
3. **Human-in-the-loop interaction:** A user was involved in actively monitoring and adjusting the software display parameters to generate an image that allowed for objects to be detected and visually determined to be an object of interest. The original usage involved the launching of side-scan sonar software in the default plot settings with a manual starting and stopping of the recording.

To quantitatively measure the effects of the changes, the RGB luminosity or perceived brightness of sections within the plotter window was used. As was shown in Figure 1, the electrical interference produced a relatively bright return compared to the sand bottom.

Admittedly, “objects” also produced a bright return, but as seen in Figure 1, objects represented a small area compared to the noise [17]. Thus, we measured the brightness of each sonar image in specified areas of each image (red box in Figure 6). An image with more noise has a higher brightness. The images produced by sonar software were returned as color images. However, only the location and relative brightness contained any information. The color palette was simply a stylistic choice by the software operator. Thus, the perceived brightness was determined from the pixel RGB values [18]. The formula to measure the image brightness was based on the RGB values, as shown in Equation (1).

$$L = 0.2126R + 0.7152G + 0.0722B \quad (1)$$

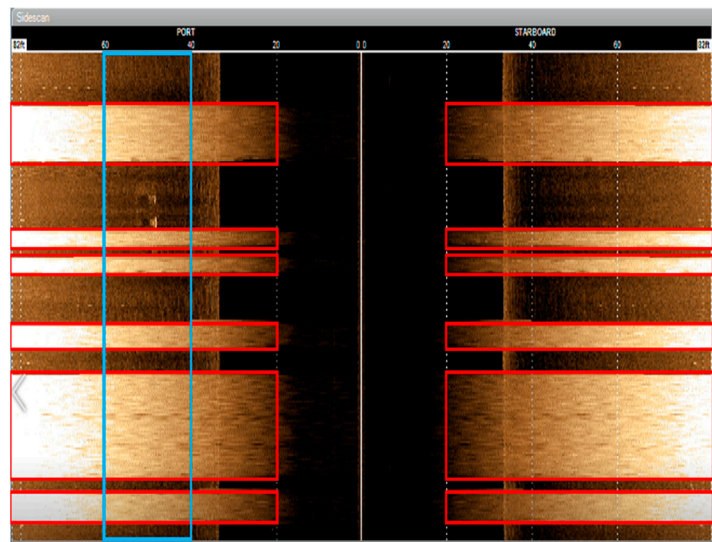


Figure 6. Reference image of Starfish 990F with intense banding from using an electric trolling motor. The red box represents the area of the image where the brightness was measured to quantify the noise in the horizontal direction. The blue box represents the area of the image where the brightness was measured to quantify the noise in the vertical direction. These same pixel areas were used in each image but only depicted here for clarity.

Retrieving the RGB values in the images was accomplished with functions built into the MATLAB Image Processing Toolbox [19]. These functions allow researchers to evaluate bands of bright returns by specifying bounding boxes for MATLAB to return. Two functions from the toolbox were used to retrieve the edges of the noise bands and extract the RGB values. The two functions are described as follows:

1. *impixelinfo*—returns the cartesian coordinate pair of the pixel location where the user’s mouse pointer is positioned over and the intensity of the pixel.
2. *impixel*—returns the pixel color values at specific pixel locations within a picture in terms of RGB.

Due to the large number of pixels that may be present in the plotter window, each band was averaged and then averaged once again to generate an RGB value for the image. Lastly, the image RGB value was used to calculate the perceived brightness as shown in Equation (1).

4. Results and Discussion

Figure 6 is the image produced without any mitigation and was used as the reference image to quantify any improvements. The reference images contained interference that completely overpowered the return of underwater objects, as shown in Figure 6.

Figure 6 was the result of retaining an electrical connection to the USV system, routing the transducer cable through the same tie-down points of the USV power and data cables,

and running side-scan software without adjustment. The perceived brightness of the image in the horizontal and vertical directions are shown in Table 1.

Table 1. Perceived brightness values for reference image.

Configuration	Perceived Brightness (Lumens)	
	Horizontal	Vertical
Reference	230.75	122.41

Reducing the brightness focused on using passive techniques that did not introduce additional components to the system. For each effort, a sonar image was captured with and without the physical separation of the cables and the perceived brightness of the bands were calculated.

4.1. Initial Mitigation

Initial efforts focused solely on the effectiveness of separating the transducer cables from the WAM-V system and did not use electrical isolation or software tuning to improve the sonar image. Tests were conducted with the propellers operating in air rather than in water. This resulted in the bandings shown in Figures 7 and 8 for routing near and away, respectively.

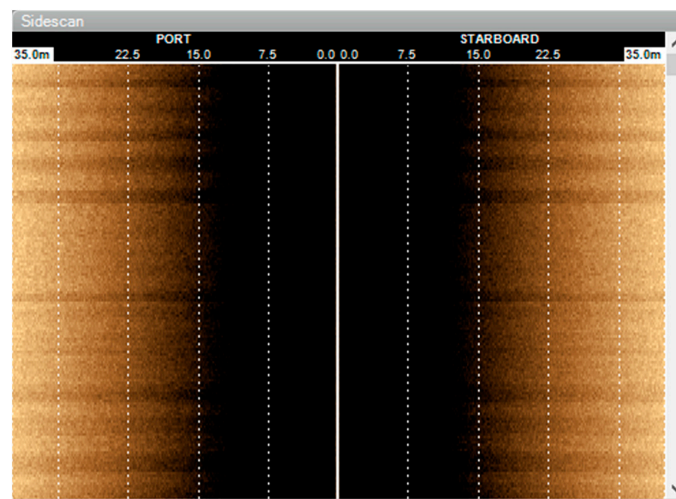


Figure 7. Sonar image with cables routed closely.

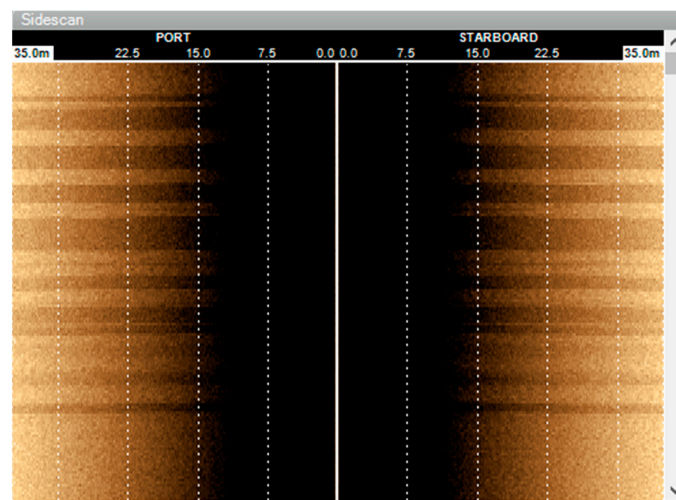


Figure 8. Sonar image with cables routed away.

Solely distancing the sonar cables from the WAM-V motor cables did not yield an observable improvement when compared to the reference image. Thus, the sonar system was completely disconnected from the WAM-V and software was accessed remotely. This resulted in Figures 9 and 10.

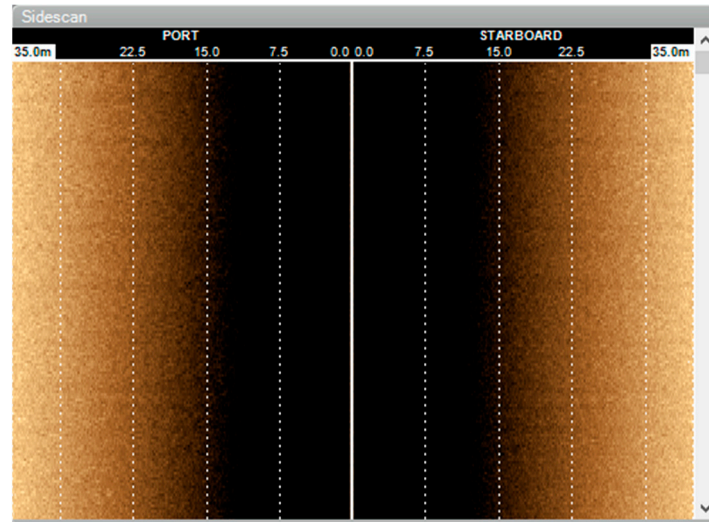


Figure 9. Electrical isolation with cables routed closely.

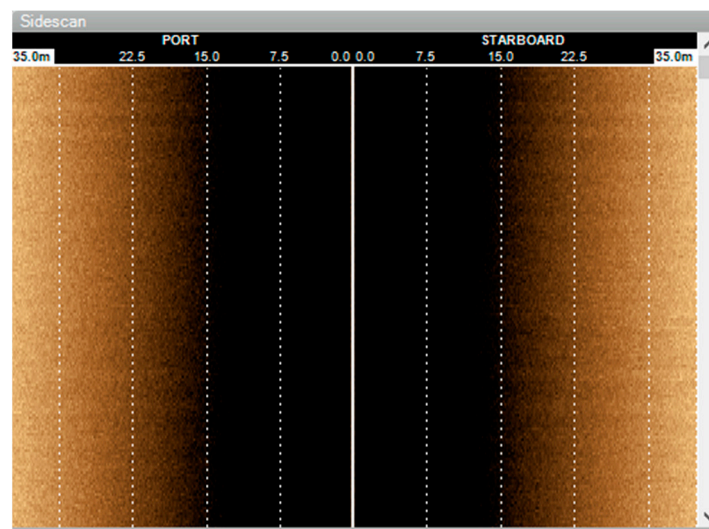


Figure 10. Electrical isolation with cables separated.

Comparing the perceived brightness in Figures 7 and 8 versus Figures 9 and 10 did not immediately indicate a change in the intensity of the banding. However, there was an observable difference between the reference image and the initial mitigation tests. Therefore, the perceived brightness of the sonar returns for the horizontal and vertical directions are shown in Table 2.

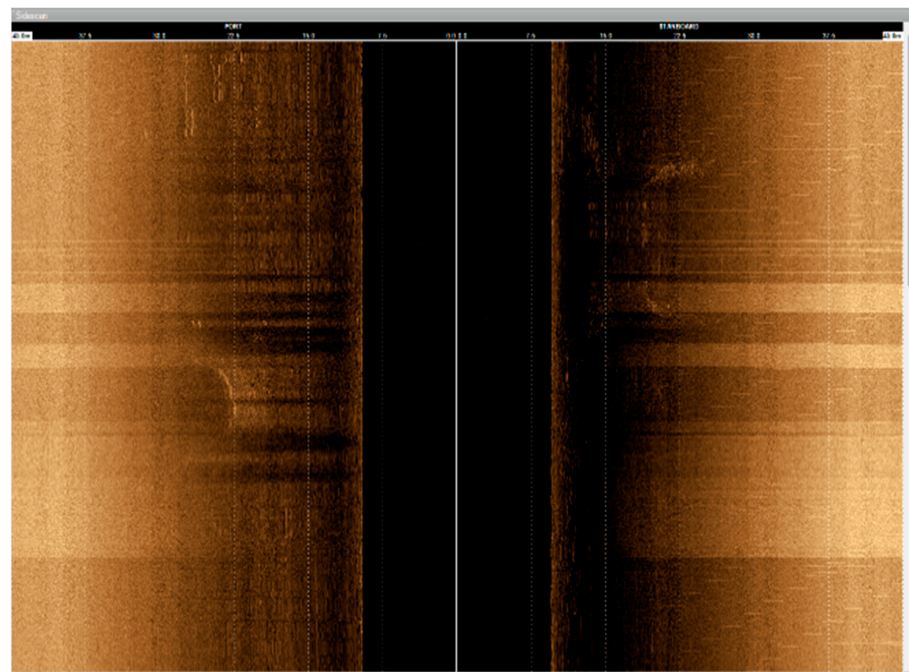
When compared to the brightness of the reference image, the electrical isolation and separation of the cables yielded the greatest improvement to the sonar image. However, this was attributed to testing the motors in air and did not represent expected operating conditions for maritime use. Implementing electrical isolation on the WAM-V would be a significant alteration to the WAM-V system and prompted preliminary testing with MRSUH to evaluate the feasibility and predict the performance.

Table 2. Perceived brightness for mitigation efforts.

Configuration	Perceived Brightness (Lumens)	
	Horizontal	Vertical
No isolation Cables near	217.01	122.52
No isolation Cables away	223.74	124.43
Isolation Cables near	225.83	127.99
Isolation Cables away	201.58	107.90

4.2. Scaled Isolation with Initial Tuning

The performance attained by electrical isolation, physical separation of cables, and the potential for further improvement in the sonar image prompted an investigation into the benefit of allowing a sonar operator to tune the settings of the plotter window using remote desktop protocols with MRSUH as the host USV. This configuration resulted in the sonar image shown in Figure 11.

**Figure 11.** Sonar image with initial human involvement in data collecting process.

An immediate improvement could be seen visually when comparing plots generated in the initial mitigation test and the scaled isolation test. The perceived brightness of the image for the vertical direction in Figure 11 was determined to be 77.42, a significant reduction. This proved to be promising for applications to larger vessels like the WAM-V. Therefore, the efforts applied to MRSUH were scaled upwards for testing on the WAM-V.

4.3. Full Isolation with Tuning

The final test to reducing the banding from the image used the cumulative effort of all previous tests aboard the WAM-V. This resulted in Figures 12 and 13 for electrical isolation, human-in-the-loop interaction, and routing cables near and away, respectively.

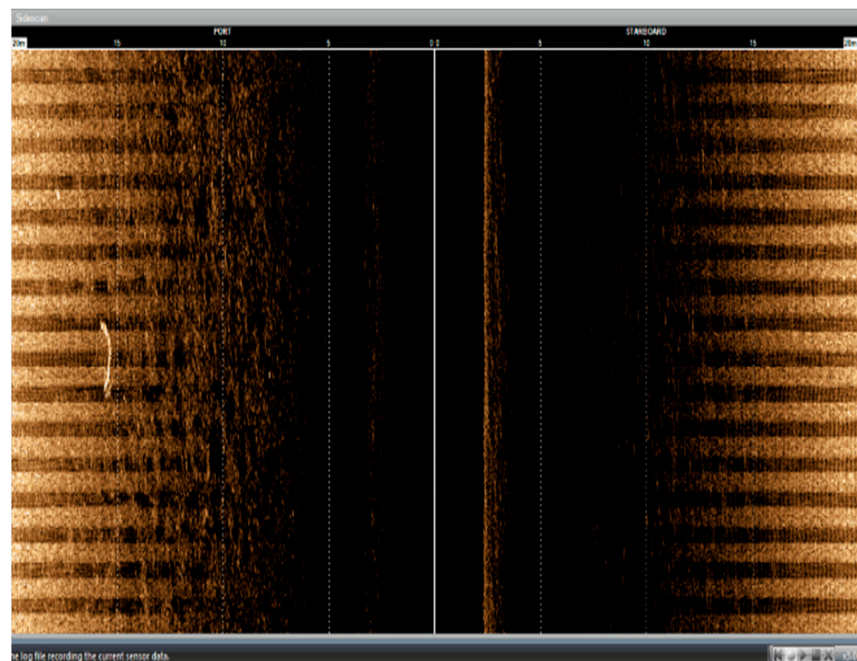


Figure 12. Sonar image with cumulative effort applied to the WAM-V with cables routed closely. (The object on the left is the same object as the object on the left seen in Figure 13.)

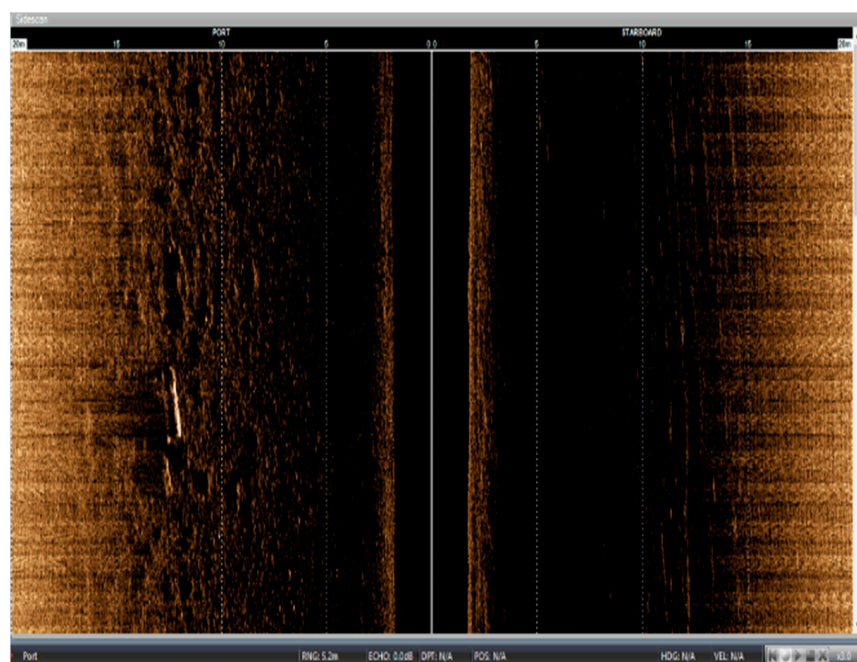


Figure 13. Sonar image with cumulative effort applied to the WAM-V with cables separated. (The object on the left is the same object as the object on the left seen in Figure 12.)

The WAM-V was driven along the same portion of shoreline at a set velocity. Errors between the images were attributed to environmental perturbations from ocean currents and wind acting on the vessel. The images were compared using a common feature. The resulting perceived brightness calculations are shown in Table 3 with respect to routing cables near and far, respectively.

Table 3. Perceived brightness for cumulative efforts.

Configuration	Perceived Brightness (Lumens)	
	Horizontal	Vertical
Total isolation Cables near Tuning software	116.46	44.09
Total isolation Cables away Tuning software	118.20	31.51

Following the significant decrease in the perceived brightness of the scaled isolation test, the WAM-V demonstrated a similar behavior in that the increased effort applied enabled more features of the seafloor and potential objects of interest to appear in the sonar image. While further efforts can be made to continue to improve the image, the detectability of underwater objects is now possible and is acceptable for identifying UXOs.

5. Conclusions and Perspectives

The initial implementation of a Tritech Starfish 990F and a WAM-V for identification of UXOs was deemed incompatible due to interference in the sonar image that obscured and overpowered the potential acoustical returns from underwater objects. This prompted an evaluation of the interfaces between the systems to ensure that the collected data did not require copious amounts of postprocessing in a secondary software tool with a focus on the electromagnetic sources. It was determined that the sonar image could be improved at the time of data collection by approximately 49% through the total electrical isolation of the sonar system from the host platform, the physical routing of the transducer cables away from the high-powered electric trolling motor cables, and an operator present to tune the software settings. Additionally, the mitigation techniques qualitatively improved a user's ability to see the details of detected objects in the sonar display window.

The methods presented would be appropriate to supplement in situ sensing systems that are in the development or testing phase. This includes experimental systems such as optical, electromagnetic, or acoustical technology found at MTRs. Furthermore, bathymetry systems aboard commercial and recreational fishing boats, research vessels conducting biological surveillance of ocean life, and search and rescue operations would benefit from mitigating interference. Addressing interoperability issues aboard electrically based USVs can provide an environmentally conscious, economically affordable, and operationally less risky alternative for unmanned surveillance applications. Further work may investigate the integration of other COTS technologies such as sub-bottom profilers with existing USVs to verify cross-platform performance, active filtering circuits such as a bandpass filter, or isolating materials such as shielding for conductors. Additionally, there may be other sources of interference that are inherent to unmanned surface vessels such as structural vibrations and acoustical noise from propellers that may require further mitigation from designers or system integrators.

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Conflicts of Interest: The authors declare no conflict of interest.

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