Contents

I. BACKGROUND

Almost 70% of the planets surface is covered by oceans. From energy generation to commerce, the oceans are an essential part of human society. However, this environment is known for its harshness on materials and equipment. Steel is greatly affected by exposure to salt water by corrosion. Since most ocean assets are constructed with steels, this creates an enormous maintenance cost for ocean activities. In the early 2000's the cost of corrosion was estimated a 3.1 percent of the USA's GDP [1].

A. *Underwater Marine monitoring*

To combat corrosion and the other degrading effects of the ocean such a marine growth, detection techniques and constant monitoring is required. Historically, this inspection process was accomplished with dive teams or, in extreme scenario's, dry docking. In recent times, underwater drones, remote operated vehicles (ROV's), and autonomous underwater vehicles (AUV's) have become the more popular method of inspection. The drone system currently available have several sensors, but tend to require manual control, lack certain sensor systems, and consist of specialized configurations [2] [3]. Figure 1 show an example of the current monitoring drones available.

Figure 1: Underwater monitoring drone from Blueeye Robotics [2]

Thus, there is a market for modifiable, autonomous, and efficient marine monitoring system

B. *Corosion monitoring*

Perhaps the most sought-after monitoring system for marine equipment is for corrosion. Aqueous corrosion is constant, inevitable, and can be difficult to detect [4]. Several methods exist to detect corrosion. For monitoring in an ocean environment, these methods must work in and out of water, and detect beneath protective coatings [5]. Additionally, these methods must be non-destructive in nature. The available technology which fit these requirements are summarized in Table 1.

Table 1: Available Corrosion Detection Technology

Type	Description
Ultrasonic	Use ultrasonic emission in the water to detect different hull compositions at close range [5], [6]. Example sensor feedback shown in Figure 2.
AI based Visual inspection	Use AI and other algorithms to enhance non-invasive sensing equipment detection [7]
IR heat mapping	Use thermal wave propagation and infrared temperature field measurements to observe variation in coated steel [8].
Laser profilometry	Non destructive evaluation of a material surface profile to detect and monitor corrosion [9]
Magnetic Flux Leakage	Use magnetic coils to induce and measure magnetic fields in material to detect defects [10]
Eddy Current Detection	Use a probe and inductor to induce and measure magnetic eddy currents in materials and identify defects [11]. Example use shown in Figure 3.
Electrode Probe	Test the resistivity of the material via 2 electrodes to test for corrosion. Note requires a contact probe.

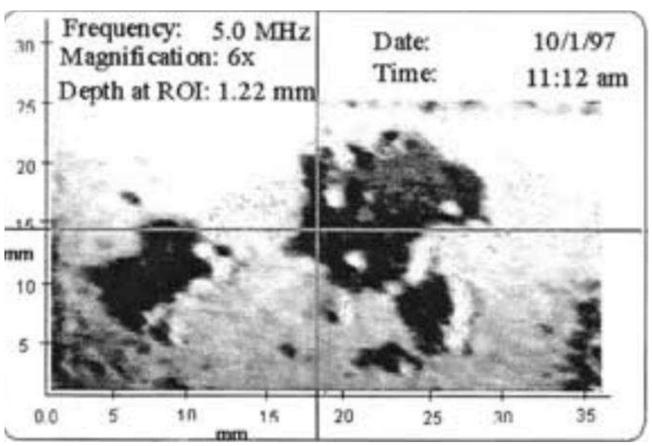

Figure 2: Ultrasonic reading from corroded aluminium plate [12]

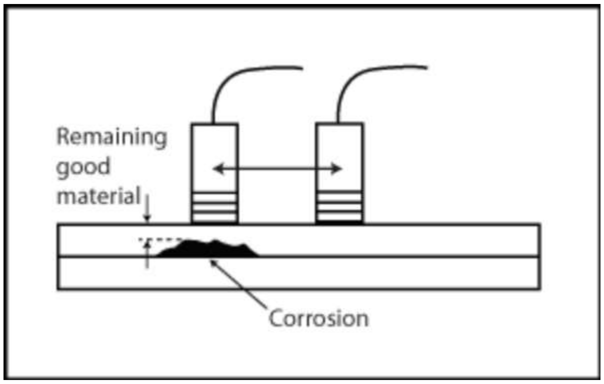

Figure 3: Eddy Current Corrosion Detection [11]

While these methods have proved viable for corrosion detection, work needs to be done to deploy this technology in an autonomous mobile system.

C. *Underwater Unmanned Vehicles*

Many underwater drones, ROV's, and AUV's exist for maneuvering inspection, and autonomous behaviour in the ocean. These range from remote operated tethered ROV's for focused inspection to magnetically attached hull crawlers [3], [13]. The broad selection of these devices more than meets the mobility needs of a static monitoring environment (such as a docked ship or ocean turbine). Therefore, a sensor and control system are needed for deployment on these vehicles.

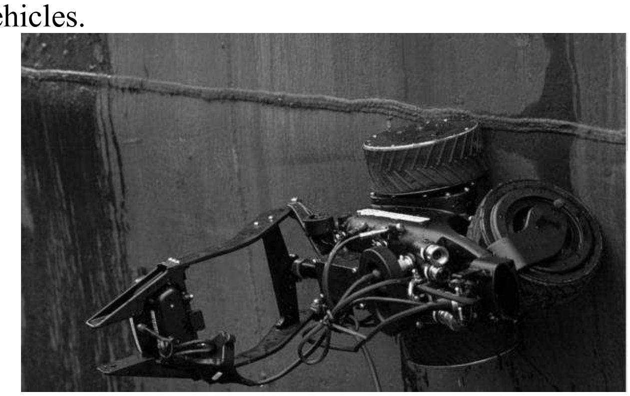
Figure 4:DT640 hull crawler detection system [3].

II. OBJECTIVE

A. *Problem*

An online (real-time), integrated, and low management marine monitoring system is needed to combat corrosion and other degradation effect on marine assets. Corrosion in early stages is difficult to detect due to surface coating and large exposed areas of marine equipment. The battle against corrosion is constant and expensive. With a real-time and automated detection system, ocean equipment may be monitored constantly. This will increase the odds of early detection and prevent the need for manual inspection of hulls, potentially reducing corrosion cost significantly. Underwater drone and drone swarm technology has the mobility and capacity to achieve these goals; however, there is a need for an adaptable sensor array and data analysis system which can be deployed using the available drone technology.

B. *Purpose*

The objective of this work is to design a commercially producible sensor package and control system which may be mounted to existing underwater drone technology. This system should scan marine assets for corrosion and damage, coordinate with multiple instances or devices, and analyze data for online display. Additionally, the system must offer an advantage over current marine monitoring technology in terms of speed, scale, and human resources.

C. *Aims*

The aims of this project are to develop a sensor package that:

1. Detects corrosion and defects on marine devices, vessels, and structures
2. Is configurable for specific needs and situations
3. Deploys and integrates on underwater drones, ROV's, AUV, and similar vehicles
4. Links with devices over a network to coordinate large scale monitoring
5. Does not require human attention while completing normal operation.

D. *Limitations*

The capabilities of the mounted vehicle will not be considered unless extreme needs present themselves because they are assumed not to be the limiting factor. Additionally, the vehicle software interface is assumed to be compatible with the final design. Detection through excessive organic or other debris will not be considered since this is variable and requires additional attention. The project will be based on previous work and literature. Additional analysis may include:

- Communication range and throughput
- Power requirements
- Sensor range and required clarity.

III. POTENTIAL SOLUTIONS

All solution must integrate a variety of sensors for corrosion, damage, marine growth, and visual inspection. Different user may have different requirements regarding the monitoring needed; thus, the package must be modular in nature and allow for custom configuration. Additionally, since available power and communications on drone systems cannot be guaranteed, the system must be independent of the drone itself.

The difference in solution presents itself in terms of deployment and use case.

A. *Harbor/Port Wireless Based Swarm (Drone Linked)*

One solution includes a fleet of drone equipped with the sensor package. In this solution the drone is slaved to the sensor package itself. Communication with a central control and movement commands are handled by the sensor package and relevant instruction relayed to the drone. Communication buoys would span the area of interest to allow for underwater wireless communication relay between the drones and a central control center.

The drones would systematically scan docked vessels, equipment, and structures with an algorithm to maximize scan time. Multiple drones may work squads to minimize the time each boat spend under inspection.

The drones would have a local hub to return for recharge and maintenance. Central control could also override the basic algorithm for high priority scans of vessels and objects.

B. *Ship based drone with wired package.*

This solution is for medium or large vessels which may set anchor outside of ports or harbors. This also applies to structure such as offshore oil rigs of wind turbines. These vessels would have one or multiple drones equipped with a sensor package. These systems would be tethered to the ships from which they may receive power and communication. The drones would be deployed at certain time when the vessel is stopped. They would quickly follow set paths to scan the entire ship and send data back to the command unit. This command unit may also be off site if a satellite or cellular network is available.

C. *Dedicated Tow Fish (Vessel Only)*

This device would operate constantly as the vessel is in motion. Attached to a tether, a tow fish would house the sensor package and adjust itself slowly across the entire hull of the ship. The tow fish would communicate and be powered through the tether connection to maximize deployed time. The difficulty of this method is obtaining accurate measurements with the disturbance of the vessel in motion. This system requires the ship to be in motion for positioning. Thus, it is not feasible on stationary platforms or structures.

D. *Large array position by multiple or large vehicle*

This system would attach multiple drones to a single, large, sensor package. The package would be positioned and moved under and along vessels and equipment and complete a scan in a few slow passes. The idea for this device is maximizing scan width and minimizing number of passes to decrease time for complete scan coverage.

IV. Initial Assessment

To select a potential solution, a weighted decision chart will be created with several criteria. These criteria will target qualities of a solution that will most fully meet the non functional requirements of the product. The primary non functional requirements of the product are

1. Product improves speed of detection for corrosion and other ailments on marine assets
2. Product can be configured for a specific task with different sensors and equipment.
3. Product reduces human resources needed to preform this task.
4. Product offer an advantage over current means of detection and monitoring through ease of use, quality of results, or quantity of scanning (total surface area scan per unit time).

A. *Criteria*

The following criteria will be weighted in order. The exact weights will be determined exactly when the discrepancy between the solutions is known.

The first criteria of this assessment will determine the types of viable sensing equipment for the solution. Should only some of the methods be usable (i.e. Only magnetic flux and eddy current), the ability of the system to fully detect and monitor will be examined closely. Since a requirement is configurability, a system that limits the available sensor will also receive a penalty.

The second selection criteria rates a systems autonomy and human resource needs. Should a system require a lot of attention it will receive a lower score than a one with lots of autonomy.

The 3rd criteria determines which solution would most effectively scan an entire vessel/platform completely once. This rating will help measure the potential speed of a solution.

The 4th selection criteria attempts to rate the scalability of a solution. This will consider the change in scenario from one to several vessels or platforms and compare the hardware, software, and maintenance requirements of the system.

The 5th criteria observes the potential operating times of the solution. If a solution only usable for small windows of time, it will receive a lower score than one available more of the time.

The 6th criteria will be a qualitative estimate of how easy the system may be to use and maintain. This may be subjective to the individual completing the assessment and thus will have the lowest weighting.

Using this chart, a primary solution will be selected an analyzed for feasibility. Additionally Criteria may be added if required.

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