University of Victoria
Faculty of Engineering

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Autonomous Corrosion Monitoring System for AUV Deployment

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In partial fulfillment of the requirements of the B.Eng. Degree

Letter of Transmittal

University of Victoria
Faculty of Engineering

Sept 6, 2022

Re: Autonomous Corrosion Monitoring System for AUV Deployment

Dear Monty Raisinghani:

Attached is the report “Autonomous Corrosion Monitoring System for AUV Deployment” in fulfillment of the ENGR 446 requirement at the University of Victoria.

This report aims to design a method for corrosion monitoring using autonomous underwater drones. The selected design uses available drone technology to deploy a sensor module in a networked swarm system. The focus of this report is the sensor module and, specifically, the embedded corrosion detection device on board.

Other design aspects of this system have a defined purpose but are not analyzed in this report. Once a prototype corrosion detection sensor module has confirmed this analysis, the requirements of the other components of the design will be better known.

Thank you for evaluating my submission. I look forward to receiving your feedback.

Regards,

Matthew Ebert, 4th year Computer Engineering Student
ENGR 446, Fall 2022 term
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GLOSSARY

PEC	Pulse Eddy Current
AUV	Autonomous Underwater Vehicle
ROV	Remote Operate Vehicle (underwater)
OTS	Off the shelf
IR	Infrared
HE	Hall Effect
PWM	Pulse Width Modulation
ADC	Analog Digital Converter
EC	Eddy Current
SMU	Sensor Module Unit
CU	Command Unit
RU	Relay Unit
MCU	Microcontroller Unit
PCU	Power Control Unit
Op Amp	Operational Amplifier Device

ABSTRACT

Corrosion is a main cause of degradation and decreased performance for marine assets. Mitigation of corrosion requires constant and costly monitoring and maintenance. Currently, most corrosion monitoring is preformed by human operators which take many billable hours and must be scheduled, causing downtime for the vessel. Consequently, there is a need for an online, integrated, and low management marine corrosion monitoring system.

The proposed system consists of sensor module units installed on available AUV devices, air-water communication relay nodes, and a centralized command unit. This solution would be implemented in a static environment such as a harbor or port. The drones would systematically and constantly scan docked and arriving vessels for corrosion. The collected data would be analyzed and stored for future use.

The primary component of this system is the sensor module which uses a pulse eddy current (PEC) detection array to scan for corrosion. The sensor module communicates with the command unit through the underwater network and the drone itself to coordinate activities and motion. The PEC array consists of an excitation circuit (controlled via PWM from an MCU), a differential magnetic sensor, and a filter amplifier circuit which sends an analog voltage to an ADC for analyses.

Simulations of these components and circuits were preformed to estimate the power and electrical requirements of the PEC unit. Other OTS components were selected to preform a power analysis of the sensor module which estimated a maximum power draw of 64.88W.

The main limitation of this system is the PEC array lift off requirement which is less the 4mm. This will require a mechanical solution for positioning the sensor of the target area. The main advantage of this system is the configurability and expansion potential.

Future work should focus on testing the PEC unit design and recording the potential feedback signals so that the final components may be selected, and a classifying model developed.

1 INTRODUCTION

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 through 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 at 3.1 percent of the USA's GDP [1].

1.1 Project Background

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 tend to require manual control, lack certain sensor systems, and consist of specialized configurations [2] [3]. Figure 1 shows an example of the current monitoring drones available.

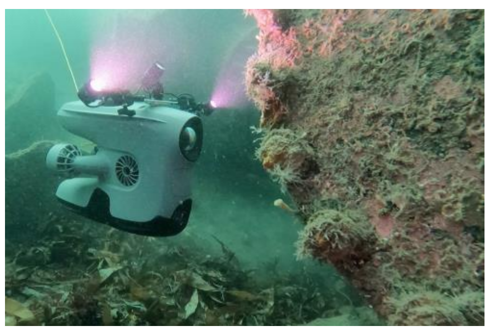

Figure 1: Underwater monitoring drone from Blue Eye Robotics [2]

1.1.1 Detecting 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, the method must work in and out of water and detect beneath protective coatings [5]. Additionally, the method 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].
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].
Electrode Probe	Test the resistivity of the material via 2 electrodes to test for corrosion. Requires a contact probe.

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

1.1.2 AUVs

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], [12] (Figure 1). 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, only a sensor and control system are needed for deployment on these vehicles.

Figure 2: DT640 hull crawler detection system [3].

1.2 Solution Requirements

An online (real-time), integrated, and low management marine monitoring system is needed to combat corrosion and other degrading effects on marine assets. Corrosion in early stages is difficult to detect due to surface coating and the large, exposed areas of marine equipment. The battle against corrosion is constant and expensive. With an 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.

1.2.1 Scope

The scope of this project is 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. Requires minimal human attention while completing normal operation.

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.

2 DISCUSSION

This section reviews several potential solutions. The harbor based wireless swarm solution is analyzed and recommended for implementation.

2.1 Potential Approaches

4 systems have been considered to meet these requirements.

2.1.1 Harbor/Port Based Wireless Swarm (Drones Linked)

One solution includes a fleet of drone equipped with the sensor module. In this solution the drone is secondary to the sensor module 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 in squads to minimize the time each boat spends 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.

2.1.2 Ship Based Wired Drone.

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 times 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.

2.1.3 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.

2.1.4 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.

2.1.5 Solution Assessment

To select a potential solution, a weighted decision chart was created with several criteria. These criteria target qualities of a solution that 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).

2.2 System Description

The **harbor-based drone swarm** approach was selected for analysis. This approach was determined to have the highest potential for success. The decision charts can be found in Appendix A. This solution consists of sensor module units (SMU) installed on AUVs, air-water communication relay nodes (RN), and a centralized command unit (CU). The sensor modules collect data and communicate with both the drones and central command. The relay's possesses transceivers for both radio and water communications that allow for underwater sensor modules to communicate with the land-based command unit (Figure 3). Below is an example deployment scenario.

A harbor purchases several drone systems and equips them with sensor modules. Relay devices are installed on piers to give communication coverage throughout the harbor. The relays communicate via Wi-Fi to the central command unit and use an underwater sonic/laser communication method to communicate with the sensor modules. The sensor modules use mesh network technology to increase the signal and range of underwater communications.

Directed by the CU, the sensor modules control their respective drones to systematically scan new and moored vessels for corrosion. All data is saved and processed at the CU. AI algorithms are employed on the new and archived data to enhance the detection capabilities of the system. A few employees monitor and review the finding of the system. Harbor members and boat owners pay a monthly subscription to receive regular scans and updates on the health of there hulls which pays for the system.

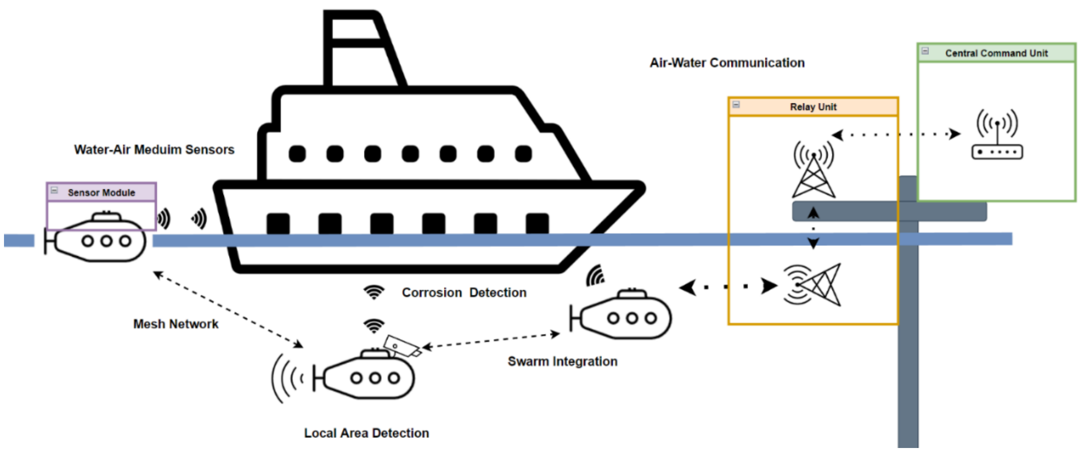

Figure 3: A sample deploy system using the sensor modules, relays, and CCU.

The primary device for this system is the sensor module. Underwater communications, AI algorithms, and corrosion data analysis are secondary to a working detection device. They also have been developed in other systems [13]. Consequently, the focus of this analysis is on the SMU and corrosion detection from an autonomous drone. Other aspect of the system will be considered in a later report.

2.2.1 Sensor Module

The focus of this report is the SMU. A preliminary design is shown in Figure 4.

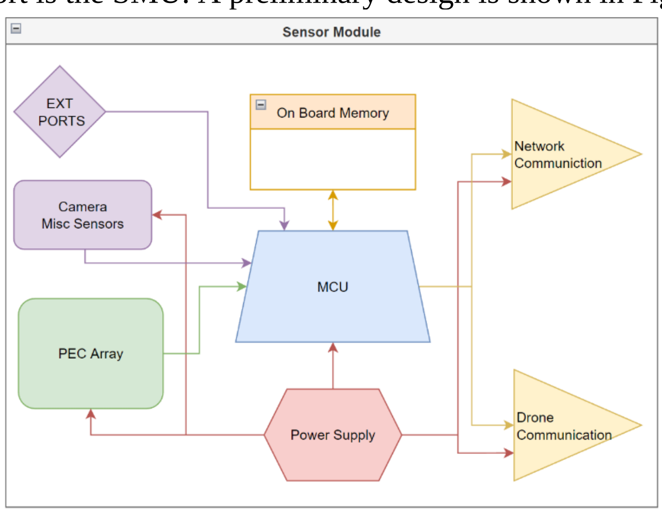

Figure 4: Sensor module system diagram.
**PEC: Pulse Eddy Current*

The MCU handles all processes within the SMU. Through 2 communication devices, the MCU can receive and send data with the system network and the drone itself. The MCU has external ports (EXT PORTS) which allows a wired connection with an external computer or peripheral device. The onboard memory is for local data storage and backup storage in case of network communication failure. The camera and misc. sensor unit is to assist in navigation, obstacle avoidance, and manual override of a human operator. The Pulse Eddy Current Array (PEC) is the primary sensing device of the SMU.

2.2.2 PEC Array

The pulse eddy current (PEC) was selected as the corrosion detection system for the SMU for various properties which will be discussed in section 2.3. The decision chart for this selection is shown in Appendix A. The PEC array system design is shown in Figure 5.

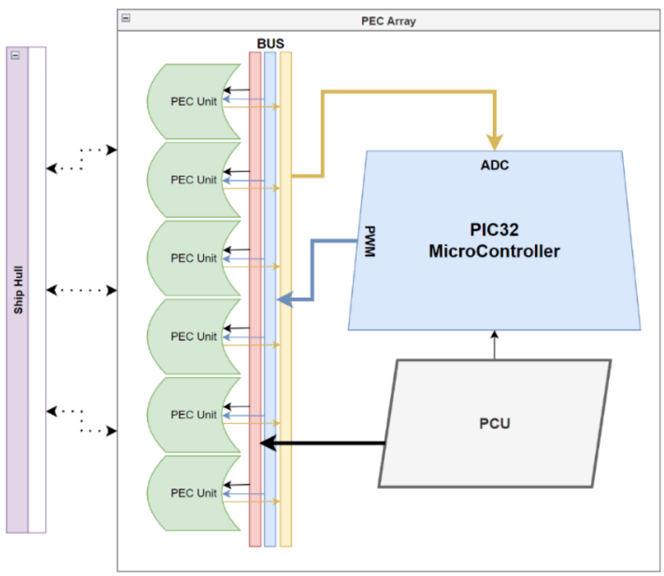

Figure 5: PEC array system.
The array is made of one or more PEC detection units (Figure 6).

The PEC array consists of multiple instances of the PEC detection Unit (Figure 6). Each unit can detect corrosion in its area of effect. The area of effect of an individual unit is small (~40mm) due to the range of the detection sensor (Hall effect); consequently, an array of these devices will be used to create a large scan field.

2.3 Sensor Module Analysis

The PEC array is primary unit of the SMU. Other component may be purchased OTS and require little analysis. A custom design is required for the PEC array to function on an AUV. Consequently, the engineering analysis will focus on this component.

2.3.1 Pulse Eddy Current Hardware Design

The PEC sensing device will include

1. An excitation coil
2. 2 Hall effect sensors
3. A PWM excitation circuit
4. An amplifier circuit
5. A bandpass filter

The arrangement of these components is shown in Figure 6. The 2 Hall effect sensors (HE) allow for a differential measurement which reduces the need for a reference signal and makes the sensor more versatile [14].

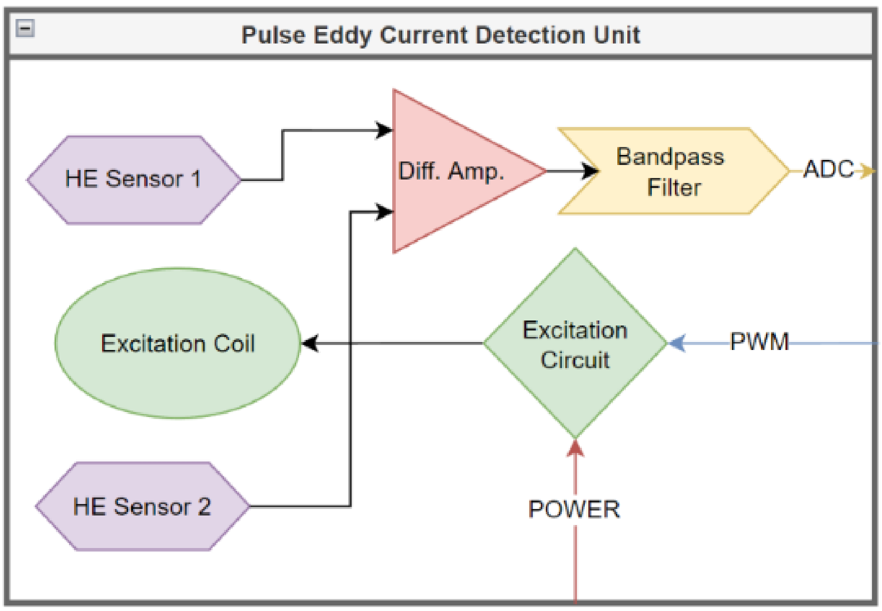

Figure 6: PEC detection unit consisting of an excitation circuit and coil, 2 Hall effect sensor, and an amplifier and filter circuit.

2.3.1.1 Pulsed Eddy Current Detection Theory

EC detection uses an AC-driven inductor to induce eddy currents in a conducting sample. The induced eddy currents vary around flaws or defects in the conducting material. A magnetic sensor can detect these currents and variations (Figure 7).

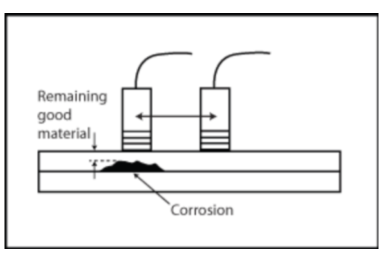

Figure 7: Eddy Current Corrosion Detection [11]

The penetration depth of these signals is related to the frequency of the driving signal as shown in the equation below [14].

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \qquad \textit{Equation 1[14]}$$

δ is the depth where the return signal is at 1/e reduced density, ω is frequency, μ is magnetic permeability, and σ is electrical conductivity. Traditional EC uses a sinusoidal input at a given frequency. With only one excitation frequency, the sensor is limited to one penetration depth distribution. Alternatively, many frequencies (and therefore depths) can be expressed if a modulated square wave drives the inductor. The Fourier transform and power spectra of a pulsed square wave demonstrates this property (Figure 8). This is known as pulsed eddy current detection (PEC).

$$f(t) = \begin{cases} A, & -\frac{T}{2} \le t \le \frac{T}{2} \\ 0, & |t| > \frac{T}{2} \end{cases} \qquad F(\omega) = \frac{2\,sin\left(\frac{\omega T}{2}\right)}{\omega} \qquad \textit{Equation 2 [14]}$$

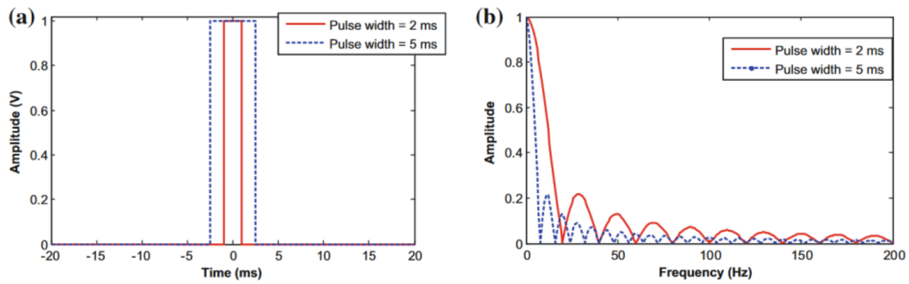

Figure 8: Power spectra of different pulses [14]

With PEC, the input wave may be modulated to achieve different depths and apply varying power to the inductor coil. Varying the pulse width also eliminates the need for a reference signal [15] (Figure 9).

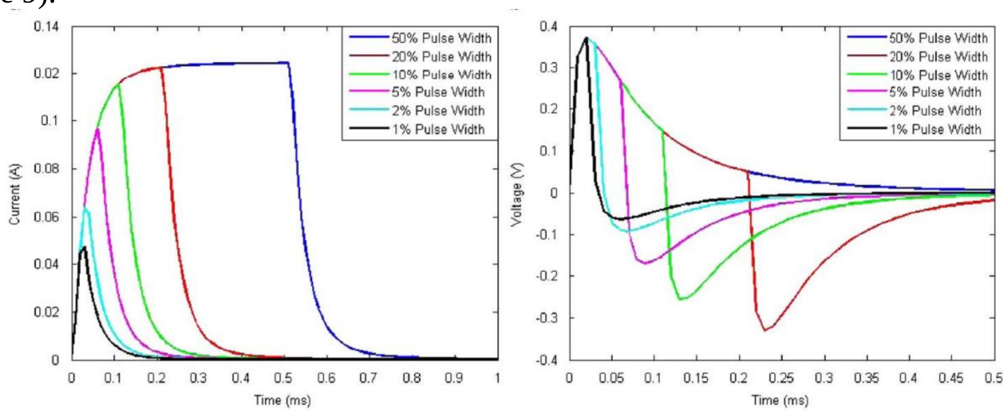

Figure 9: Simulated transient response of PEC [2]

PEC detection offers many advantages over tradition EC detection. PEC can easily scan multiple depths in a surface with a single frequency pulse. Since the excitation signal is a pulse rather than a sinusoid, PWM signals from a microcontroller can control the sensor without the need for a sinusoidal function generator.

2.3.1.2 Hall Effect Sensors

Magnetic sensors are commonly used as the detector for a PEC system. These devices detect the coupled magnetic field induced by the driving coil and is directly proportional to the eddy currents in the material.

A HE sensor is a common and widely used device. Equipment such as coils or magnetoresitive devices exist, but these have additional requirements or supporting hardware to function [14]. Some magnetoresitive devices such as giant magnetoresistance (GMR) have been shown to have higher accuracy or lower noise. Should the HE be ineffective at these devices will be considered as a substitute.

Hall effect (HE) sensor have the sensitivity requirements and are commonly used in this application [14], [16]. The governing equation for a HE sensor is

$$V_{HE} = K\ B \qquad \textit{Equation 3}$$

where K is a constant coefficient specific to the device and B is the magnetic field density.

2.3.1.3 Excitation Circuit

A simulation (using SPICE) was preformed on the designed excitation circuit to show the coil response to a PWM signal from the MCU.

Figure 10 shows the current response in the excitation coil to PWM input from a microcontroller.

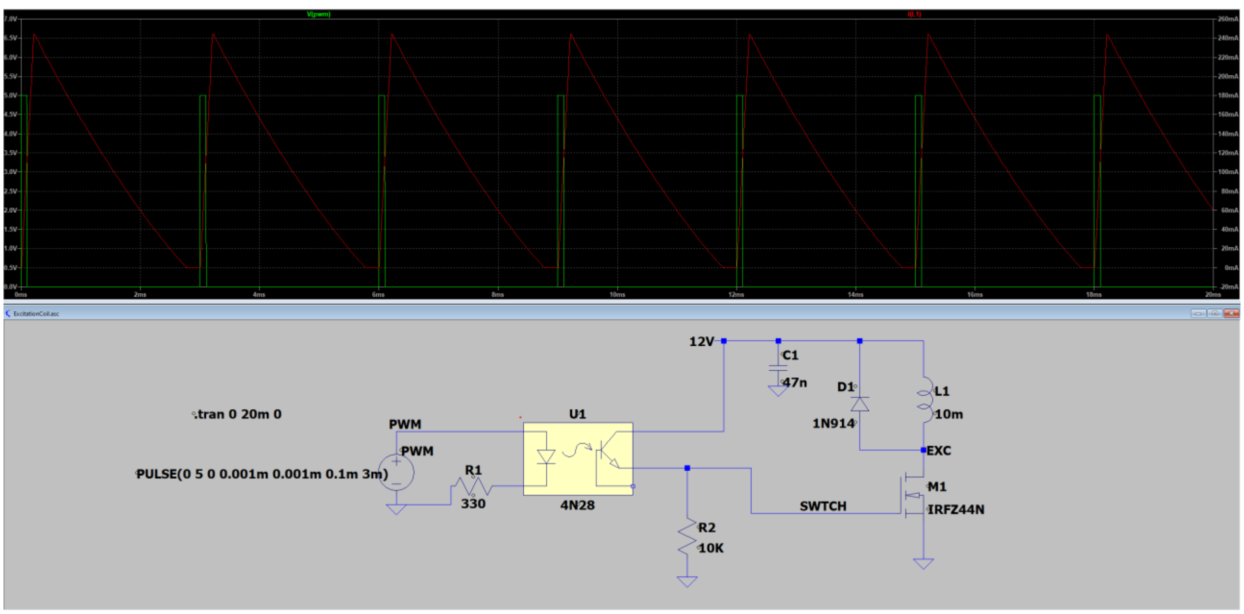

Figure 10: Simulated excitation inductor circuit for PEC sensor unit.
Green plot shows pulses from PWM controller. Red show inductor current (peak 245mA).

An optocoupler (4N28) is used to isolate the microcontroller from the high-power inductor circuit. A IRFZ44N NMOS transistor was selected to control the current to the excitation coil L1. The IRFZ44N is fast switching and has a drive voltage of 10V [17]. The 10mH inductor was selected as an overestimation place holder. The 1N914 diode is placed to drain the stored energy of the inductor to prevent a reverse power surge back through the NMOS. The 1N914 is fast switching and can dissipate 500mW of power.

With a peak power surge from the inductor of

$$P_{peak} = I_{max} * V_{drop} = (250mA * 1V) = 250mW \qquad \textit{Equation 4}$$

we have a 2x safety factor for the diode. The capacitor C1 is for filtering of noise from 12V supply line. It may be tuned as necessary.

The NMOS transistor may be ‘overkill’ for the performance requirements of the system. However, this will allow multiple coils to be driven from the same circuit, potentially decreasing the complexity and number of components. With a 200mA draw, up to 50 coils could be driven by this transistor. Heat management will be essential in this case, and no more than 25 coils is recommended to maintain a 2x safety factor.

The inductor chosen for simulation has an inductance of 10mH. Likely, the actual value of the inductor will be significantly lower. Tests will show the required magnetic flux density to achieve the needed return signal strength. Should a smaller inductor be needed, the driving voltage may need to be reduced to limit the current. A buck converter and filter circuit would serve this purpose. The power requirement of the PEC array will also decrease in this case.

2.3.1.4 Resonance analysis

C1 and L1 in the above circuit form a parallel resonance circuit. Although, the supply voltage is DC, the PWM control creates an AC response. For the current values, the resonance frequency was calculated as

$$f_{resonance} = \frac{1}{2\pi(LC)^{\frac{1}{2}}} = 7.341kHz \qquad \textit{Equation 5}$$

Since the pulse frequency of PEC system falls between 80kHz and 1MHz, the circuit should not enter resonance during operation. However, a note should be made while constructing the PWM to avoid frequencies lower to 20kHz to avoid this resonance point.

2.3.1.5 Amplifier Circuit

The differential amplifier circuit was simulated in SPICE software.

Figure 11 shows the designed differential amplifier circuit and it’s simulated response to input from HE sensors.

The exact amplification needed is unknown at this time. Testing will reveal the amplification needed from the response of materials and sensor units. The gain can be adjusted easily through substitution of the sensors above and will be adjusted until the output range falls between 0 and 3.3V (based on microcontroller ADC voltage [4]).
The amplification of this circuit from input to output adheres to

$$V_{out} = V_{in} * \left(\frac{R_3}{R_1}\right),\ if\ R1 = R2\ \ and\ \ R3 = R4. \qquad \textit{Equation 6}$$

Figure 11 is configured with a gain of 10.

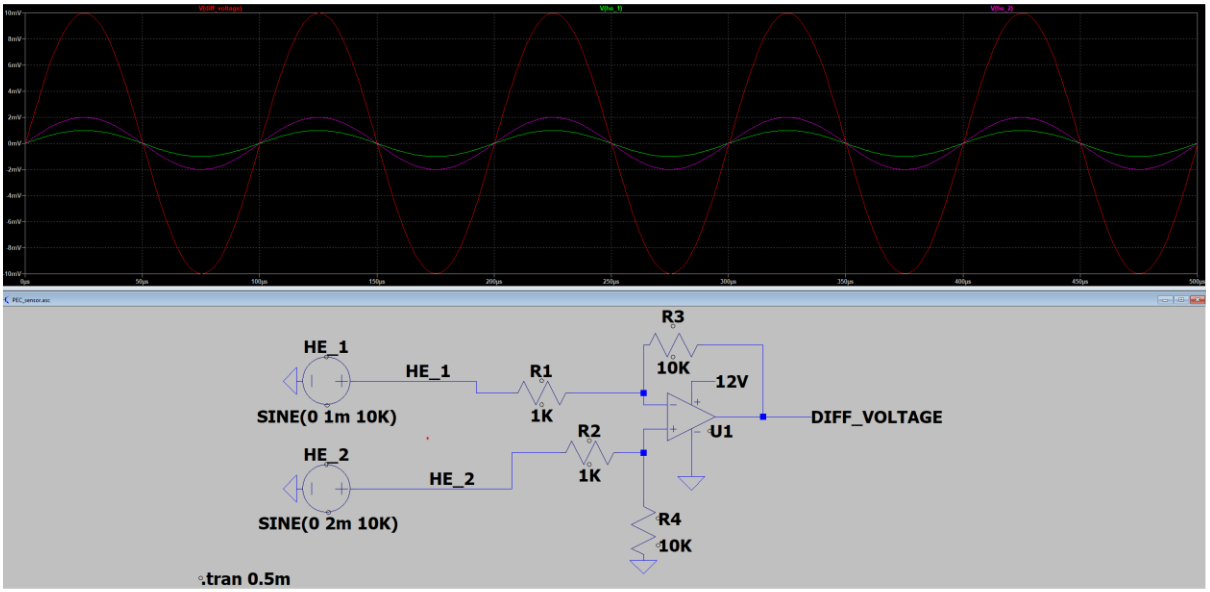

Figure 11: Simulated difference amplifier circuit for acquiring HE difference data from PEC sensor unit.

2.3.1.6 *Bandpass Filter*

A bandpass filter will be needed at the output of the amplifier to mitigate noise cause by the sensor devices, power regulators, and the operational amplifier. Testing is needed to determine the precise range of frequencies to filter, but the design will take the form of Figure 12.

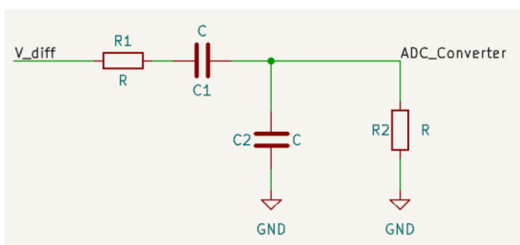

Figure 12: Bandpass filter design

The high and low cut off frequencies and band width equation for this circuit are

$$f_h = \frac{1}{2\pi R_1 C_1} \qquad f_l = \frac{1}{2\pi R_2 C_2} \qquad BW = f_h - f_l \qquad \textit{Equation 7}$$

This passive circuit will consume power from the amplified return signal. This consumption should be consistent with all signals. However, should this circuit interfere with the signal analysis, this design can be integrated into the differential amplifier to create an active filter. Should this allow 2 much noise to propagate through the system, an OTS low noise amplifier may be purchased to fill this role.

2.3.2 PEC Array

An array of PEC sensor units will be used to increase the scan area of the system. Each unit will be positioned relative the scan area as shown in Figure 13. A nominal lift off distance of 3mm was selected based on work from Kral J. which showed a decreased sensor response above 4mm [19].

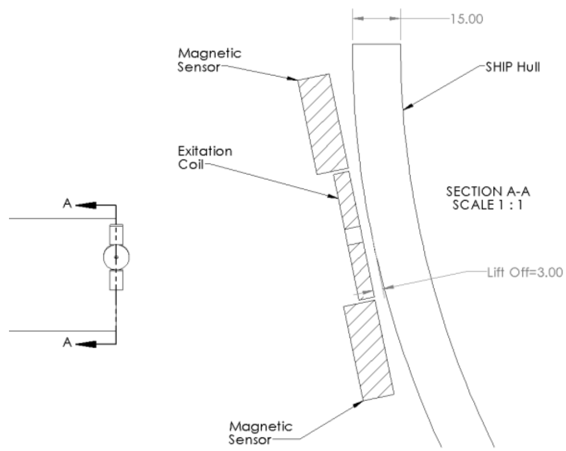

Figure 13: PEC unit scanning position on ship hull.

An array will be formed to maximize spatial resolution of HE sensors (Figure 14). The exact spacing may change if test reveal closer or farther spacing is required based on the excitation coil effect and HE sensitivity.

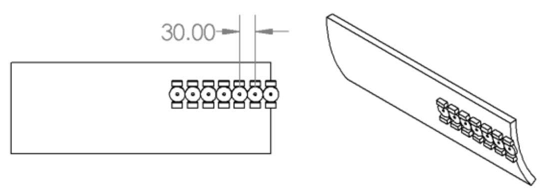

Figure 14: PEC array configuration

To maintain this lift off distance, rollers or mechanical guides may be needed.

2.3.3 Microcontroller

The preliminary selected microcontroller is the PIC32MZ2064DAS176 [18]. This micro was selected for the properties

- 45 channel ADC (12-bit): To read data from DAQ
- 9 PWM Modules (250ns resolution): To control excitation circuit
- **Integrated Graphics Processor**: For fast data processing and AI implementation
- **200MHz clock speed**: High speed processor for real-time functionality
- 128MB externally addressable DDR2 DRAM: Large RAM for data processing
- **5 SPI and 6 I2C modules**: Interfaces for other peripheral devices.

This PIC32 device operates between 2.6 and 3.3V and requires a maximum of 500mA [18].

The main reason for selecting the PIC32 microcontroller was the large number of ADC channels and PWM outputs. The size of the array will require many HE sensors. Should the resolution requirements exceed the 45 channels available on the microcontroller, a switching methodology can be adopted. The array can be split into several sub arrays with enable switches. Multiple HE sensor can be wired to the same ADC port and read individually with the switching algorithm.

The integrate graphics processor on the PIC32 will allow for fast data and image processing. Real-time decision can be made locally with the analysis of this data and video feed.

2.3.4 Power and Charging

The power needs of the system will change with additional peripherals including the wireless communication system. However, estimation can be made. The considered devices and their electrical specification are shown in Table 2. This table assumes 12 PEC detection units in the system. 12 units with a 40mm spacing covers 0.36m. This matches with some standard lengths of small underwater drones and AUV's [20].

Table 2: Electrical Characteristics of Components

Component	**DC Voltage (V)**	**Max Current (mA)**	**Power (W)**
PIC32MZ2064DAS176	3.3	500	1.65
PEC Array (12 units)	12	245 x (12)	35.28
UW-COM Unit	--	--	2.6 [21]
Under Water Camera	--	--	15.4 [22]
Additional Components*	--	--	10*
		TOTAL	**64.88**

** Other components are unknown at this time; however, compared to the main devices they will consume significantly less power. 10W is allocated as a large buffer.*

64.88 W is the absolute maximum power draw of this system. A battery was selected with appropriate head room to extend the life of the system and operating time. The CSB HRL 1280W battery can provide 12V at 80W and has dimension small enough to mount to an AUV. Based on the data sheet, the battery could sustain a steady 65W for over 90min [23]. The operating time may be less than this due to the pulsing power draw of the PEC array.

The value of 245mA used for the PEC system in Table 2 is an extreme maximum estimation. This current would be drawn if the excitation inductor was left fully power for more than 0.5ms. Since these inductors will be pulsed, the average current over time will be significantly lower and with proper storage capacitor usage, might be reduced significantly. Additionally, the power magnitude will vary depending on the pulse width selected but will always be less than the full 250mA.

2.4 System Limitations

The major limitations of this solution are

1. PEC requirements
    a. Small displacement from scan target (liftoff<4mm)
    b. High number of electrical components (PEC Unit: Capacitors, Op Amps, NMOS, Inductors)
    c. Large power requirements
2. Large initial software development
3. Large number of different devices (RU, SMU, CU)

The small displacement distance will require a mechanical solution to position the PEC array. This may take the form of a flexible rotating arm or hinge system to allow the array to mold to the target surface. The number of electrical components may add a large cost to each SMU. This cost may be mitigated by increasing the number of coils and HE sensor in each PEC unit to reduce supporting circuitry. While untested, there is a potential for a large power requirement especially from the PEC array. To mitigate the down time of each SMU, a battery swapping or fast charging system may be needed.

Software for swarm control, data analysis, and communication is needed for a functional system. Consequently, there is a high initial software development needed. With the systems configurability and expansion comes the downside of having many individual devices. This is unavoidable for this solution. Maintenance, installations, and repair will have to be actively managed by a sufficiently trained team. However, the overall maintenance should be minimal especially compared to the systems operating time.

2.5 System Advantages

The major advantages of this system are

1. Accurate, configurable, and fast detection.
2. Environmental robustness
3. Easy expansion
4. Low initial cost
5. Minimal system downtime

The PEC array may be scaled to any number of units (limited by ADC channels). This allows for a configurable scan area which directly corelates to scan speed. Additionally, since the PEC unit is a magnetic device, it is mostly independent of medium and temperature.

The nature of the swarm system allows for simple expansion through introduction of more drones and relay nodes. Additionally, only a few drones and nodes are needed for the initial system which can keep start-up costs low. The swarm system can operate nearly constantly besides regular recharges and maintenance. These recharge time can be staggered among devices to keep the system always operational.

3 CONCLUSION

Corrosion causes a large expense for any marine asset. To minimize this cost and maintain equipment, constant monitoring is required. There is currently a need for an autonomous corrosion monitoring system to increase the chance of early corrosion detection and reduce the need for human intervention.

The proposed system consists of a sensor module attached to available drone technology, a relay unit to allow communication underwater and in air, and a command unit to control the drones and collect and analyze data

The sensor module is the main component of this system. The proposed sensing device uses pulse eddy current technology to detect corrosion on or inside external metal material. An array of PEC units will be used to scan a large area simultaneously. Each PEC units controlled via a PWM signal from a microcontroller and returns an analog voltage to an ADC.

The PEC unit circuits were simulated to estimate the power and signal processing requirements. Other components such as a microcontroller and underwater communication device were selected from existing products based on data sheet information.

A power analysis was preformed, and a maximum power draw of the system was determined as 64.88W. This is the absolute maximum power draw expected from the SMU. A battery of appropriate size and power was selected.

The main limitation of this system is the small displacement requirement of the PEC array. A mechanical device will be required to handle this requirement. The main advantage of this system is its constant operating time and expansion potential. If implemented correctly, human hours spent on corrosion monitoring could be significantly reduced which could greatly decrease the cost of corrosion over time.

4 RECOMMENDATIONS

The greatest unknown of this system is output and input signals of the PEC array. To determine the actual component value required, a test PEC unit should be developed. Next, this unit should be used to scan sample pieces to determine the signal response to corrosion so that a detection AI may begin development. Once the PEC unit is confirmed work should begin on integrating communication devices and the drone SMU interface.

If these components can be brought to an initial state other portions of the system can be integrated, and a prototype developed.

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APPENDIX A: SOLUTION RATINGS

A.1 Criteria for deployment assessment selection with corresponding weights.

No.	Criteria	Weighting
1	**Autonomy of the system**: The more potential autonomy a system can possess the higher the score.	0.3
2	**Scan effectiveness:** The faster and more thorough a system can scan for corrosion the higher the score	0.3
3	**Scalability:** The easier it will be to mass produce or increase the size of an implemented solution the higher the score	0.2
4	**Operating Timer:** The more time a system can be operating and/or actively scanning the higher the score	0.1
5	**Maintenance:** A system with a less need for human implemented maintenance or downtime maintenance will receive a higher score	.01

A.2 Criteria for monitoring technique assessment selection with corresponding weights.

No.	Criteria	Weighting
1	**Range:** A method which can monitor at a greater distance from the target will receive a higher score	0.2
2	**Detection Depth:** A method which can detect corrosion at a deeper material depth will receive a higher score.	0.4
3	**Scalability:** The easier it will be to mass produce or increase the size of an implemented solution the higher the score	0.1
4	**Coverage Area:** A method which can scan a greater area in a given time will receive a higher score.	0.1
5	**Environment Immunity:** A method which is more resistant to changes in the environment will achieve a higher score	0.2

A.3 Wieghted Decision Chart

Deployment Method	Range = [0,5]										
Criteria	Autonomy	Score	Effective Scan	Score	Scalability	Score	Operating time	Score	Maintenance	Score	Total
Weight	0.3		0.3		0.2		0.1		0.1		1
Harbor Swarm	5	1.5	3	0.9	4	0.8	4	0.4	2	0.2	3.8
Ship Wired Drone	3	0.9	2	0.6	2	0.4	1	0.1	4	0.4	2.4
Tow Fish	3	0.9	1	0.3	3	0.6	4	0.4	4	0.4	2.6
Large Array	2	0.6	5	1.5	1	0.2	2	0.2	2	0.2	2.7

Corrosion Detection	Range = [0,5]										
Criteria	Range	Score	Detection Depth	Score	Scalability	Score	Coverage Area	Score	Environment Immunity	Score	Total
Weight	0.2		0.4		0.1		0.1		0.2		1
Eddy Current	3	0.9	4	1.2	4	0.8	3	0.3	5	0.5	3.7
Ultrasonic	3	0.9	5	1.5	2	0.4	3	0.3	1	0.1	3.2
Magnetic Flux Leakage	2	0.6	2	0.6	4	0.8	2	0.2	5	0.5	2.7
Electrode Probe	0	0	3	0.9	5	1	5	0.5	5	0.5	2.9