

Miniature Autonomous Submarine

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Abstract

Welding services companies struggle with inspecting underwater pipelines for welding quality. Our solution is a Miniature Autonomous Submarine that utilizes machine learning and a decision support system to revolutionize underwater inspections. This advanced submarine navigates accurately, capturing detailed images and data, making inspections faster and more efficient compared to traditional methods.

Introduction

Problem Statement:

Underwater welding inspections are risky and challenging for human divers due to poor visibility and underwater currents. To address this, an autonomous solution is needed to make these tasks safer and more manageable by gathering data in the difficult sea environment.

Project Constraints:

- Submarine dimension should be 50 cm in all directions.
- Submarine operation should be up to 3 m.
- The weight for scientific instruments or camera should be less than 0.5 kg.
- Submarine can operate in seawater of salinity of 37 g/dm³.
- The total budget should be less than 10,000 SR.

Target Specifications:

- Maximum submarine weight is 7 kg.
- Maximum submarine speed of 2 knots.
- Maximum submarine flow resistance 1 knots.
- Maximum submarine rise/fall speed 1 knots.
- Corrosion rate for submarine body less than 10 microns/year
- Maintain reliable communication up to 10 meters away.
- Operate for at least 1 hour on a single charge.
- Autonomous operation.
- Image resolution is 4MP.

Project Impact:

- Economic Impact:
 - ❖ Enables detailed aquatic surveys and data collection.
 - ❖ Reduces overall operational costs.
- Societal Impact:
 - ❖ Aids in scientific research and environmental conservation.
 - ❖ Enhances the safety of underwater operations.
- Environmental Impact:
 - ❖ Facilitates detailed surveys, reducing resource consumption compared to traditional methods.
 - ❖ Minimizes environmental pollution.

Prototype Design

Body Part:

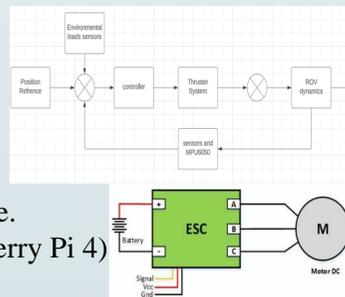
Consists of two main components selected for operational integrity and aquatic performance:

- Acrylic pipe
- 3D-Printed Components



Electronics Part:

- Key Sensors:
 - ❖ Ultrasonic sensor.
 - ❖ Temperature sensor.
 - ❖ MPU 6050 sensor.
- Thrusters and ESC.
- Batteries and LAN cable.
- Microcontroller (Raspberry Pi 4)
- Raspberry Pi Camera.



Testing / Validation

- The total weight is 5.5 kg.
- Adjusting the speed to be 2 knots by Raspberry Pi and electronic speed controller.
- Adjusting the flow resistance 1 knots by Raspberry Pi and electronic speed controller.
- Adjusting the rise/fall speed 1 knots by Raspberry Pi and electronic speed controller.

- Battery will operate 37.95 Ah for more than one hour.
- Camera with 8 MP.
- Autonomous operation with navigation system.
- Acrylic material with corrosion rate of less than 1 microns/year.
- Wired communication utilizing a cable longer than 15 meter

Navigation System

- x_{ij} : Binary variable representing whether the tour goes directly from location i to location j .
- t_{ij} : Time of traveling from location i to location j .
- a_i : x-coordinate location of the place needed to visit.
- b_i : y-coordinate location of the place needed to visit.
- c_i : z-coordinate location of the place needed to visit.
- k : x-coordinate location of the submarine.
- w : y-coordinate location of the submarine.
- v : z-coordinate location of the submarine.
- u_i : a continuous variable representing the position of the i -th location in the tour.
- d_{io} : the distance between the location i of the submarine and the obstacle.
- d_{min} : the minimum allowable distance from the obstacle.

$$\text{Minimize } Z = \left[\sqrt{(k - a_i)^2 + (w - b_i)^2 + (v - c_i)^2} \right] + \sum_{i=1}^n \sum_{j=1}^n t_{ij} x_{ij}$$

Subject to:

1. Each location is visited only once:

$$\sum_{j=1, j \neq i}^n x_{ij} = 1 \quad \text{for } i = 1, \dots, n$$

2. Each location is left only once:

$$\sum_{i=1, i \neq j}^n x_{ij} = 1 \quad \text{for } j = 1, \dots, n$$

3. Subtour elimination to avoid cycles:

$$u_i - u_j + n x_{ij} \leq n - 1 \quad \text{for } i \neq j, \quad i, j \neq 1$$

4. Prevent self-loops:

$$x_{ii} = 0 \quad \text{for all } i \in N$$

5. Submarine returns to the starting location:

$$\sum x_{ij} - \sum x_{ji} = 0$$

6. Submarine visits only one location at a time:

$$\sum x_{ij} + \sum x_{ji} \leq 1 \quad \text{for all } i, j \in N, i \neq j$$

7. Obstacle avoidance:

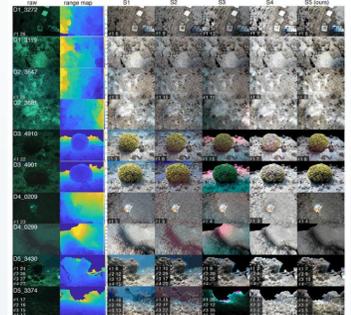
$$d_{io} \geq d_{min}$$

$$x_{ij} \in \{0,1\} \quad \text{for } i, j = 1, \dots, n$$

8. Connectivity constraint:

$$\sum x_{ij} \geq \sum x_{ik} + \sum x_{jk} - 1 \quad \text{for all } i, j, k \in S, i \neq j \neq k$$

Objects Visualization



Conclusion

Our project introduces a Miniature Autonomous Submarine specifically designed for underwater welding inspections, utilizing machine learning algorithms for precise inspections and decision-making based on image analysis. With its compact design, navigation capabilities, and high-resolution data collection, the submarine ensures efficient and reliable inspections in challenging conditions, revolutionizing underwater technology and representing a collaborative breakthrough across engineering and computer science disciplines.

Recommendations

- **Enhanced Communication:** Implement wireless communication for better data transmission and remote-control capabilities, enhancing performance in challenging underwater conditions.
- **Enhanced Operation:** Increase operational depth capability beyond 3 meters, ensuring reliability across diverse underwater environments.
- **Improved Power:** Develop efficient power management systems to extend operational endurance and battery life.
- **Improved Navigation:** Enhance navigation algorithms for increased accuracy and autonomy in underwater environments.