Free-Roving Subsea Cable Inspection Drone

A Technical Feasibility Study

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November 10, 2025

Outline

The Problem - Subsea Cable Inspection

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- Backbone of the modern internet infrastructure, carrying 97-99% of all intercontinental data traffic
- 500+ cables worldwide, a total of 14 million kilometers
- Around 2-5 cm in diameter

Before we dive into our design and feasibility assessment, let's give some context to the problem we're tackling: Subsea cables. Your internet connection, whether that be for online banking or video calls, 97-99% of that data goes through a dense network of over 500+ undersea cables, spanning a total of 14 million kilometers over the seafloor making it THE largest and possibly greatest man-made infrastructure ever.

This is the backbone of the internet, and when they fail, the consequences are severe. Despite the significance of these cables, they are no thicker than your average garden-hose around 2-5 cm in diameter, with hair-thin strands of optical fibre embedded within, designed to remain undisturbed across the seabed.

The Problem - Subsea Cable Inspection

- Averages 200 faults a year, particularly in shallow waters ($\sim$200m)
- Shetland Islands cutoff in 2022
- Traditional inspection methods use tethered ROVs, which can limit motion and increase cost

In shallow waters however, these subsea cables are susceptible to a wider range of disturbances, largely from human activities such as anchoring, or snagged by nets, resulting in roughly 200 faults a year.

In October 2022, both cables serving the Shetland Islands were damaged. For days, 23,000 people had no internet, couldn't use card payments, couldn't access online banking. Businesses lost thousands. Emergency services were disrupted.

These aren't rare events, they require constant monitoring and effective maintenance. When a fault occurs, an army of ships strategically placed around the world would be able to identify and repair the location of the fault, which usually involves the usage of a tethered drone to inspect the damaged cable.

Despite the effectiveness of tethered communications and unlimited power, this comes at the cost of a limited range of motion and risks of entanglement, as well as higher maintenance costs for dedicated vessels.

Problem Definition

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"A free-roving (no umbilical cable) submarine inspection drone is required for undersea cables: operating down to 250 m depth. It should have an endurance of 2 hours continuously powered operation, carrying video and ultrasound imaging equipment drawing a 30 W electrical load, and have suitable propulsion to travel up to 4 m/s peak speed with 1 m/s cruise. Total mass is to be ¡ 25 kg, to allow easy handling on board the mothership."

Operating Environment

- ρgh gives ∼25 bar pressure, ∼4 ˚C seawater, insulation for electronics and waterproofing
- Saltwater corrosion & biofouling, limited to plastic materials
- Far below the surface, limited visibility. Not affected by surface wave currents driven by wind
- High signal attenuation

Problem Definition

At 250 m, pressure is roughly 25 bar and temperatures are low. Materials must resist corrosion, sensors must work in turbid water, and communications are limited to acoustic modems – no radio or GPS below the surface.

Problem Definition - Technical Challenges

1. Hydrodynamics
Analyze underwater drag forces to estimate thrust needed for efficient movement.

- Degrees of freedom

2. Mechanical Design
Develop the mechanical system ensuring all components fit within the 25kg weight limit.

- Buoyancy system
- Structural integrity

3. Power Consumption
Identify energy storage limits to define mission duration and vehicle size within constraints.

- 2 hours continuous operation
- Support 30W load as well as communications and mechanical systems

4. Communication and Control
Assess feasibility of underwater wireless communication methods for control and data transfer.

- Attenuation in seawater

Existing Solutions

Existing Solutions

Iver3 by L3Harris

- Rated at 200m
- 27-40kg depending on configuration
- 8-14-hour endurance by 784 WHr of rechargeable lithium-ion batteries
- Single thruster, fins for pitch/yaw control

ecoSUB

- Rated at 500m
- 4kg depending on configuration
- 10-hour endurance by alkaline batteries
- Single thruster, fins for pitch/yaw control

Boxfish AUV

- Rated up to 600m
- 25kg with Salt water ballast
- Up to 10 hours by 600Whr Lithium Polymer batteries
- 8 3D-vectored thrusters allowing 6 DoF

Many consumer solutions already exist, however they vary in their degree of satisfying the requirements as stated previously. Commercial designs such as the Iver3 and the ecoSub opt for a fully autonomous solution through mission planning and programmable actions, whereas others such as the Boxfish use a hybrid of tethered and untethered communication to get the best of both worlds.

Technical Approach

System Design

- Autonomous/programmable solution to remove the need for high-quality real-time data transmission which limits untethered ROVs
- 8-thruster design for stability and hovering capabilities for detailed inspection
- Reinforced acrylic casing for pressure resistance

Communications and Control

Communications and Control

Autonomous control with on-board IMU and DVL for real-time navigation and mapping

Surface Communication:

- RF transmitter: WiFi 802.11n Ethernet standard (possibly needs a base station / emitter on the boat)
- Satellite: Iridium SBD for retrieval

Underwater Communication:

- Signal attenuation due to water
- Acoustic modems required (no radio or GPS underwater)

Communications and Control - Link Budget Analysis

Signal attenuation due to water:
Received power = Transmitted power - Transmission loss + Array gain

Transmission Loss (TL) $= 20\log_{10}(R) + \alpha R \times 10^{-3}$
Where: R = range (m), α = absorption coefficient $\approx$ 3 dB/km at 25 kHz

For $R = 500$m: TL $= 20\log_{10}(500) + 3 \times 0.5 = 54 + 1.5 = 55.5$ dB

Link Budget Calculation:

- Source level: 180 dB re 1 μPa at 1m
- Noise level: 60 dB (sea state 3)
- Array gain: 10 dB
- Required SNR: 10 dB
- Received level = 180 - 55.5 + 10 = 134.5 dB
- **Margin = 134.5 - 60 - 10 = 64.5 dB** ✓

Hydrodynamics

Hydrodynamics

Thruster profiling:

To keep control and power consumption low, we opted for a single thruster design with fins for pitch and yaw control.

Key considerations:

- Drag force analysis for 1 m/s cruise speed and 4 m/s peak speed
- Required thrust estimation based on vehicle geometry
- Degrees of freedom: 6 DoF control using 8 thrusters
- Efficient propulsion system design

Power Consumption

Power Consumption

Power Budget Analysis:

Requirements:

- 2 hours continuous operation
- 30W for video and ultrasound imaging equipment
- Additional power for:
  - Thrusters and propulsion
  - Communication systems
  - Navigation sensors (IMU, DVL)
  - Control electronics

Energy Storage:

- Lithium-ion or Lithium Polymer batteries
- Must fit within 25kg total mass constraint
- Battery mass vs. energy density tradeoff

Mechanical Design

Mechanical Design

Ballast Design:

Key Design Considerations:

- Pressure housing: Reinforced acrylic casing rated to 25 bar (250m depth)
- Buoyancy control system
- Structural integrity under pressure
- Material selection:
  - Corrosion-resistant plastics for external components
  - Pressure-resistant materials for housing
  - Minimal biofouling surfaces
- Total mass constraint: ¡ 25 kg
- Weight distribution for stability

Cost and Feasibility

Cost and Feasibility

Technical Feasibility:

- Communication systems: Feasible with acoustic modems (64.5 dB margin)
- Power requirements: Achievable with modern Li-ion/LiPo batteries
- Mechanical design: Within established engineering practices
- Control systems: Standard IMU and DVL navigation proven in similar AUVs

Cost Considerations:

- Component costs: Thrusters, sensors, batteries, housing
- Manufacturing and assembly
- Testing and certification for 250m depth rating
- Comparable to existing solutions (Iver3, ecoSUB, Boxfish AUV)

Conclusion

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Summary:

- A free-roving subsea cable inspection drone is technically feasible within the specified constraints
- Key design decisions:
  - Autonomous operation to reduce communication bandwidth requirements
  - 8-thruster design for 6 DoF control and hovering stability
  - Acoustic communication with sufficient link budget margin
  - Lithium battery technology for 2-hour endurance
- Trade-offs balanced between:
  - Maneuverability vs. power consumption
  - Communication capability vs. autonomy
  - Component weight vs. functionality

Next Steps:

- Detailed component selection and integration
- Hydrodynamic modeling and simulation
- Prototype development and testing