AUTONOMOUS BIOFILM MAPPING

by OCEANUS ROBOTICS

ABSTRACT

Biofilm accumulation on submerged surfaces influences **nutrient cycling**, **oxygen dynamics**, and **marine infrastructure degradation**. This study presents a custom-designed autonomous underwater vehicle (AUV) built to monitor biofilm growth across environmental gradients in the **Gulf of Mexico.** The AUV's **modular substrate plates**, **optical imaging**, and **environmental sensors** (temperature, dissolved oxygen, salinity, nitrates) *(See Fig. 4)* enable long-term autonomous data collection. On 30-day missions with 24-hour sampling intervals, modeled data showed biofilm coverage increasing rapidly before plateauing, reaching up to **82%** in nutrient-rich coastal zones. **These broad results demonstrate both the effectiveness and implementability of AUV-based systems for continuous biofilm monitoring across larger marine regions**.

BACKGROUND

Biofilms form when microorganisms attach to submerged surfaces and produce **extracellular matrices**. Their growth follows a logistical pattern: lag phase → exponential growth → plateau due to resource limitations.

This topic is important because excessive biofilm accumulation:

- Contributes to **hypoxia** (low oxygen zones)
- Accelerates **corrosion of marine infrastructure**
- **Disrupts ecosystem balance** and nutrient cycling.

The Gulf of Mexico is a critical study site due to **high nutrient runoff**, **seasonal hypoxia**, and **warm temperatures**. Traditional sampling methods **lack temporal resolution**, while an AUV enables continuous, **large-scale monitoring**, making it **more scalable** for real-world environmental tracking.

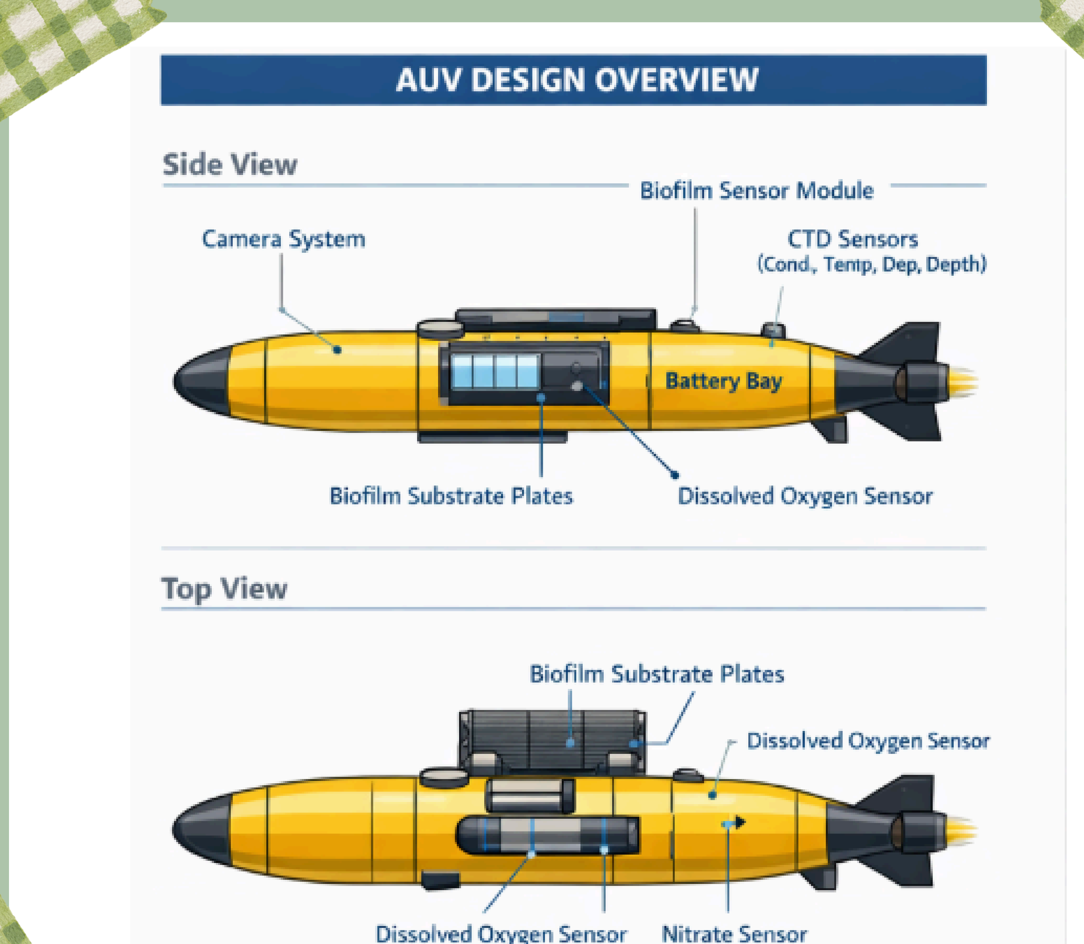
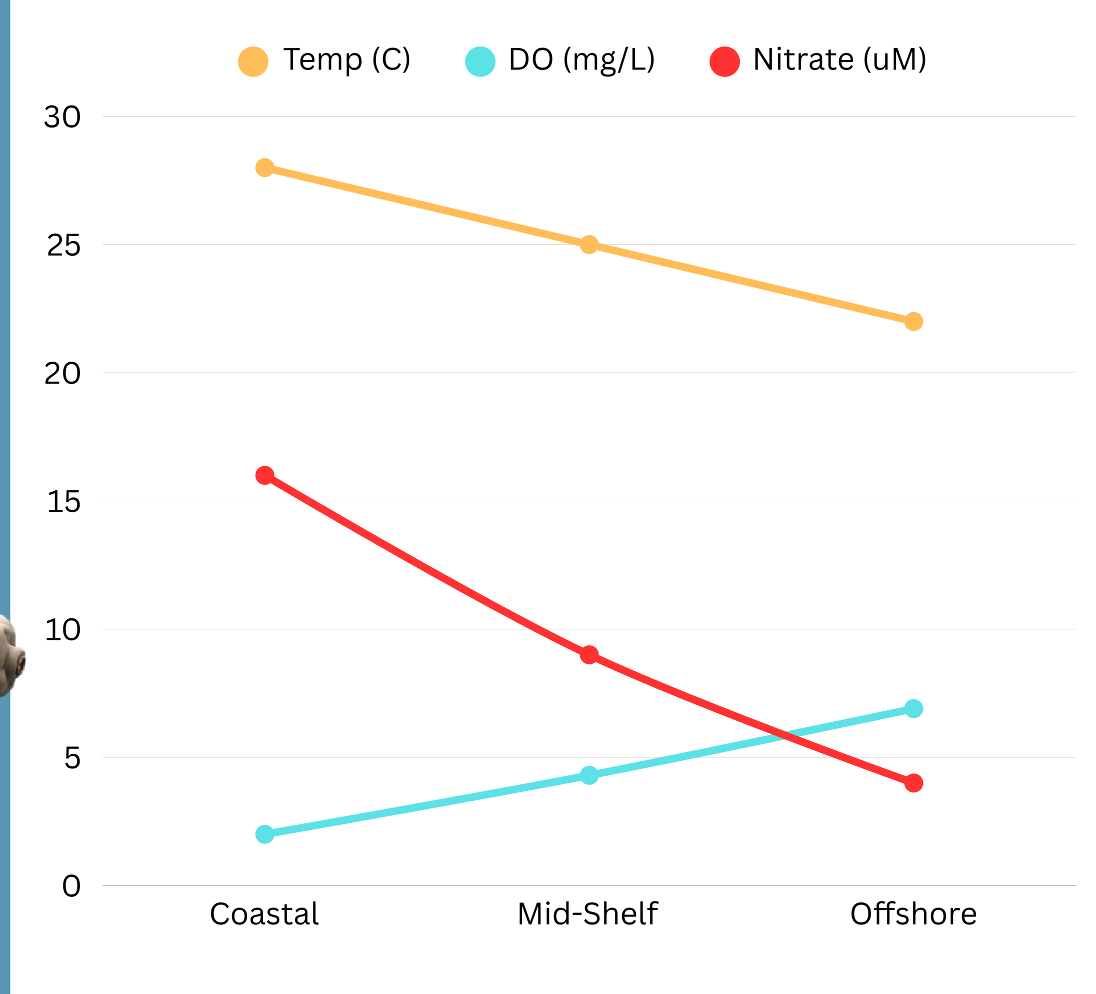


Figure 1: AUV Design Blueprint

Figure 2: Coastal vs. Offshore Growth Comparison



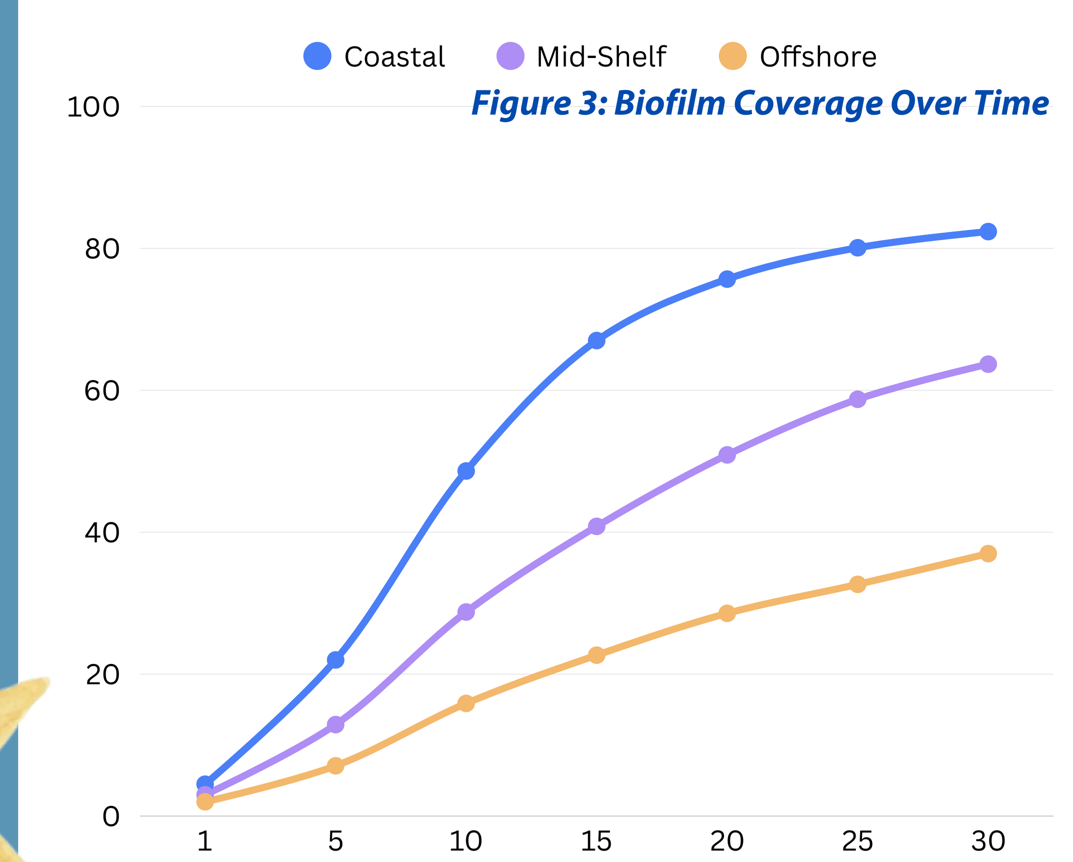


Figure 3: Biofilm Coverage Over Time

APPROACH

This approach was chosen to maximize data consistency, spatial coverage, and modern implement-ability. *(See Fig. 1)*

This custom AUV was designed with:

- **Interchangeable biofilm substrate plates** → standardized, repeatable measurements allow consistency in scientific settings.
- **Optical imaging system** → **non-destructive monitoring** over time.
- **Integrated environmental sensors** → provides evidence for **direct correlation** between growth and conditions.

A 30-day deployment with daily sampling was selected to capture the **full biofilm growth cycle**, rather than exclusively early-stage trends. Multiple zones (coastal, mid-shelf, offshore) were used to test how environmental gradients influence accumulation.

This design allows the system to function as a consistent and reusable monitoring platform.

RESULTS

Biofilm coverage increased over time following a logistic growth pattern.

- Coastal zone reached 82% coverage during peak growth periods
- Mid-shelf reached ~**63%**
- Offshore reached ~**36%**

(See Fig. 3)

Growth rates:

- **Strong positive correlation with nitrates (r=0.89)**
- **Strong negative correlation dissolved oxygen (r=-0.75)**

Observed pattern:

- **Rapid growth: Days 5-15**
- **Slowing: Days 15-25**
- **Plateau: Days 25-30**

DISCUSSION & REASONING

- The results support the original hypothesis that **nutrient-rich, low-oxygen environments** promote faster biofilm growth.
- Our design choices directly supported this: Inclusion of nitrate sensors allowed us to confirm nutrient-driven growth, long-duration deployment allowed us to see the entirety of **the microbial growth phase**, and multi-zone testing showed how environmental gradients influence accumulation.
- This demonstrates that the AUV was intentionally designed to gather data on ecological relationships.

DATA PROCESSING

- Daily images were analyzed to calculate % surface coverage *(see Fig. 2)*
- Growth trends were modeled using logistic regression
- Correlations were calculated between environmental variables and growth

Data from the **coastal site** showed the highest growth rates, supporting the relationship between nutrients and biofilm accumulation.

CONCLUSION

- This study demonstrates that AUV-based monitoring can successfully capture the full lifecycle of marine biofilm growth in the Gulf of Mexico.

Moreover, **the system is highly adoptable** as:

- Modular design allows **deployment across multiple regions**
- **Autonomous operation** reduces the need for human sampling
- Data can be **expanded into large-scale** environmental monitoring networks.

NEXT STEPS

- Deploy multiple AUV units for real-time, wide-area monitoring
- Integrate machine learning models for predictive biofilm growth
- Add microbial analysis (DNA sequencing) for species-level insights
- Adapt the system for **industrial applications** such as ships, pipelines, and offshore rigs.

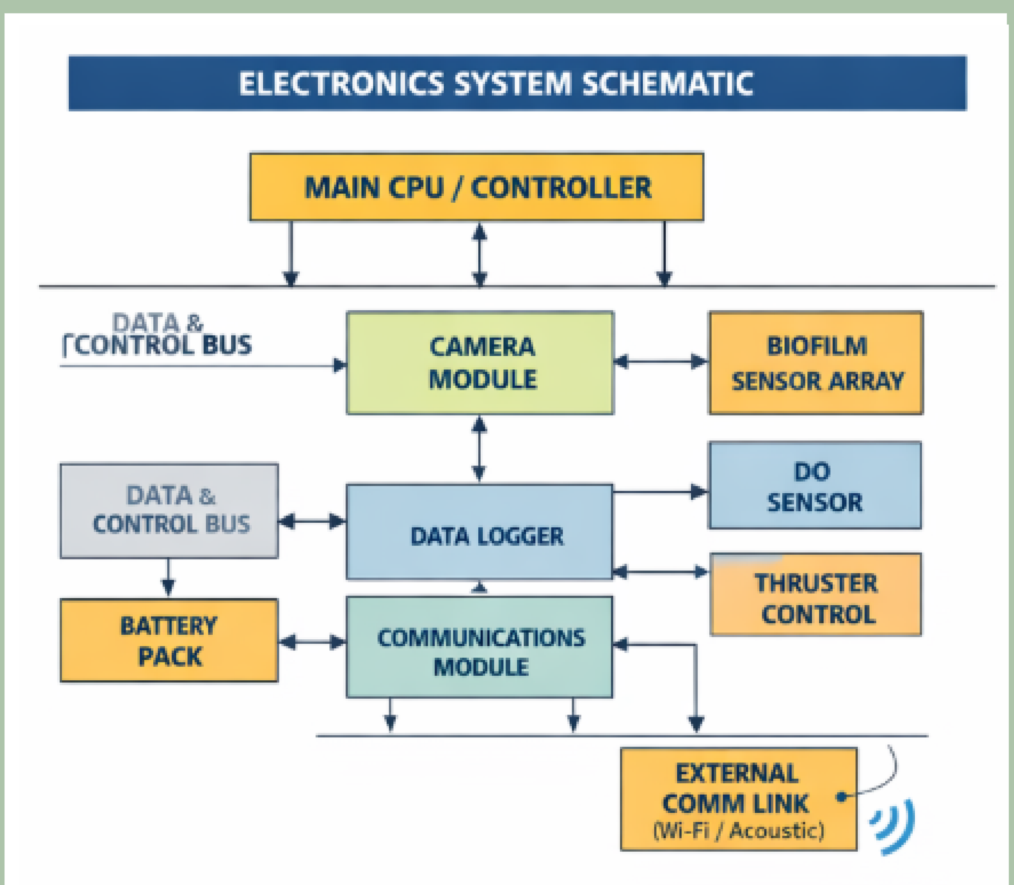


Figure 4: Circuit Loop

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