Poster Abstract: Hybrid Underwater Environmental Monitoring

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Abstract

Many underwater monitoring tasks, such as submarine life studies and pipeline inspections, are usually performed manually. Automated underwater monitoring has the potential to increase safety, improve timeliness, and decrease costs. We propose a hybrid solution of stationary sensor buoys and swarms of autonomous underwater vehicles (AUV) and report on our current progress of its realization. Our solution is based on sensor network technology and a small mobile underwater robot developed in our institute.

1 Motivation

Recent advances in electronics and robotics—particularly in the context of low-power sensor networks and small mobile underwater robots—enable automated and potentially unsupervised environmental underwater inshore monitoring. Among the practical applications are water quality monitoring, structural monitoring, and the study of marine life [1].

In this application field, a hybrid solution embracing stationary sensor buoys and swarms of autonomous underwater vehicles (AUV) and autonomous surface vehicles (ASV) offer a monitoring solution that is flexible, cost-efficient, reusable, and self-organizing. The stationary, sparse network of sensor buoys in the area of interest enables a rudimentary, coarse-grained but cheap, timely, and almost non-invasive monitoring facility. The buoys report their sensor readings to a base station via, e.g., GPRS. The detection of unusual events—e.g., poor water quality close to a pipeline—triggers the activation of the swarm of AUVs and ASVs, which set off to explore the area in more detail and find the source of contamination, e.g., the pipeline leakage.

In this paper, we perform a feasibility analysis regarding the realization of such a flexible, hybrid underwater monitoring platform. In Sec. 2, we discuss the requirements of

typical environmental underwater monitoring scenarios and devise a suitable system architecture in Sec. 3. Here, we outline our current progress with the development of low-power, low-cost AUVs and ASVs connected with a low-cost, low-power acoustic modem. We also study the feasibility of using typical sensor nodes to realize sensor buoys and discuss the exploitation of regenerative energy sources.

2 Requirement Analysis

Targeting the application scenarios outlined in Sec. 1, the following requirements must be met for their successful realization w.r.t. economic and sustainable success:

- **low unit cost** for economical advantages,
- **tiny form factor** to allow for non-intrusive monitoring,
- **low power consumption** to achieve perpetual operation of sensor buoys and long swarm mission times,
- **flexibility** to permit application-specific modifications,
- **localization** for swarm interaction and positioning,
- **fast response times** for swarm coordination tasks,
- **robustness** against damage and faulty behavior.

Current underwater vehicles, sensor capsules, and long-range communication hardware mainly aim at deep-water applications, such as trans-continental pipeline or cable monitoring and search-and-rescue missions after ship or airplane accidents. To fit the needs of deep-water scenarios, these appliances are particularly pressure-resistant and robust. Therefore, they come at high unit costs, have large dimensions, and a relatively high power consumption. The mission time of such underwater vehicles is hence limited to a few hours of operation under manual control with a low number, usually being one, of vehicles. Stationary sensors, in contrast, may achieve longer operation time yet suffer from low spatial resolution due to their unit cost. Particularly due to their size and unit cost, both cannot be employed for cost-sensitive inshore scenarios—e.g., the observation of limnic eruptions, structural monitoring, harbor inspections, and aquaculture monitoring—or coastal monitoring.

3 System Architecture

Our goal is to enable fine-grained, precise, yet non-intrusive monitoring in inshore and coastal scenarios at a low price point. To meet these contradicting demands, we envision a system architecture as shown in Fig. 1 comprising
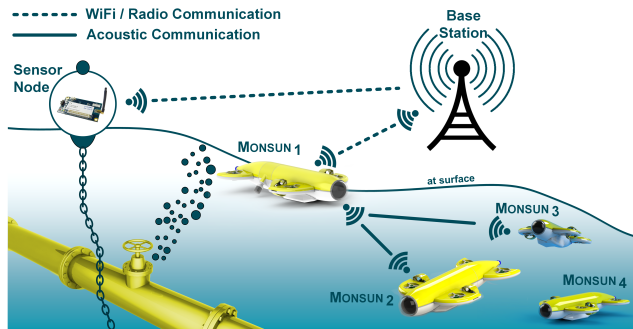
Figure 1. Schematic collaboration between MONSUN AUVs with stationary sensor buoys in a pipeline monitoring application. Edges indicate communication links.

- stationary sensor buoys equipped with a minimal sensor configuration and communication facilities and
- mobile, autonomous underwater and surface vehicles with high-precision sensors and acoustic communication devices for swarm communication.

3.1 Sensor Buoys

Sensor buoys periodically collect sensor readings and send them, e.g., to a base station in a harbor or via IEEE 802.15.4, GPRS, or a satellite link directly to the Internet. They should only be equipped with a minimal sensor configuration for cost and energy consumption reasons. We intend to use low-power, off-the-shelf sensor node hardware plus a long-range radio and a GPS unit. To achieve perpetual operation without manual maintenance, buoys should be supplied by regenerative energy sources. Such a sensor buoy configuration yields an approximate power consumption of 50 mW with a 5% radio/GPRS duty cycle. To match this consumption, a solar cell of less than 200 cm^2 is required. Since the solar energy intake is hardly predictable, we have recently investigated methods and algorithms for sustainable operation of solar-powered sensor nodes in, e.g., [3].

To assess the feasibility of our inshore deployment scenario, we evaluated the communication range of IEEE 802.15.4 high-power radios over open water. For this, we deployed a base station node at land side that sent a ping packet to a second node on a paddle boat (positioned using GPS) that answered with a pong in order to measure the round-trip packet reception ratio (PRR), the radio signal-strength indicator (RSSI), and link-quality index (LQI) values over various distances. Up to 300 m the PRR was almost 100%, dropping nearly linearly to 60% at about 800 m (the maximum distance feasible). We are hence confident that IEEE 802.15.4 radios will suffice coastal deployments.

3.2 Autonomous Swarm Vehicles

Upon detection of abnormal sensor readings, a swarm of mobile, autonomous underwater and surface vehicles is sent out to investigate the situation in more detail. We developed the MONSUN robot (e.g., see [2]). It has a length of 60 cm, a diameter of 10 cm, and an approximate unit cost of €2 000; its typical mission time is 5 h with an energy budget of 70 W h. Moreover, we developed the surface vehicle SURFER with a size of 30 cm × 40 cm × 15 cm. It is
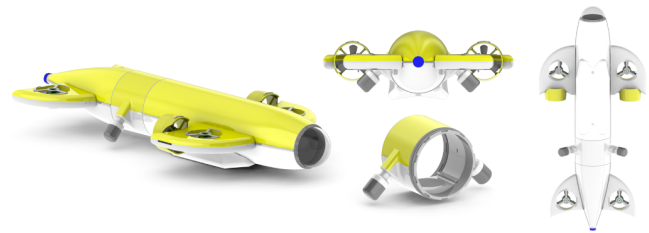

Figure 2. CAD drawing of MONSUN AUV equipped with two hydrophones for acoustic communication.

equipped with a netbook to supply sufficient computation power for navigation plus Wi-Fi and UMTS for communication. It comes at a price point of approx. €2 200 and offers an operation time of at least 5 h.

To enable swarm behavior, communication among the AUVs and ASVs is mandatory. In an underwater scenario, acoustic communication is particularly suitable for distances of several meters as envisioned in our application. As outlined in Sec. 2, there is a lack of low-power, low-cost acoustic communication devices. Therefore, we are currently developing such an acoustic modem with a particular eye on a seamless integration with our AUVs and ASVs. Its total unit cost is approx. €250, of which €180 are due to two hydrophones. The electronic circuit has a near bank-card-sized circuit layout. Power consumption is 530 mW for listening/receiving and 770 mW for sending. Compared to the typical consumption of a MONSUN AUV, this corresponds to an overall power consumption of less than 6%. The modem achieves a data rate of up to 2 kbit s^{-1}, depending on overhead due to encoding and synchronization. The communication radius is above 10 m, an appropriate value for the envisioned swarm scenario. Flexibility is achieved through a modular filter design and software-based de-/modulation.

4 Future Work

Our study shows that hybrid underwater environmental monitoring is feasible. We have pointed out that it is possible to produce low-power, low-cost sensor buoys and autonomous underwater and surface vehicles, so that such monitoring applications become economically attractive. As next step, we will equip a small fleet of five MONSUNs with our acoustic modems and perform communication tests in inshore and coastal environments. We plan to manufacture sensor buoy prototypes for a real-world test deployment.

5 Acknowledgments

6 References

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