Lifeforms potentially useful for automated underwater monitoring systems

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Abstract

Biohybrids combine artificial robotic elements with living organisms. These novel technologies allow for obtaining useful data on the environment by implementing organisms as "living sensors". Natural water resources are under serious ecological threat and there is always a need for new, more efficient methods for aquatic monitoring. Project Robocoenosis introduces the use of biohybrid entities as low-cost and long-term environmental monitoring devices. This will be done by combining lifeforms with technical parts which will be powered with the use of MFCs. This concept will allow for a more well-rounded data collection and provide an insight into the water body with minimal human impact.

Introduction

Currently worsening environmental conditions pose a threat to global water supplies and communities inhabiting them. This trend causes for urgent need to gather water quality data globally and more efficiently. Traditionally, water monitoring studies are carried out with surveys, sample collecting and various sensors. This provides a precise and reliable readings on the examined water body. However, due to the immense complexity of aquatic environments, a need arose for a more extensive and continuous water monitoring. Project Robocoenosis aims to develop a novel methodology for that purpose, with the use of "biohybrid entities" (Thenius et al., 2021). These devices are made by combining the electrical and mechanical robotic parts with living organisms. This system allows for extracting useful information from the organisms which respond instantly to changes in the environment with various behavioural or physiological changes. The biohybrid will also be self-powering by being equipped with Microbial Fuel Cells (MFC). These structures consist of an anode and cathode chamber which extract electricity by relying on natural processes occurring in the sediments and the availability of organic matter. Here, the focus is placed on lifeforms and devices that can potentially provide valuable insight into the aquatic communities and environmental changes affecting them.

It is of merit to note that the concept of using organisms as biosensors is not entirely new (Kirsanov et al., 2014; Fini et al., 2009). The project Robocoenosis will combine existing technologies (Wang et al., 2015; Enviro-Analytical, 2021; Dzierżyńska-Białończyk et al., 2019) and well-researched organisms to construct a new, self-sufficient biohybrid. This concept aims to compliment traditional monitoring methods, providing an additional insight into the water quality. The combination of different lifeforms will allow a, so called, ecosystem hacking.

Methods

Lifeforms

Zebra mussel For the sake of biological safety, it is essential to use lifeforms from the respective environments to avoid introducing alien species (Stiers et al., 2011; Guzman-Novoa et al., 2020). First lifeform investigated for the underwater monitoring setup is zebra mussel *Dreissena polymorpha* (Pallas, 1771). It is a broadly distributed species considered invasive in most of Europe. Mussels have been considered useful bioindicators due to their longevity, clustered colonies and high vulnerability to the surrounding waters due to their feeding and breathing mechanisms (Grabarkiewicz and Davis, 2008). Its sensitivity to various sensors, especially low oxygen and heavy metals, often results in abnormal behaviour, such as closing the valves. This can be observed by attaching it to the robotic setup and observing its movements with continuous image analysis (Figure 1). When the valves present fluttering movements or are closed for a prolonged period of time, an alarm will be triggered to announce a potential disturbance to the environment.

Daphnia Another organism considered a useful bioindicator is the water flea *Daphnia* sp. (Müller, 1785). It is highly sensitive to many environmental stressors including changing salinity, oxygen levels, heavy metals and many others (Michels et al., 2000). Stress responses can include abnormal swimming (slower speed, increased sinking, spinning), disrupted phototaxy (light-related responses), haemoglobin accumulation and mortality (Rajewicz et al., 2021). These behaviours will be observed by continuous movement track-

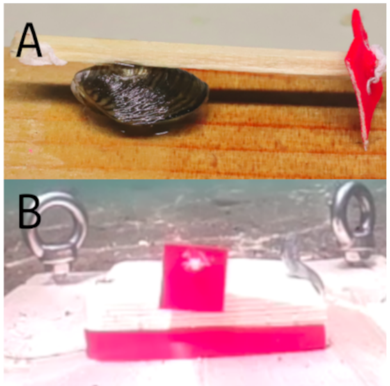

Figure 1: Zebra mussel mounted on the underwater setup A: red tag mounted on the top valve and B: view on the mussel from the camera attached to the setup.

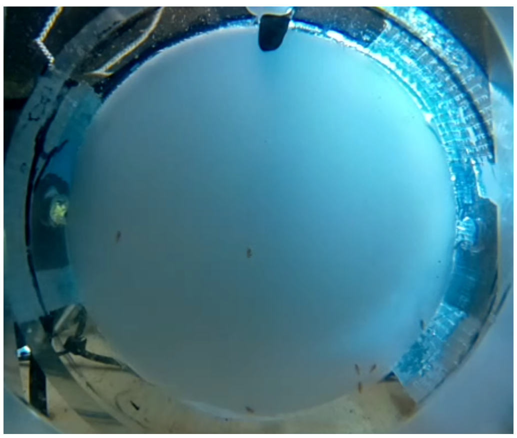

Figure 2: Daphnia swimming in the flow-through chamber with background illumination as part of the monitoring setup.

ing of the swimming animals enclosed in the setup. A flow-through cage was built where *Daphnia* can swim freely while being exposed directly to the surrounding waters (Figure 2). This will also allow the animals to sustain themselves normally by feeding on the algae present in the water. Because of the stress reactions occurring immediately after the exposure to the stressor, *Daphnia* can be a reliable source of information on the water condition.

Microbial Fuel Cells

Microbial Fuel Cell will be explored as a power source alternative as well as an additional bioindicator. Thanks to their working principles, MFCs can provide information on dissolved oxygen, toxins, bacterial activity and others. These can be monitored by tracking the electrical current produced and delivered to the biohybrid entity (Cui et al., 2019). Certain species of bacteria, such as *Geobacter sulfurreducens*, are able to perform aerobic breathing and produce an electric current (Poddar and Khurana, 2011). This proves a feasible method of a long-term production of electricity supplies that can be harvested by the MFC. The major limitation of this energy-harvesting method is that the currents provided are low in voltage and difficult to amplify. This will be resolved by using multiple MFCs connected by a super capacitor. Additionally, low-power electronics will be used for short periods of time and be put in sleep mode between the monitoring periods. This energy will be stored and used for powering micro-controllers and other low-energy devices contained within the biohybrid.

Discussion

In this work, certain ideas and concepts used in the project Robocoenosis are presented. With the use of biohybrid entities, environmental monitoring can be performed more efficiently by removing the time usually used for sampling surveys, enabling a faster detection of catastrophic events, such as leakages of toxins, heavy metals, etc. Using behavioural and physiological reactions as natural sensors requires the use of well-researched organisms and meticulously planned environmental setups. Data obtained with this methodology will come with a degree of ambiguity due to the complexity of the aquatic environment and varying degrees to which they affect the living organisms. For this reason, the method developed is meant to compliment the classical sensor approach. The use of organisms will allow for monitoring the overall quality of the water body and reduce the need for maintenance and costs usually associated with using classical probes and sensors. The big advantage of biohybrid entities compared to fully artificial systems is that lifeforms have the ability to self-calibrate and self maintain. Compared to technological systems that usually need frequent maintenance (ThermoScientific, 2007), a simple observation of lifeforms leaves a longer maintenance break. In combination with energy harvesting and low-power electronics (MFC and STM32 microcontroller), it is possible to create an ultra-long runtimes of possibly several years. This leads to long-lasting, affordable and reliable measuring system. In theory, the system works with no maintenance, although the practical limitations will be investigated.

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