Water Intellibuoy – An EPS@ISEP 2018 Project

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Abstract. This paper reports the collaborative learning experience of a team of five Erasmus students who participated in EPS@ISEP – the European Project Semester (EPS) at Instituto Superior de Engenharia do Porto (ISEP) – during the spring of 2018. EPS@ISEP is a project-based learning capstone programme for third and fourth year engineering, product design and business students, focussing on teamwork and multidisciplinary problem solving as well as on the development of sustainable and ethical practices. In this context, the Team developed a drifting intelligent buoy to monitor the water quality of urban water spaces. Motivated by the desire to build an intelligent buoy for urban water bodies, the Team conducted several scientific, technical, sustainability, marketing, ethical and deontological analyses. Based on the findings, it has derived the requirements, designed the structure and functional system, selected the list of components and providers and assembled a proof of concept prototype. The result is Aquality, an intelligent drifting buoy prototype, designed for private sustainable pools. Aquality monitors the quality of the pool water by measuring its temperature and turbidity, while interfacing with the user through a mobile application. Considering the EPS@ISEP learning experience, the Team valued the knowledge and skills acquired, and, particularly, the collaborative learning and working component of the project, *i.e.*, working together towards one goal while maintaining high motivation and cohesion.

Keywords: Collaborative learning, Project based learning, Technology, Education.

1 Introduction

The European Project Semester (EPS) is a one semester capstone project offered by 19 European engineering schools to engineering, product design and business undergraduates. EPS challenges students from multiple educational backgrounds and nationalities to join their competencies to solve multidisciplinary real life problems in close collaboration with industrial partners and research institutes during the spring semester [4]. In 2018, Team 2 was composed of Sten Pajula, an Electrical Engineering student from Estonia; Geert van Velthoven, an Industrial Engineering and Management student from the Netherlands; Charlotte Imenkamp, a Biomedical Engineering student from Germany; Mireia Estruga Colen, a Mechanical Engineering student from Spain and Hervé Houard a Product Development student from Belgium. The Team chose to develop an intelligent drifting buoy to monitor water quality because this challenge matched the interests of the whole Team and allowed the Team members to individually contribute with their educational knowledge.

Water is one of the most important resources on Earth. When humans come in contact with water, in pools or urban lakes, it becomes necessary to monitor and maintain the water quality on a regular basis. The World Health Organisation states that the water quality is a "parameter of immediate operational health relevance (. . .) and should be monitored most frequently in all pool types" [7]. An unmaintained pool can lead to the growth of harmful infectious microorganisms and bacteria. To efficiently maintain the water quality of a pool, it is mandatory to continuously monitor the condition of the water. This proves to be a time and money consuming activity [6]. With Aquality, this task is simplified since it autonomously monitors the water quality and informs the user of the current water quality status.

The Team's vision was to design, build and test a buoy equipped with sensors to collect data on the quality of the water in natural ponds or pools. The buoy should drift on the water, collect data and inform or alert the user according to the findings. To determine the quality of the water, two parameters were chosen: temperature and the turbidity level. Together, they provide information about the condition of the filtration system, which is directly connected to the oxygen saturation, a highly relevant water quality indicator for ponds or pools inhabited by fishes or plants.

The Team was able to design, create and test together the Aquality prototype, which autonomously monitors water quality and, with the help of the companion mobile application, informs and makes relevant suggestions to the user. This comfortable solution contributes to save time and money in terms of water pool quality monitoring and maintenance. By working together in a multidisciplinary team, the Team members had the opportunity to learn from each other and collectively, and achieve further than they would have individually.

This paper is divided in five sections. This first section describes the context, team, problem, goals and contributions. The second section describes the background of the project, namely the state of the art, marketing, sustainability and ethics studies. Based on this research, the Team designed and developed the product which is described in section three. Section four contains the functional test results. Finally, section five presents the conclusions of the project and suggestions for further work.

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[4] https://www.isep.ipp.pt/Course/Course/44

2 Background

This section presents the different background studies conducted by the Team to define the proposed solution.

2.1 Related Work

After an initial brainstorm, the team decided to focus on natural swimming pools. A natural swimming pool uses biological filters, such as plants, to filter and maintain the quality of the water. Natural pools require less maintenance than conventional ones, the year-to-year costs are lower after construction is finished and they are chemical free. They only need to be kept well-skimmed and clean of debris. The filtration system works through the roots and sediments as in a natural lake. This causes turbidity depending on the presence of algae. Because of the filtration system it is impossible to completely remove sediment and living organisms and a high turbidity could indicate a problem in the filtration [3,10]. Even though the popularity of natural swimming pools is increasing [10], there are no dedicated products on the market for monitoring its water quality – only the companies who build and maintain these pools offer post-sale services. Nevertheless, this section presents four products of interest with a wide range of application both in terms of environments and sensors:

- DIY buoy: The Do It Yourself (DIY) buoy is a scientific product, whose purpose is to collect data for weather forecast. It's a start-up prototype made by a team based in North America. It runs on the Arduino Trinket Pro 5 V from Adafruit. A solar panel charges a small Lithium Polymer battery to provide additional power. The buoy collects data, including latitude and longitude, speed, instantaneous direction, water and internal board temperature and tilt angle. The data is transmitted via a satellite communication link [2].
- Bluetooth Pool Thermometer: The wireless pool thermometer shows the current temperature in an application. It includes a check for high and low temperatures and notifications, when the temperature exceeds the upper limit or the supported range and when the battery is low [1].
- Seneye Pond: The Seneye Pond measures the water temperature, Ammonia, pH, total light and water level. The sensors are connected via Wi-Fi or USB to a website, where additional advice is provided [9].
- pHin: pHin continuously measures the chemicals and temperature in a pool or hot tub. It is connected to a mobile phone app and a smart monitor via Wi-Fi and notifies whenever the water quality needs to be balanced. This product is sold as a product-service system where services, like repairs, upgrades and maintenance, are provided through the payment of a monthly fee. In the case of pHin, the monthly fee also includes the delivery of chemicals [8].

Taking into account the sensor comparison in [4], the team considered the use of pH, turbidity, temperature, oxygen and motion sensors. The comparison showed that pH, turbidity and temperature sensors were within the reach of the

100 € budget allocated to the project. Finally, the Team decided to measure the turbidity and temperature, estimate the oxygen value based on the correlation between oxygen saturation and water temperature, instead of using an oxygen sensor, and drop the pH sensor since it requires frequent calibration.

Based on this state of the art study, the conclusion was that the buoy should facilitate the maintenance of a natural pool. This rising business offers the perfect niche and the buoy will combine the best features of the related products. The main components will be a solar panel, a battery, a Wi-Fi module and turbidity and temperature sensors. The sensor data will be presented in a mobile application, which will also offer additional advice about natural pool maintenance and the state of the buoy. For a better customer service, the team will also adopt a product-service system.

2.2 Marketing

Based on the market analysis, the team decided to create an intelligent buoy for natural swimming pools. It will be sold as a Product Service System, meaning that customers will receive advice on how to maintain the water quality of their pool. Besides, the company is responsible for the maintenance of the product. The buoy should be sold through the Internet, targeting families with natural swimming pools, wishing to easily estimate water quality. These customers will pay a monthly fee around 20 €.

2.3 Sustainable Development

The team performed the life-cycle analysis of the product as well as for the future theoretical company involved in the manufacturing. The environmental, economic and social dimensions of sustainability were considered. The conclusions made the Team opt for polyvinyl chloride (PVC) – for recycling convenience – as the product's main material and offer client service, instead of simply a product. That means that the client will return the product sporadically, when updates on hardware are made. The company will reuse the exterior and upgrade only the interior, to reduce the waste produced, before returning the product to the client.

2.4 Ethical and Deontological Concerns

The ethical and deontological study helped the Team gain a better understanding of the issues which appear during the development of a product, namelly, in terms of environmental ethics. The Team believes the buoy could help making natural pools more attractive and the pool industry more sustainable. Therefore, the buoy must be sustainable and comply strictly with the environmental ethics. Combined with sustainability, the ethics analysis has again proved PVC to be the correct choice of building material. The sales and marketing ethics resulted in a clear vision of the advertising, price and employees policy.

3 Project Development

Aquality was developed to help monitor and maintain the water quality of natural pools. This water quality is ensured by a fragile ecosystem, filtering the water in an environmentally friendly way. Understanding the fluctuations in the quality of the water is thus of utmost importance. Different parameters are measured to allow the user to get a clear and understandable overview of the health of the pool's micro-biotope.

3.1 Requirements

The broad requirements for developing Aquality were defined in the project proposal. This included a limited budget of 100 €, the usage of open source software and technologies, opting for low-cost hardware solutions, complying with the applicable EU directives and using the International System of Units. Besides these general requirements, the Team derived the following requirements:

- Functional requirements: The buoy must be a self sufficient prototype, which floats on the surface and collects data.
- Usability requirements: The data must be read and presented in a user friendly way (mobile application / browser).
- Environmental requirements: The materials and manufacturing must comply with environmental requirements, according to environmental and sustainable development practices.

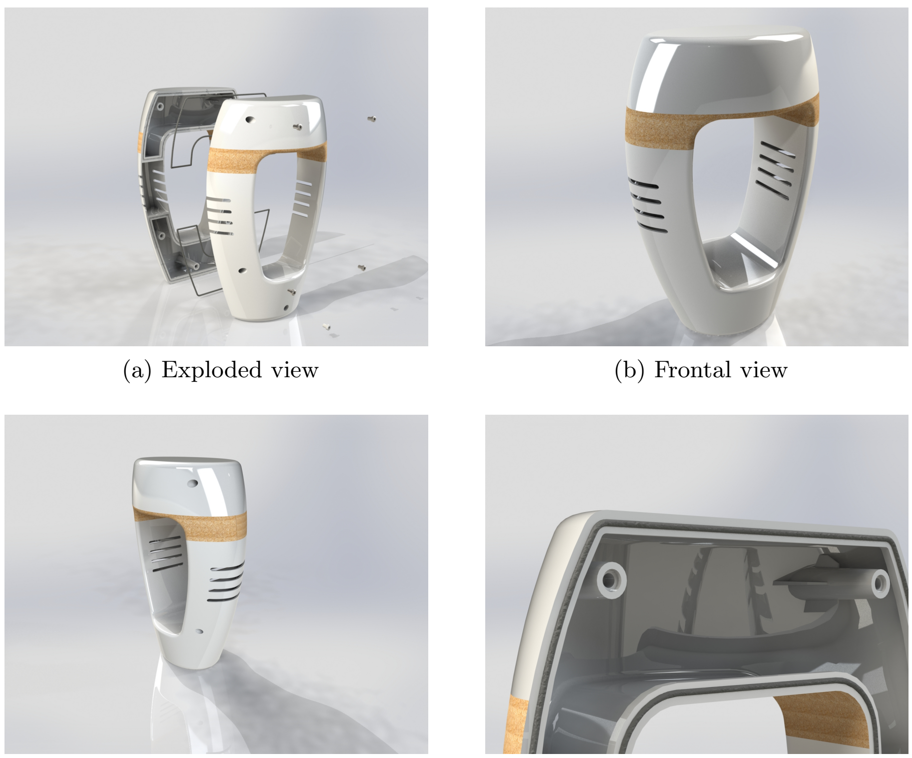
3.2 Functionalities

The user will communicate with the device through Wi-Fi via a smartphone application. The device will send out relevant data, as temperature and turbidity, and notify the user about ongoing changes in the pool. This gives the owner the possibility to be remotely notified.

3.3 Structure Design

The main architecture of the product was explored using hand-drawn sketches. With the help of the computer aided design (CAD) software SolidWorks, these sketches were translated into a 3D model. Multiple iterations were needed to obtain a model fit for a 3D printer. In each iteration the most relevant renders were made, using SolidWorks PhotoView 360, to allow the Team to assess the model in detail. During this design stage, all requirements were kept in mind.

The final result, depicted in Figure 1, is a buoy consisting of two watertight compartments where the different components are housed. Between these compartments, the Team created a flooded area to place the sensor probes without compromising the aesthetics of the buoy. Very early, the Team realised that the prototype would have to be made of two separate shells. This meant that a reliable solution had to be found to join the two shells together tightly and ensure the water tightness of the buoy. The solution was to place a rubber seal between the two watertight compartments and fasten both halves together with five screws (two on the top and three on the bottom part of the buoy) plus o-rings. Due to the somewhat complex design of the buoy, the Team chose to 3D print the prototype. This meant that the design had to be adapted further. One of the major changes was related to the maximum printing dimensions of the available 3D printer. Each shell had to be split in two halves, so that they could be successfully printed, and, afterwards, be glued together. Figure 1 displays the details of the designed structure.



(a) Exploded view (b) Frontal view

(c) Lateral view (d) Rubber seal and screws

Fig. 1: Aquality buoy structural design

3.4 Control System

The electronics inside Aquality features a Wi-Fi enabled controller, sensors and a power unit, according to the conceptual diagram of the prototype control system displayed in Figure 2. Since Aquality is designed to be self-sustainable, the power unit includes a solar panel, battery and charger. The type of sensors installed was constrained by the budget.

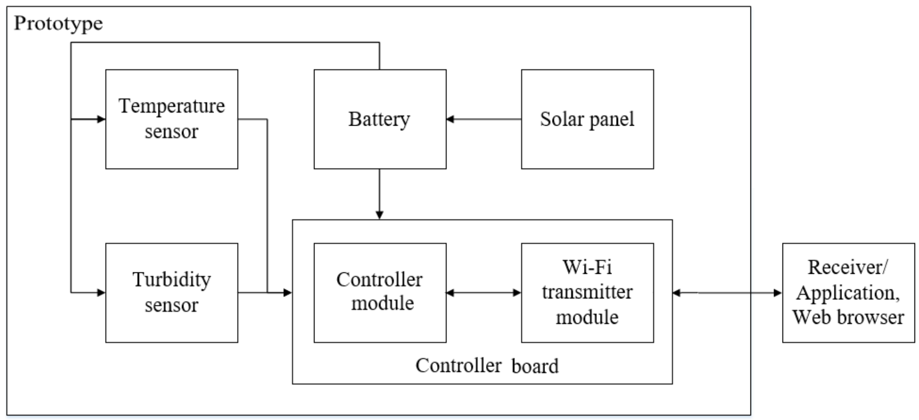


Fig. 2: Conceptual diagram

3.5 Mobile App Development and IoT Platform

The smartphone application is an important feature to offer a pleasant user experience and to drive competitive differentiation of the product. The first step of developing the application was to identify the use cases and define the main functionalities, which are to display the water temperature, air temperature, turbidity and water quality, offer support and recommend maintenance (animals or plants). Figure 3 presents the use case diagram, *i.e.*, the different ways the user may interact with the app. The on-board sensor data is communicated and stored in a cloud-based IoT platform named Easy Internet of Things (EasyIoT) [5]. Figure 4 shows the dashboard of the EasyIoT, displaying Aquality's sensor data.

4 Tests, Results and Discussion

To ascertain the correct functioning of Aquality, several software and hardware tests were planned, including the mobile application, consistent and correct data readings from sensors and water tightness to keep the electronics safe. The detailed planned functional tests were the following:

- Software tests: (*i*) reading sensor data; (*ii*) uploading sensor data to the cloud-based EasyIoT platform; and (*iii*) downloading from the EasyIoT platform and displaying sensor data on a web browser/mobile application.

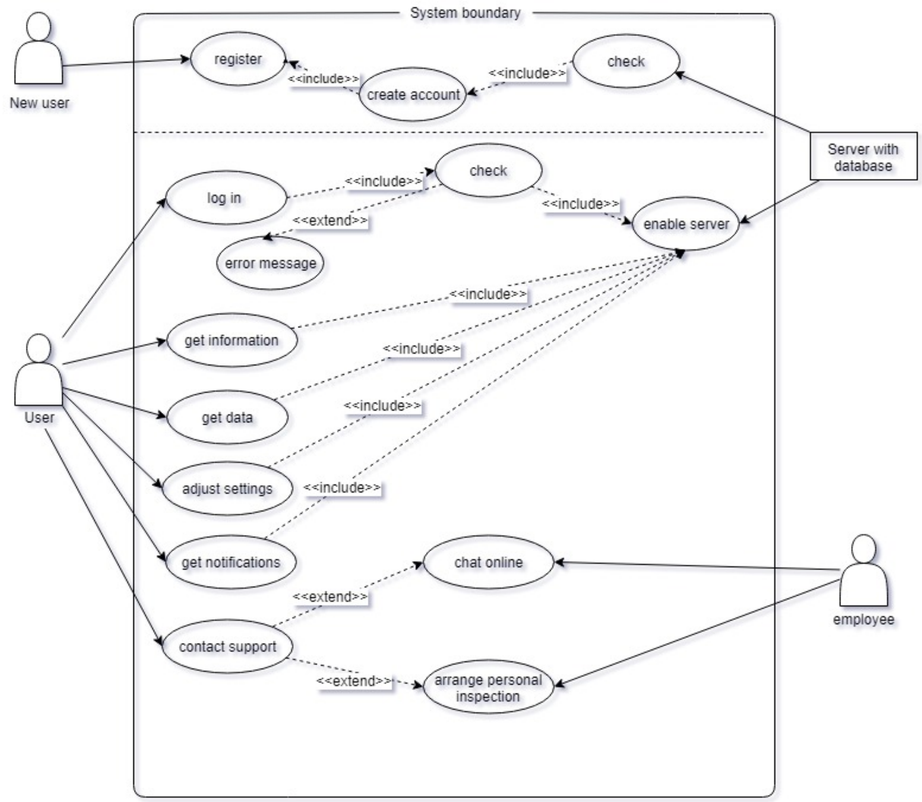


Fig. 3: Use case diagram

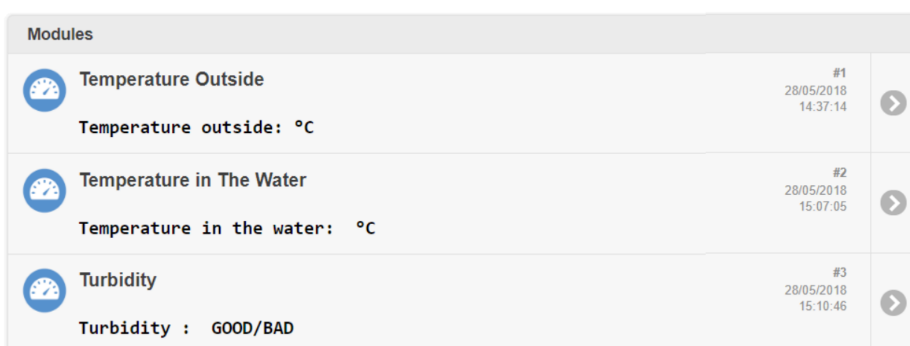


Fig. 4: Displaying the sensor data in the EasyIoT platform dashboard

- Hardware tests: (*i*) watertightness; (*ii*) floatability; (*iii*) consistency and credibility of the sensor readings; (*iv*) Wi-Fi reach; and (*v*) autonomy of the prototype.

4.1 Tests

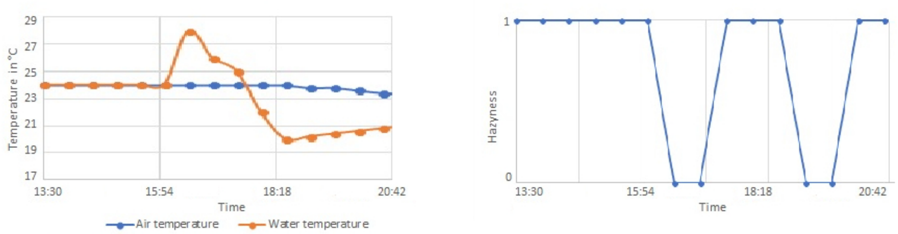
In the current stage of the project, the software tests were performed, but the hardware tests were postponed due to the 3D printing delay.

The methodology behind the software testing was based on trial-and-error, which means that the code was tested, debugged and tuned until the desired results were achieved.

Concerning the planned hardware tests, *watertightness* will be tested by submerging the prototype underwater for six hours. Afterwards, the prototype interior will be examined for leakages. *Floatability* will be tested by putting the buoy in the water. To achieve the desired waterline on the product, the ballast shall be adjusted. The *sensors consistency and credibility* will be tested by submerging the sensors and logging the readings. These readings will be compared to calibrated scientific measurement devices and the sensor readings calibrated by software. The *Wi-Fi reach* will be tested by measuring the approximate distance between prototype and Wi-Fi router, from the spot where last signal from prototype was received. Finally, the *autonomy of the prototype* will be tested by measuring the time the battery takes to charge and achieve sufficient amount of energy to power the prototype.

4.2 Results

The software tests were performed by submerging one temperature sensor in a water cup and leaving the other outside. The turbidity was tested with two separate cups, one with hazy water and another with clear water. Figure 5 displays the results of both tests.

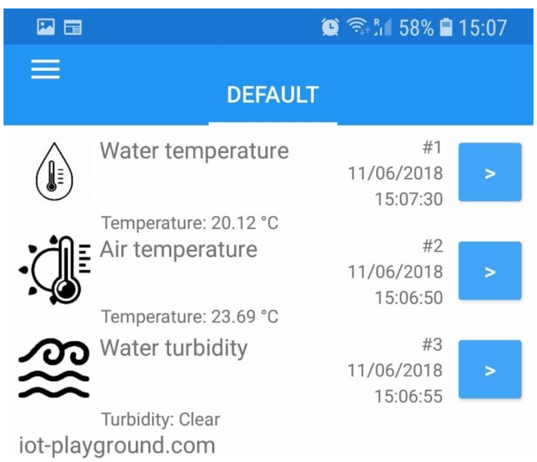


(a) Temperature (b) Turbidity

Fig. 5: Sensor tests

Figure 5a depicts the temperature test: (*i*) before 15:54, both temperature sensors were unsubmerged; (*ii*) after 15:54, one sensor is held in palm of the hand; and (*iii*) after 16:00, the same sensor was kept submerged in the water. The temperature measured by this sensor slowly rose before decreasing and stabilizing near room temperature. The turbidity sensor was tested by changing the sensor between the clear and hazy water cups. Figure 5b shows the clear – zero (0) – and hazy – one (1) – turbidity readings. In this test, the placement of the sensor changed at 16:00, 17:00, 18:30 and 19:30.

Finally, Figure 6 displays the tangible outcomes of this EPS@ISEP project: the EasyIoT mobile application displaying the sensor readings (Figure 6a) and the final printed prototype (Figure 6b).



(a) EasyIoT mobile application

(b) Final prototype

Fig. 6: Final outcomes of the project

5 Conclusion

The main objective of the project was to motivate and unite the Team around the development of Aquality's proof of concept prototype, while improving the active learning and soft skills of each member. This paper reports this journey.

The product under development is user-friendly, features Internet connection and is self-sustainable in terms of power. The user-friendly application and the information it provides is unique as far as the team knows. Because of trends in pool management and worlds constant thrive for a greener future, the potential market is expanding.

Further development is necessary to transform the prototype into a product ready for release into the designated markets. The Aquality prototype was constrained by the time, budget, insufficient knowledge in some technical areas and lack of experience in product development. The following aspects should be considered for future development:

- Development of a professional mobile application;
- Upgrade the solar panel to fully meet the buoy's energy requirements;
- Reduction of the buoy dimensions, including the development of smaller dedicated sensors.

Regarding the collaborative learning and teamwork, maintaining the motivation and unity of the Team was not always an easy task. The differences in culture, study fields and personalities can lead to frictions within the teams. In the case of the Aquality's Team, none of the latter issues surfaced because the Team members were determined, but flexible. The acquired project management skills helped to allocate tasks, meet deadlines and achieve the goals of the project.

Quoting Sten Pajula, who was responsible for the prototype electronics and coding, "*The overall experience of the project has been positive. The weekly meetings with the supervisors and Team members made the semester pass seamlessly. The Team had the project deadlines always under control and constant progress was a result of well structured work, which would have been much harder without supportive supervisors and lectures. In this semester, I have learned the basics of product development, marketing and improved the knowledge in my study field*".

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