

Smart Bicycle Probe – An EPS@ISEP 2020 Project

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Abstract. Air pollution kills approximately 7 million people every year and nine out of ten people are exposed to high levels of airborne pollutants. This paper describes the design of a bicycle air probe by a team of multicultural and multidisciplinary students of the European Project Semester, during the spring of 2020. This learning experience started with the analysis of the state-of-the-art, ethics, marketing and sustainability dimensions, and was followed by the design, development and simulation of a proof-of-concept solution. The result is GOairLight – a bicycle probe paired with a mobile app. The probe collects air quality, humidity and temperature data as cyclists ride, while the mobile app shares the collected data with the community, by means of a cloud database, presents relevant air quality information and suggests less polluted routes. Furthermore, it relies on a sustainable energy source – a dynamo powered by the cyclist – and automatic lighting. The latter feature improves cyclist visibility and raises the awareness towards the cyclist, contributing to increased road safety.

Keywords: Collaborative learning, European Project Semester, Sustainability, Air pollution, Community, Bicycle

1 Introduction

The European Project Semester (EPS) is a one-semester capstone programme designed by Arvid Andersen in 1995 to prepare engineering undergraduates to act and think globally. It adopts project-based learning and multicultural, multidisciplinary teamwork to foster scientific, technical and inter-personal skills. EPS is currently offered by a network of 19 European universities, including, since 2011, the Instituto Superior de Engenharia do Porto, (ISEP) of the Polytechnic of Porto.

GOairLight is a product designed by a team of five EPS@ISEP students during the spring of 2020. The team encompasses a variety of origins (Finland, Belgium, Scotland, France and Poland) and fields of education (computer science, product design, mechanical engineering, electrical power engineering, and environmental sciences). EPS@ISEP provides the learning framework for the team to apply and develop the skills required for the project.

The open-ended project requirements included the design, simulation and test of a functional, ethically and sustainability-aligned bicycle probe solution.

This would be compliant with applicable regulations. The cost of the materials and components required to build a prototype should not exceed 100 €.

The bicycle probe is a smart sensing bike device aimed for smart cities. The goal of GOairLight is to collect and share information about urban air quality and increase the safety of cyclists. The latter is achieved by including, in the front of the device, three bright light emitting diodes (LED). Since transportation is responsible for 31 % of total energy consumption in Europe [1], the European Commission wants to promote clean, inexpensive and sustainable urban transport to reduce air pollution. The Air Quality Framework Directive 96/62/EC [3] is the leading directive towards the reduction in the atmospheric pollutants. Air pollutants that have a limit value are ozone (O_3), particulate matter (PM10 and PM2.5), and nitrogen dioxide (NO_2). The bicycle probe will collect information about the air pollution conditions in the urban space and the gathered data will be publicly disseminated and transferred to an Internet of Things (IoT) cloud so that the public can follow the air condition in real-time. In this context, GOairLight acts simultaneously as a probe and as a disseminator of urban air quality to the community, and, in the long-run, provides riders with less-polluted alternative routes.

This paper continues with the research, design, simulation, tests, discussion and conclusion regarding the bicycle probe EPS@ISEP project.

2 Background

This section analyses related products as well as the ethics, marketing, and sustainability aspects relevant for the creation of an innovative, ethically and sustainability-driven bicycle probe design.

2.1 Related Products

Related products refer to solutions already on the market and are a valuable source of information to characterise the state-of-the-art. Tech accessories for bikes can be organised into three categories:

- **Affordable devices**, like the B'TWIN 500 [9], usually display velocity, distance, and time (VDT). The most advanced, e.g., the MSW Miniatic [8], provide also routes, which can be synchronised with a mobile app. The price of affordable devices reaches 65 €.
- **High-end devices** are equipped with high-quality sensors and materials. For example, Smarthalo 2 provides a compass navigation, automated lights, anti-theft alarm among others [16]. Other products, like the Cobi app [2], are optimised for bikers. It shares weather information and can be connected with Apple Health or Google Fit Integration devices. The price of high-end options can go up to 219 €.
- **Special devices** like Speednite [17], which is a turning indicator with a tilting head, include a system with brake light and an SOS feature. Another

example is the I LOCK IT GPS [13], which offers live tracking and warns the user in case of theft, thanks to a real-time alarm notification. The average price of special devices is 144 €.

Table 1 compares existing solutions. This comparison shows that there are no devices combining VDT, tracking, automated lighting and a mobile app interface. Furthermore, products with this collection of functionalities are expensive (up to 219 €). As a result, the team decided to create a solution comprising not only

Table 1. Product Comparison

| Category | Product | VDT ^a | Tracking | Automated Lighting | App |
|------------------|--------------|------------------|----------|--------------------|-----|
| Basic devices | B'TWIN 500 | ✓ | | | |
| | MSW Miniac | ✓ | | | |
| | Cannandale | ✓ | ✓ | | ✓ |
| High-end options | Smarthalo 2 | ✓ | ✓ | ✓ | ✓ |
| | Cobi | ✓ | ✓ | | ✓ |
| | Beeline | ✓ | ✓ | | ✓ |
| Special devices | Speednite | ✓ | ✓ | ✓ | ✓ |
| | I LOCK IT | | ✓ | | ✓ |
| | Garmin Varia | | | ✓ | ✓ |

^a Velocity, Distance, Time

these, but also a set of distinctive functionalities: (*i*) air quality, temperature, and humidity monitoring; (*ii*) renewable power; and (*iii*) multi-functional packaging.

2.2 Marketing

Air pollution kills 4.2 million people every year as a result of exposure to ambient and outdoor air pollution [15]. GOairLight recommends less polluted routes as a solution to reduce biker exposure to air pollution. The goal is to create a strong value proposition because GOairLight competes with existing solutions. Furthermore, and in the long-term, the team wants to raise customer awareness towards air quality issues as well as road safety. The user must feel connected and part of the community.

GOairLight target market is represented by the middle-upper class segment, which owns smartphones and bicycles. After researching on the most likely population to use GOairLight probe, the target was the German population, where the Gross Domestic Product (GDP) is one of the highest of the world [10], and the smartphone and bike utilisation score higher in Europe [7]. GOairLight is a novel and unique product, inducing potential customers to pay for this new technology. The SWOT analysis showed that the main threat is the acquisition

of both a smartphone and a bike. However, GOairLight team could partner up with municipalities to furnish their bikes, exploring market opportunities.

The Product, Price, Promotion and Place marketing mix (4P) helps to adapt the marketing strategy to the target market. In this respect, GOairLight will: *(i)* provide cyclists and the community with up to date urban air quality information; *(ii)* compete against related high-tech products, with prices ranging from 99€ to 219€, and contribute to improve the health and safety of the user and community for a price of 149€; *(iii)* be promoted mostly through social network advertising; and *(iv)* rely on a dedicated information and sales website for retail businesses and end-customers.

2.3 Ethics

The design, manufacturing and selling of a new product involves engineering, marketing, environment and liability ethics. In this regard, the main goal for the team, as future engineers, was to create a professional and trustworthy brand for our product. The marketing strategy was set to be, first and foremost, truthful to users and fair towards competitors. The brand will not adopt false advertising and will provide the public with clear and comprehensible information on the product. In terms of environmental ethics, the team adopted a power system composed of a human-operated dynamo (power generation) and rechargeable batteries (power storage). Considering liability ethics, the team must be compliant with applicable the European Union Directives:

- Measuring Instruments Directive [4] ensures that the scientific measurements (CO₂, temperature and humidity) are done accurately.
- Radio Equipment Directive [5] regulates the safety of user data sent through radio communication.
- Restriction of Certain Hazardous Substances EU Directives [6] restricts the usage of harmful substances in devices, allowing for more efficient recycling.

2.4 Sustainability

Sustainability-driven design considers the three pillars of sustainable development. Specifically, this project contributes to two of the 17 Sustainable Development Goals (SDG) defined by United Nations: SDG 11 – Sustainable cities and communities; and SDG 7 – Affordable and clean energy. To reduce the environmental impact, the team carefully chose the materials, components and designed for re-usability. The main case of the product is made of Polypropylene (PP), which is easily recyclable and resistant over time [14]. Despite common thought regarding the environmental damages caused by plastic utilisation, PP was the best compromise between efficiency, price and sustainability. The team decided, regarding re-usability, to: *(i)* create a service that allows the customer to substitute parts; and *(ii)* design a reusable packaging. The part substitution service follows the principle of circular economy: the user will reuse the product by repairing and recycling instead of throwing it away (opposed to the linear economy

principle). Given that, in 2017, 173 kg of packaging waste was generated per person in the EU [11], the GOairLight packaging is reusable. The shipping package, made of a bottle-recycled polyethylene terephthalate (PET) textile, can then be fitted to the middle bar of the bike and reused as a waterproof bag.

3 Proposed Solution

The creation of the GOairLight solution encompassed the following steps:

- Analysis of competing products to identify existing and missing features;
- Definition of a strong value proposition through a good, innovative concept;
- Selection of a name and logo matching the values of the product;
- Design of the control system schematics, including the selection of components and considering dimensions, power consumption, features and price;
- Creation of first drafts;
- Analysis of the product marketing, sustainability and ethics;
- Creation of communication supports (leaflet, flyer, A2 poster);
- Creation of the detailed drawings together with a 3D model of the device and packaging;
- Simulation of the control system;
- Design, development and test of the mobile application.

3.1 Concept

GOairLight probe was designed to fit the handlebar of a bike. In that position, and when the bike is moving, it collects and sends air quality data, such as eqCO₂ and Volatile Organic Compounds (VOC), temperature and humidity, to the GOairLight mobile app. The application not only receives and uploads the air data to an IoT cloud platform, but also suggests less polluted routes to take, preserving user well-being. The IoT cloud platform stores, for the benefit of the community, the air data collected by GOairLight devices. Moreover, the device switches on or off the 3-LED module automatically, depending on the light intensity. The goal is to improve the safety and visibility of the cyclist. The power is generated by the dynamo positioned on the side of the front wheel and is stored in the battery inside the main case. This way, the whole device depends on human energy and, thus, relies on a sustainable source of energy.

3.2 Design

The probe was designed to fit every bike. The mounting system is composed of three mounting screws (M5 25 mm) to attach the back case to the handlebar while the front case slides and locks to the back case. This system allows the user to easily assemble and disassemble GOairLight.

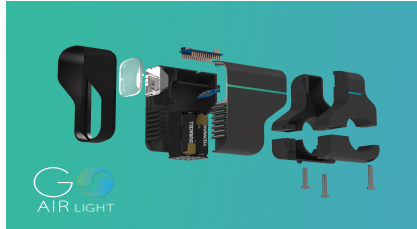
The front case is composed of a shade that acts like an extra protection against rain, and a light cover that protects the lighting module. The air flows

through a rainproof opening, allowing the measurement of air quality. The lighting module is composed of three SSC P4 LED emitters and a reflector to provide enough light intensity for seeing and being seen. The CCS811 air quality sensor collects eqCO_2 and VOC data, and works together with the Nano 33 BLE sense board (Arduino). The battery consists of four rechargeable lithium-ion 2450 mA h units charged by the dynamo. According to Table 2, the maximum expected power consumption is less than 0.5 W h.

Table 2. Maximum expected power consumption

| Component | Quantity | Voltage Current Consumption | | |
|----------------------------------|----------|-----------------------------|-------|-------|
| | | (V) | (mA) | (W h) |
| SSC Seoul P4 (U-bin) LED emitter | 3 | 3.7 | 12–20 | 0.056 |
| Arduino Nano 33 BLE sense board | 1 | 3.3 | 15 | 0.050 |
| CCS811 Air quality sensor | 1 | 3.3 | 26 | 0.086 |
| H-bridge | 1 | 5.0 | 0–36 | 0.180 |
| Total: 0.484 W h | | | | |

The GOairLight device weighs a total of 149 g and is made of two PP parts connected through a slide and lock mechanism. The front case, with a volume of $8 \text{ mm} \times 112 \text{ mm} \times 45 \text{ mm}$, holds the main device and weighs 75 g. The back case or the mounting part, with a volume of $75 \text{ mm} \times 112 \text{ mm} \times 45 \text{ mm}$, weighs 74 g. The slide and lock mechanism provides an elegant, user-friendly solution to attach and remove the front case and, thus, prevent theft. Figure 1 presents the exploded view (Figure 1a) and the 3D model (Figure 1b).



(a) Exploded view



(b) 3D Model of device

Fig. 1. GOairLight design

The design of the packaging solution considered its standard protective role during transport as well as its reuse as a waterproof bag. The result was a multi-functional object that can: (i) hold probe and dynamo during shipping; (ii) store personal belongings during cycling; and (iii) carry, once removed, the front case. The packaging is made of recycled PET-textile, has a volume of

180 mm \times 150 mm \times 50 mm and weighs 90 g. After unpacking, it can be attached to the frame of the bike using three included Velcro strips. Figure 2a presents the packaging solution, including the package with the device (Figure 1a) and the re-purposed package (Figure 2b).

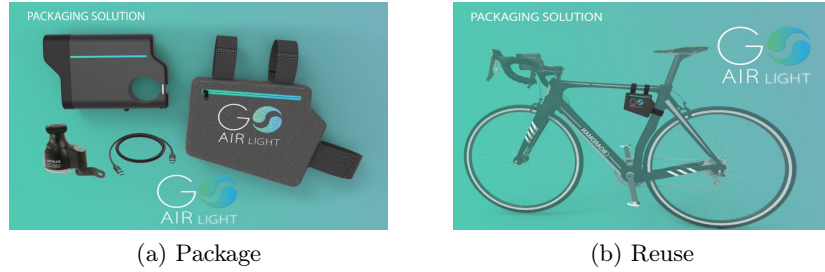


Fig. 2. GOairLight packaging design

3.3 Application Development

The mobile application has five main purposes: *(i)* download the probe data (Bluetooth connection); *(ii)* store the probe data in its internal SQLite database; *(iii)* upload the probe data to the IoT cloud platform (online mode); *(iv)* download relevant data from the IoT cloud platform (online mode); *(v)* present the relevant data to the user. The presentation of data can take several forms: show the current probe measurement; show the data gathered by the user on a map (offline mode); and show the community data (online mode).

The application is being written in Java programming language for devices with Android 5.1 or higher. The SQLite database is structured in two tables: the location and CO₂ level table, updated every 5 s, and the temperature and humidity table, updated every 2 min. The selected IoT cloud platform was Google Cloud Firestore. It contains a collection for each data type plus one for the users. Each data type document comprises the data, key, biker identification and timestamp. The Firebase is also responsible for handling user authentication, allowing the user to access community data via Google Analytics.

3.4 Simulation and Tests

Control System Simulation The simulation was carried out using Tinkercad, a virtual simulation environment for electronic systems. To simulate the system, the team was forced to use the components available in the provided library. Unfortunately, it does not include any Bluetooth connectivity device.

Firstly, the Arduino Nano BLE Sense was substituted by the Arduino Uno Rev3. This led to replacing the temperature and light level sensors integrated in

Arduino Nano with external ones and resign entirely from simulating humidity sensor. The CCS811 gas sensor was replaced by one with similar functionality — the Winsen gas sensor. Due to the characteristic of the software, some elements were used symbolically, like the dynamo and batteries configuration, since the batteries were registered as constantly charged. The boost converter was simulated using the Arduino itself. Figure 3a shows the simulation environment.

The results of the simulation were quite promising. First, the LED reacted correctly to electric current changes and, later, to a photoresistor used to simulate light intensity changes in the environment. Next, the team tested with success the air quality sensor, visualising changes of pollution level with an additional coloured LED. Finally, the temperature sensor was tested by writing the registered values in the console and comparing with those set on the simulator. The simulation showed that the implemented Arduino code was able to read values from the gas, light and temperature sensors and actuate several LED according to the readings of the sensors.

GOairLight App At the time of the writing of this paper, the application development is still in progress. So far the application is able to store and present data from the local database, which is currently populated with fake data, and upload/download data to/from the remote IoT database. Although the team cannot give any conclusive results now, these will be available mid-June. Figure 3b depicts the application mockup.

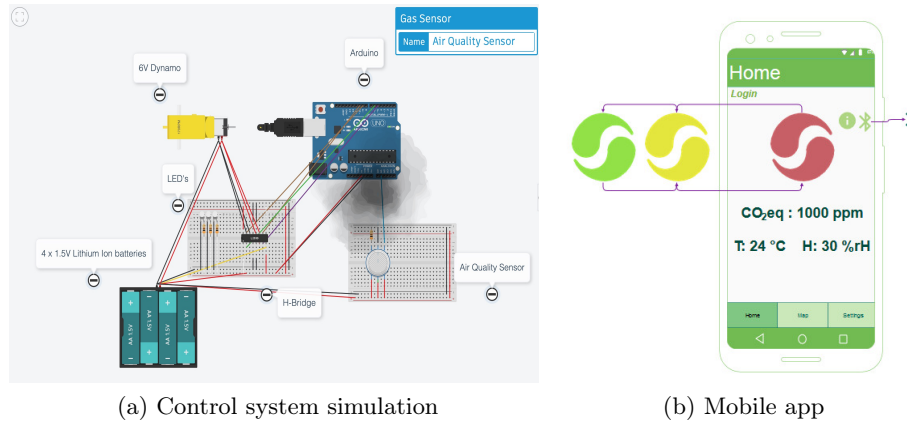


Fig. 3. GOairLight tests

4 Discussion

The simulation allowed a partial test of the Arduino code, namely, of the code that gathers data from the CO₂, temperature and light sensors and controls two LED according to the light and CO₂ levels. So far, the application stores and presents data from the local database, currently populated with fake data, and sends/receives data to/from the IoT database. These positive results indicate that, as soon as the mobile app is finished, it will be possible to exemplify further the concept, i.e., recommend less polluted paths from origin to destination.

The system can positively impact its users, making them more aware of the environment they live in and more conscious of their health. However, like most applications concerning health, it may lead to an unhealthy fixation with commuting only in clean air for some users. The combined results can possibly draw attention to the greater problem with pollution in cities.

By design, the data used in the application is meant to come from the probes. This means the collected data are dictated by user habits and willingness to use the system regularly. This means that while data from frequently visited and popular places will be more accurate, some paths might never or rarely be updated. Another limitation is the dynamic nature of pollution levels, which can be influenced for short periods of time by traffic conditions, making some measurements not indicative of the general state of air in that area. Both factors could negatively affect the accuracy of the results displayed on the map. Due to the limitations of the simulator, the team was unable to test the Bluetooth connection, the humidity sensor and the dynamo operation. Finally, the team did not assemble nor test the control system, i.e., using the actual components and collecting genuine data.

Assuming a large number of users, the resulting database of measurements could possibly be studied to determine the most polluted areas in the city, with the timestamps allowing to assess sources of pollution. Since bikers usually have very varied paths, in less urban areas the results could help city authorities identify illegal waste burning households. Increasing the number of users, it would also help the application to show more accurate information and routes, therefore a great deal of effort should go into the promotion of the product. Furthermore, the entire project can obviously be improved with the actual assembly of system. It is expected that additional safety features could be added, such as automatic backlight and turn indicators.

5 Conclusion

5.1 Project Outcomes

The GOairLight concept is based on a community approach that links citizens around the cause of urban air quality. How is it possible? GoairLight uploads the data collected by the probe during rides to the cloud, where it remains accessible to the whole community. To fulfil this main goal, the team designed an all-in-one

device with a light module, air and light sensors, and four rechargeable batteries. The system is powered by a dynamo operated by the cyclist.

The proposed design would not be possible without the preliminary work on related products, marketing, sustainability, and ethics. This study led to a viable product that can be easily industrialised, including a sustainable, reusable packaging solution. Besides, communicative supports have been carried out to promote the qualities of GOairLight, like posters, leaflets, or even a self-explanatory video of the 3D model [12].

5.2 Personal Outcomes

EPS@ISEP is an international capstone programme catalysing teamwork and fostering different skills. The opinions of the five members of the team regarding this experience is summarised below:

- “My overall experience with the project was very positive. The classes accompanying the project forced me to work outside of my area of expertise, allowing me a broader look at my field of studies. I have also learned many skills connected to my field, such as knowledge on embedded systems and mobile android applications. I believe these skills will further aid me in the future both as a student and as a professional. The online learning we were forced to adopt was a challenge, especially coordinating work with distant teammates. However, I believe it was a valuable lesson on how to work with remote teams, which is not uncommon in the IT job market.”
- “During the EPS, I have learned how to work in a multinational team effectively and efficiently. The EPS has definitely improved my communication skills, in terms of conveying different ideas and messages across the board to the whole team. Unfortunately, the COVID-19 pandemic played a big part in our EPS semester. However, skills were still developed through the use of online teaching and video software. In the time spent completing the EPS, a part that I will look back fondly on, was the opportunity of meeting new people from all over the world and to contribute my skills in a multi-skilled group.”
- “EPS@ISEP was quite a challenge for me as the creation process from the design to the development of a proof-of-concept prototype is out of my study field. However, EPS is more than the creation of a product, it is about international teamwork. Specifically, it helped me to develop team management, searching and scientific writing skills. Thanks to this project, I now know more about the marketing field, and its important role in a company, and how to communicate efficiently through visual communication supports as well as with my team. COVID-19 situation hardened the realisation of the project and made it even more challenging, but we successfully managed it!”
- “My experience with the EPS programme has been positive. I have learned how a team should work as a whole and how to improve my own doing within the group. EPS was not just focused on doing a project, but on learning other skills as well. I have learned other subjects like Portuguese, basics of coding,

project management, marketing, energy and sustainability. The team was composed of students from all over the world and everyone had a different educational background. Before I used to do my work just before the deadline and now, after this teamwork experience, I realised that team partners have to work side by side to go further.”

- “I have learned a lot by working together with students from different fields and seeing their strengths and weaknesses. It ranged from self-learning (working with new tools and improving my design skills) to peer-learning (understanding how other fields are equally relevant to the design of functional devices). Due to the outbreak of the pandemic, we were forced to switch to distance teamwork, resorting to online tools for communication. Although it was a challenge, the team was able to continue working and communicating remotely. Overall, this gave me experience and knowledge on how to work as a team without being physically together.”

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