SNIFFING THE CULPRITS

ELEMENTARY, MY DEAR SNIFFIRDRONE!

Università degli Studi di Ferrara

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

ALMACUBE

CERN Ideas

Executive Summary

This paper presents the innovative service developed for the environmental protection agencies of Italian regions, ARPA. Besides we aim at retracing the steps that over a period of four months led the team to identify the most suitable application for our technology.
The document begins by providing an overview of the project, outlining the challenges faced and introducing the team involved. It then delves into the various stages of our work, starting from the comprehension of the technology and its potential applications to our final service. Overall, the project has resulted in a valuable service that addresses the environmental protection agency needs; the developed odour scouting application holds significant potential for improving the efficiency and effectiveness of ARPA's operations. In conclusion, this document also recognizes the presence of pending opportunities for further exploration. These include the potential collaboration between our technology partner and ARPA Emilia Romagna, as well as new future perspectives that emerged after the final presentation.

INTRODUCTION

1.1 OUR CHALLENGE

The CBI.ATTRACT program is an open innovation challenge-based initiative organized in collaboration with the universities of Bologna, Modena and Reggio Emilia, Almacube, and Idea-Square, CERN's innovation hub. Throughout the project, five inter-university teams of multidisciplinary students have been studying innovative technologies funded under the ATTRACT program. The primary objective is to understand and leverage the potential of these technologies, seeking new fields of application and developing relevant solutions to address societal, human, and ecosystem needs in alignment with the UN Sustainable Development Goals.

The program employs a hybrid methodology that combines the human-centered approach of design thinking with tech-driven innovation processes. This approach aims to cultivate students' ability to identify and evaluate technological opportunities that have both global and local societal impact. Additionally, it nurtures the entrepreneurial mindset among students, preparing them to become future innovators in their respective fields.

CBI.ATTRACT is an integral part of the broader ATTRACT Academy student program, which encompasses ten student programs funded under the ATTRACT initiative. The ATTRACT program itself is a research initiative funded under the European Commission's Horizon 2020 research and innovation program. The student projects within the ATTRACT Academy program as a whole aim to foster a stronger entrepreneurial culture across Europe. They leverage the concepts and technologies developed for research purposes as a foundation for the creation of products and services that cater to the needs of our citizens.

1.2 THE TEAM

Now, let us introduce our team. We are a group of six passionate young individuals driven by the desire to actively contribute to important societal changes. Our collective enthusiasm and dedication make us a cohesive and dynamic team, where work and enjoyment coalesce seamlessly. Allow us to present the brilliant minds that form our group:

1. **Alberto Vicentini**: with a fervent passion for chemical sciences from the University of Ferrara, Alberto's exuberance is truly contagious. His love for chemistry is boundless, and woe betide anyone who ventures to ask him for a simple curiosity, for they may find themselves trapped in a labyrinth of intricate molecules!

2. **Angela Fasano**: coming from the University of Bologna, Angela is a captivating mind studying International Relations and Diplomatic Affairs. Her unique blend of logical thinking and dreamy imagination keeps us on our toes. While she claims to understand herself, we're still trying to decipher the enigma that she is. Nevertheless, her ability to bridge the gap between humanism and science is nothing short of remarkable.

3. **Anita Licata**: a visionary specializing in Precision and Sustainable Agriculture at the University of Bologna, Anita's serene and calming presence permeates our team. But don't be fooled by her tranquillity – she possesses a remarkable talent for graphic design, infusing vibrant technicolour into our project and bringing it to life.

4. **Davide Di Pasquale**: a true maestro of molecular and industrial biotechnology, Davide's expertise from the University of Bologna is unparalleled. With meticulous attention to detail, he effortlessly conducts scientific experiments. And when he's not in the lab, you might catch him drumming away, creating symphony of beats that resonates with our team spirit.

5. **Federico Guerra**: a mechanical engineering wizard from the University of Bologna, Federico's rational and detail-oriented nature is our reliable anchor. His uncanny ability to assemble and disassemble anything that crosses his path makes him our go-to person when we need a closer look at the inner workings of things.

6. **Demien Bursic**: our Master of International Management, Demien's confidence and resolute nature make him the perfect organizer. While he flawlessly plans his next two hours with the help of countless apps, the foreseeable future might remain a mystery. Nonetheless, his unwavering determination keeps us on track and propels us towards success.

1.3 METHODOLOGY

The program methodology employed in this project follows a hybrid model that combines the human-centred approach of *design thinking* with *a technology-driven* innovation process. The program is structured into three distinct phases: discover, design, and develop.

Discover (Phase A)

The initial phase adopts the *technology-driven innovation approach* and focuses on exploring and gaining a comprehensive understanding of the technology under investigation. Extensive research is conducted to identify the critical functions of the technology and determine the societal needs that could benefit from these functions. This phase embodies divergent thinking, encouraging exploration beyond technical constraints and facilitating the discovery of potential application domains. A divergent map is created to visualize the diverse range of application fields identified. The subsequent step involves a convergent process to select five opportunities. Initially, an assessment of the potential value is carried out to identify the target users, the problem to be addressed, and the potential benefits. Subsequently, opportunity validation is conducted to gain in-depth knowledge about the chosen application field. This involves evaluating the relevance of the application from both user and domain expert perspectives, as well as assessing the technology's readiness and capabilities in the identified field. Interviews with technology and field experts are conducted to understand the limitations and contextual factors involved, as well as to identify relevant stakeholders. Following the opportunity validation process, a comprehensive assessment is performed based on the overall context, the specific problem statement, and the proposed opportunity/solution.

Design (Phase B)

The second and third phases of the program rely extensively on the *design thinking approach*. It places a strong emphasis on understanding the needs and experiences of users or customers. Specifically, the design phase aims to create a compelling user experience with the technology and involves the reconstruction of the user journey, clarifying how the technology seamlessly integrates into a specific context and is utilized by the end user. Additionally, user personas are developed to enhance the understanding of the users. These personas serve as fictional representations of different user types, capturing their characteristics, needs, goals. By integrating user personas into the design process, it is possible to ensure that the final product caters to the diverse requirements and preferences of the intended users.

Develop (Phase C)

The final phase is dedicated to transforming conceptual solutions into tangible outcomes. The objective of this phase is to demonstrate that the technology can effectively deliver the user experience. The emphasis is on reproducing, testing, and validating the technology's ability to provide a concrete solution for the identified need.

PHASE A – DISCOVERY

In this report, we present the findings and progress of a Challenge-based Innovation program undertaken by a team of six interdisciplinary students. The objective of the program was to explore innovative applications for a technology known as Sniffirdrone. The project started with the Discovery phase, which involved understanding the technology and identifying feasible application fields.

2.1 TECHNOLOGY UNDERSTANDING

During the initial phase, the Sniffirdrone technology was extensively studied to comprehend its components and functionalities.

The aim was to dive deep into the functions of our technology, to find out the needs that could be met by them.

The 16 MOX sensors, 1 NDIR and 4 electrochemical inside the e-nose allow to detect and measure odor, pollutants, and chemical signals. The drone allows to follow the scents of poisonous clouds, smells, drugs, people and animals, and vehicles. The algorithm permits to plot a real-time 3D map of the smellscape, while the machine learning allows to digitalize human information such as bad odors, perfumes, and fragrances (hedonic tone).

2.2 DIVERGENT THINKING AND IDEA GENERATION

Utilizing divergent thinking techniques, we engaged in an ideation process to generate a wide range of potential application fields for the Sniffirdrone technology. To facilitate this process, our team had the privilege of working at IdeaSquare, located within CERN. This environment fostered creativity and inspired us to explore exciting and unconventional ideas.

Figure 1. Team Sniffirdrone at CERN

Some lectures were provided by researchers of CERN. We learnt about what they do in CERN, how we could exploit the concept of "exponentiality" to diverge, how biases could obstacle our creative thinking, and how to perform interviews with the researchers.

To visually represent the divergent information and ideas generated, we constructed a divergent map that incorporated all our innovative concepts and insights (fig. 2). This map was constructed based on the primary functions of our technology: detection, signaling, 3D maps plotting, scent tracking, and digitizing human senses. From there, we explored what it could actually follow, detect, signal, plot, and digitize. In the subsequent step, we identified the various fields in which our technology could be applied. This exercise played a vital role in identifying potential application areas.

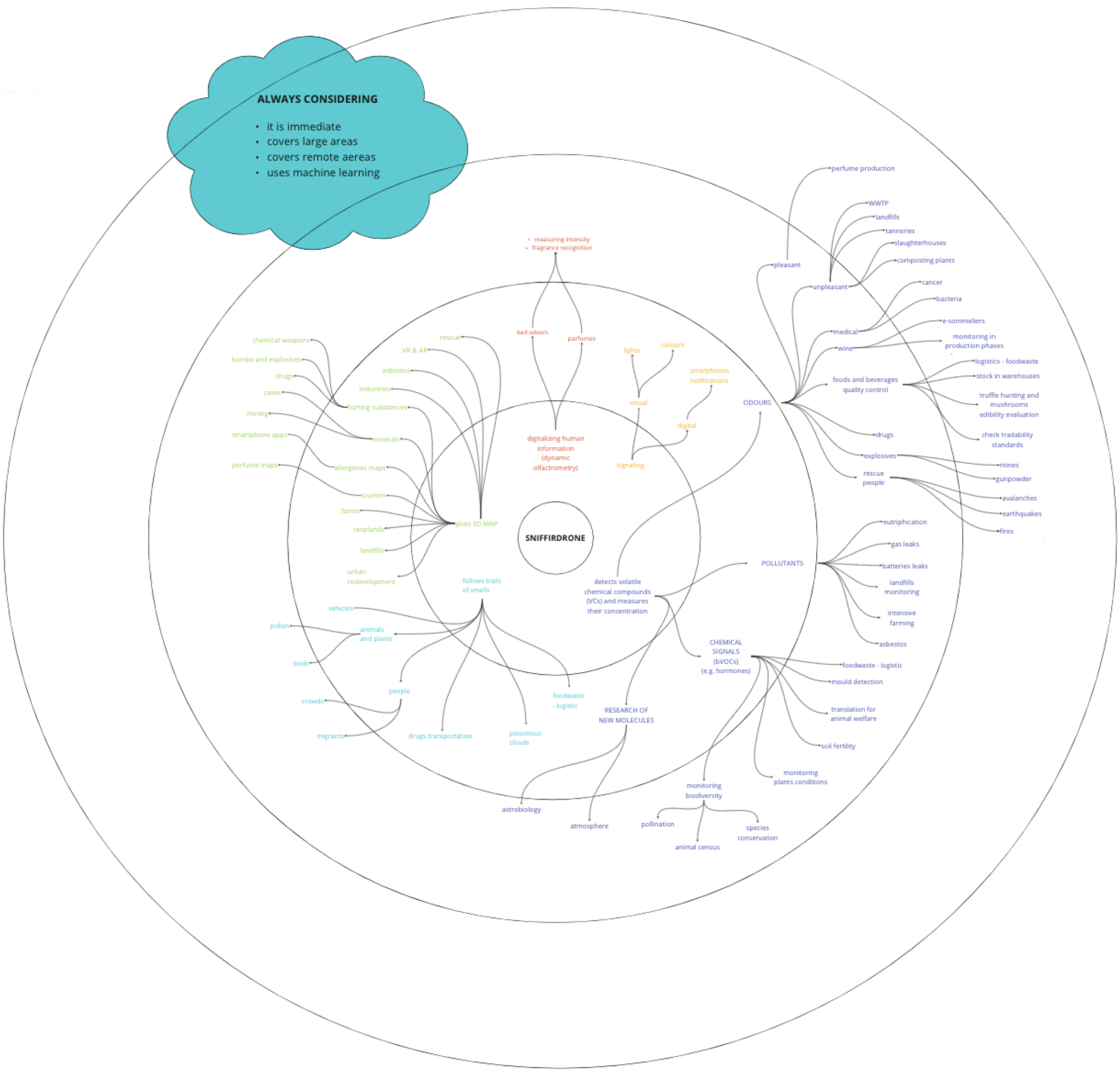


Figure 2. Divergent Map

During our brainstorming sessions, we thoroughly considered odors, perfumes, smells, emissions, and volatile organic compounds (VOCs), which resulted in the generation of numerous application fields. Among them, we found particular interest in addressing emissions from landfills or industries, odorless VOCs associated with drugs and mines, VOCs emitted by people in need of rescue, and biological VOCs emitted by animals and plants. These application fields held significant importance and potential for our technology.

2.3 CONVERGENCE AND IDENTIFIED OPPORTUNITIES

After engaging in discussions with researchers, professors, coaches, and experts at CERN, we reached a convergence on these five opportunities. Throughout the process, our aim was to strike a balance between realism and creativity, ensuring that our ideas remained grounded while retaining an element of imagination and possibility. We selected five main opportunities:

1. Precision Farming: utilizing the drone-based odouring system to detect fruit ripeness, stresses and diseases in crops at an early stage, enhancing agricultural efficiency.

2. Landfill Monitoring: applying the Sniffirdrone technology to identify smells and emissions in landfills, enabling better regulation and monitoring of waste management.

3. Disaster Response: implementing Sniffirdrone in post-catastrophe scenarios, such as earthquakes and avalanches, to aid in the rescue and location of affected individuals.

4. Monitoring the health status of honeybees: Sniffirdrone could serve as an excellent indicator of overall ecosystem stability, both in the short and long term.

5. Human trafficking: utilizing Sniffirdrone as a scanner in wide logistic hubs to fight against the illegal transportation of people.

2.4 INSIGHTS FROM INTERVIEWS

To gather valuable insights and perspectives, we conducted interviews with researchers and experts in relevant fields. These interviews provided us with critical information and guidance, aiding our decision-making process. The interviews helped us refine our understanding of potential application fields and allowed us to explore the feasibility and viability of each idea.

2.4.1 Crop protection

We had the opportunity to engage in a discussion with a precision fruit production professor of the University of Bologna, Luigi Manfrini, to gain insights into the potential applications of Sniffirdrone in plant status monitoring. Vineyards, which are not covered by nets, could benefit from drone technology for grape quality classification and managing phytopathology. Additionally, other crops like walnut groves, crops with shells, and extensive horticultural crops can be effectively monitored using drones. The potential for drones in detecting and managing phytopathology and weed-related issues shows promise.

2.4.2 Rescue operations

In the context of rescue, a professor of the University of Bologna, Daniela Perrone, told us that humans and animals produce acetone and ketone bodies under stress conditions (they can be smelt in slaughterhouses for example), even not in prolonged fasting regime (during which ketone bodies are produced continuously). Living organisms also exhale other minor VOCs such as small aromatic molecules or non-polar molecules up to 20 carbon atoms long, but although the e-nose is sensible to them, the concentrations in which they would be present around a person (or a plant) would be too low.

2.4.3 Human trafficking

According to a recent study (*S Giannoukos et al 2018 J. Breath Res. 12 027106)* the composition of human body odour is a combination of VOCs exhaled through breath and secreted through skin sweat. By reproducing the conditions of trapped humans, scientists have been able to identify the matrix of chemicals that can identify a human being. This is why we thought of using this technology to detect the presence of human beings hidden in the containers of large international hubs, ports in the first place.

2.4.4 Landfills monitoring

We could deepen the topic thanks to a call with Professor Dal Pozzo, University of Bologna, expert in environmental laws concerning industrial emissions. We were told that hydrogen sulphide is one of the main constituents of landfill odorous gas, so it can be chosen as a marker: if detected, it is highly probable that also all the other minor substances typical of landfill odorous gas are present.

2.4.5 Honeybees monitoring for biodiversity

We interviewed an entomologist of the University of Bologna, Professor Sgolastra, who told us that monitoring honeybees' health serves as an excellent indicator of overall ecosystem stability, both in the short and long term. This application aligned well with our goal of contributing to the sustainable development goals of the European Union. We thought that thank to Sniffirdrone we could monitor molecules emitted by honeybees under certain stress conditions.

2.5 VALUE ASSESMENT AND TECHNOLOGY SCENARIOS

Just before the First Milestone, our team conducted a value assessment to validate the feasibility and desirability of the five potential application fields for the Sniffirdrone technology. This assessment involved early validation of whether the technology could meet specific needs and if those needs were relevant to people. We utilized the Technology Scenarios matrix (fig. 3) along with interviews to carry out this assessment.
Technology scenarios are defined as alternative realities envisioned by answering the question "What if," which explore the possibilities enabled by the technologies we are working with.
For each of the five previously mentioned application fields, we applied the Technology Scenarios matrix to assess the value.

Figure 3. Technology-Scenarios matrix

2.6 EPO FRAMES FOR FIRST MILESTONE

To present our ideas and opportunities effectively, we utilized the Evidence-Problem-Opportunity (EPO) frame (fig. 4). This frame allowed us to provide evidence of the identified problems, showcase the opportunities, and establish the relevance and reality of the opportunities to the audience.

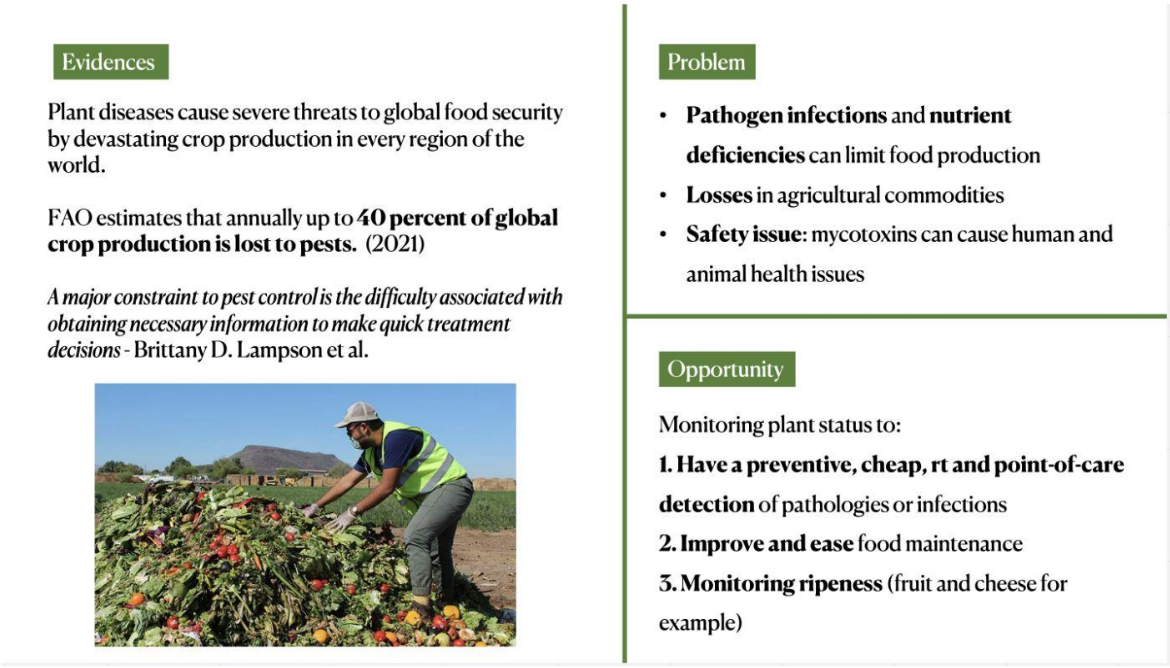


Figure 4. EPO frame example

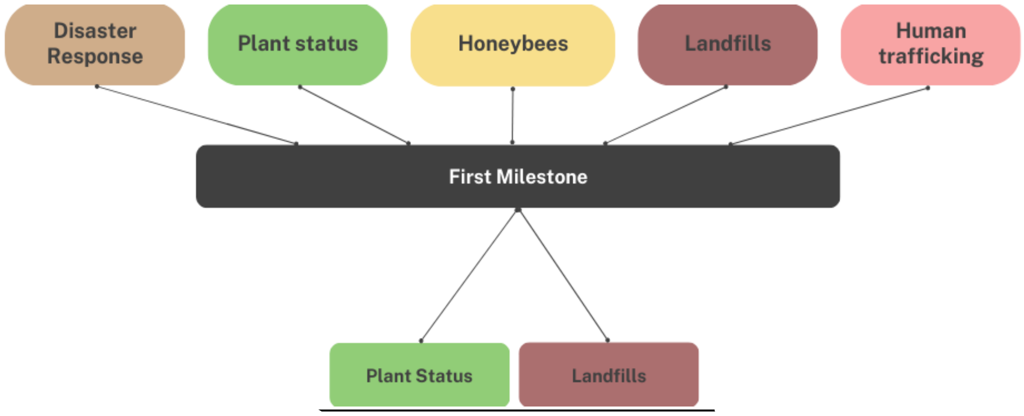
We presented the five identified opportunities and sought feedback from both experts and non-experts. Through these interactions, we discussed pros and cons of each opportunity field and we decided to cut three out of the five applications we had identified: rescue operations, huma trafficking and honeybees montoring:

- Using Sniffirdrone for rescuing people posed challenges due to the mixing of Volatile Organic Compounds released by both rescuers and those to be rescued;
- The application field briefly shifted towards human trafficking in big harbors, but the lack of a market for this type of technology led us to abandon the idea;
- The honeybees monitoring was limited by research-interest-only;

2.7 CONCLUSION OF THE DISCOVERY PHASE

Following the considerations above, we converged on two application fields for further exploration: Plant Status Monitoring and Landfill Monitoring. These areas showed significant potential for utilizing the Sniffirdrone technology effectively.

Phase A of our Challenge-based Innovation program involved comprehending the Sniffirdrone technology, exploring diverse application fields, and identifying promising opportunities. Through extensive research, interviews, and collaborative efforts, we proceeded with **Precision Farming** and **Landfill Monitoring** as our primary focus areas. In the subsequent phases, we will delve deeper into these fields, working towards developing practical solutions and innovative applications utilizing the Sniffirdrone technology.



Embracing the sustainability focus, we also strived to align our efforts with the SDGs. For instance, in the context of "monitoring plant status," our identified SDGs were (2) zero hunger, (12) responsible consumption and production, and (15) life on land. Similarly, for "landfills monitoring," the identified SDGs included (2) zero hunger, (12) responsible consumption and production, (11), and (6) clean water and sanitation.

Figure 5. SDGs

PHASE B – DESIGN

As we moved forward with our groundbreaking project, we reached a crucial point where we shifted our focus from figuring out if our idea was doable to creating something people truly desired. Moving from feasibility to desirability marked an exciting shift that required a fresh perspective and a focus on people's needs. This chapter illustrates the crucial elements of the design phase, where we transitioned from solely checking technical feasibility to crafting a product that not only meet functional needs but also deeply resonated with our intended users.

3.1 DESIGN THINKING AND PRETOTYPES

We embarked on the design phase by approaching the design thinking method and the human-centered innovation mindset.

In the context of design thinking, understanding the distinction between *"needs"* and *"solutions"* is crucial. Needs represent the underlying problems, desires, or challenges that users experience. They go beyond surface-level observations and tap into the deeper motivations and aspirations of users. Solutions, on the other hand, are specific ways to address those needs and solve the identified problems. While needs focus on the "what" and "why," solutions are concerned with the "how." Differentiating needs from solutions has been important because it enabled our team to explore a wider range of possibilities and avoid being constrained by preconceived notions.

3.1.1 Stakeholder map

Hence, discovering user needs has been a crucial step in our design process, allowing us to pursue solutions that address the core challenges and aspirations of the final users. In order to discover the needs, firstly, we identified the possible users of Sniffirdrone by drawing a stakeholder's map (fig.6), which representing all the actors belonging to the design context helped us to prioritize the users' interviews (3.2).

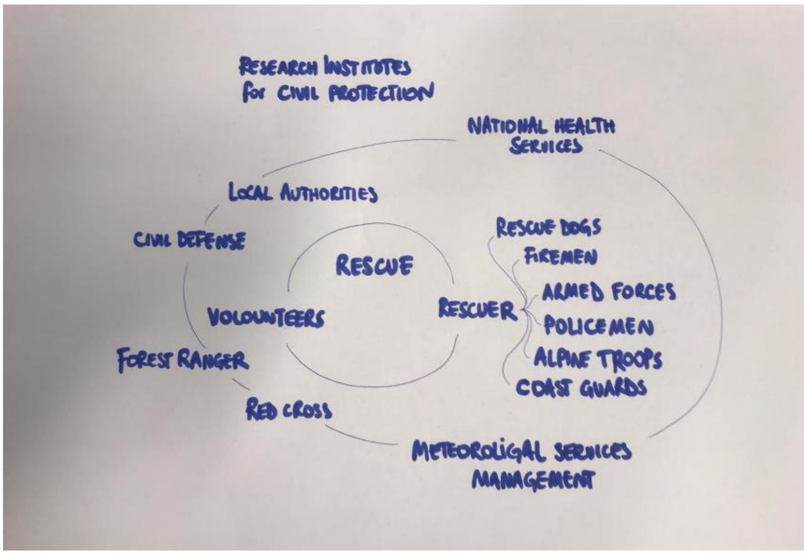


Figure 6. Stakeholder map

3.1.2 Pretotyping

It has also to be stressed that design thinking is a making-based approach to problem-solving that involves pretotyping and prototyping stages. These have the main aim to discover design directions exploring and learning about our users and not just to demonstrate decisions already made.

In fact, building pretotypes of our solution has been useful in demonstrating our solution more clearly to the possible users interviewed and receive relevant feedback and insights (fig.7).

Figure 7. Pretotypes

3.2 INTERVIEWS

To get more information and a clearer idea of the feasibility of the chosen possible applications, we attended further meetings with experts of those fields. Deep interviews played a key role in uncovering users' needs, as they provided an opportunity to ask open-ended questions and actively listen to their experiences, pain points, and desires. Additionally, careful observations of users in real-life situations revealed unspoken needs and behaviors that may not be captured through interviews alone. Employing conversation triggers, such as prompts or stimuli, also helped elicit user feedback and insights about their needs.

3.2.1. A deeper understanding of Sniffirdrone

First, a call with Professor Agustín Gutiérrez Gálvez from the research centre was fundamental to get a deeper understanding of what the technology is made of, how it works and its limits:

The 16 electrochemical MOX detectors that make up the e-nose are not specific (they respond to multiple gases without distinguishing between them) and can be easily replaced to adapt the sensor array to different specific applications. One of the major criticalities to evaluate is whether the concentration of the substances to detect is high enough. This poses a significant limit for plant status, while does not represent a problem for landfill emission monitoring, where the concentration and the nature of the analysed compounds are comparable to the ones arising from WWTPs. In favour of the latter also goes the rapidity of the drone in moving and measuring, which allows to monitor large landfill areas. There is also the cross-sensitivity problem: same substances could be generated by different sources and in this case the gas analysing chamber cannot distinguish between them. This means that a possible external source of acetone or isoprene would constitute a great interferent both to the search for people and to the evaluation of plant stress level.

The measurement is performed continuously at a scanning rate of 5 m/s (less than the average drone speed of 10 m/s because of the sensors measuring speed limit), which allows to build a 3D map of a small plants of half a square kilometer in no more than 5 minutes.

The drone can be piloted either manually (by a trained drone pilot) or automatically along a programmed path thanks to the DJI software. The drone batteries with the Sniffirdrone equipment last about 25 minutes, but less whether the payload is increased. If the drone is used in open windy spaces, the measures cannot be precise because the volatile compounds to analyze get upset and the 10 meters tube used to face the downwash problem oscillates significantly causing the measure to be approximative, averaged around one meter.

Considering the small size of the gas analyzing chamber, there is enough room for other sensors and equipment to be mounted on the drone for other applications, but without exceeding the maximum payload of the drone.

The currently used drone, a DJI Matrice 600, can carry up to 5 kg, but the next drone that will be used for the project will be larger and have a maximum payload of 8 kg.

3.2.2. Discoveries for plant status application

As concerns the plant status application idea, the interviews with Prof. Daniela Perrone, researcher and expert in natural organic substances at the University of Ferrara, and with Doctor Centritto from the CNR allowed us to get more knowledge about the volatile compounds emitted by plants.

These substances, also called "green volatiles", are mainly isoprene and isoprenoids (mono-, di- and sesquiterpenes). Most of them are heat resistant and exhaled by the plant especially under temperature, humidity and ozone stress in order to increase or diminish the photosynthesis. The fruits, when ripe, release ethylene that is a really small and non-polar molecule and so highly volatile. Plants, as insects, communicate through pheromones too, using them to attract helpful insects or repel harmful ones and parasites (Geraniums and chrysanthemums emit pyrethrins for example). These substances though are emitted in very low concentrations (in the order of ppts) and constitute biochemical signals that can be recognized only by their complementary biochemical sensors, which mainly are protein and glycosidic in nature.

In general, it’s really hard to correlate a specific plant condition with a certain mixture of volatile substances, especially with nonspecific electrochemical sensors solely. Another criticality to evaluate is whether the action range of the emitted substances is wide enough to allow the e-nose to detect the chemical signal. This requires the execution of many tests on the field, for which many efforts and time are needed. Doctor Centritto told us that other efficient systems to monitor plant status already exist, for example thermocameras doing hyperspectral measurements, and that special regional and national services, such as plant pathological observers, already perform the needed controls. There are also other phenomena related to uneasy plant conditions, among which the closure of the stomata.

All the difficulties brought to light made us feel more and more the infeasibility of the plant status monitoring application, it is really sectorializing and requires much research. Prof. Gálvez also told us that for precision agriculture in greenhouses drones with chemical sensors already exist.

Thanks to other meets and papers about the big issue of plant diseases, we started to consider the idea of monitoring not the substances emitted by the plant itself, but those emitted by the pathogenic microorganisms present on it. Xylella in particular is the biggest plant pest problem in Italy and so it would be really important to have a way to predict the progress of the pathogen in advance.

Unfortunately, though, the too low concentration problem is still present and also in this field many research is needed, especially in finding the specific biochemical sensors to use.

3.2.3. A better understanding of landfill emission monitoring

The landfill emission monitoring application started to seem the most feasible one with the Sniffirdrone technology. We could deepen the topic thanks to a call with Prof. Dal Pozzo, expert in environmental laws concerning industrial emissions.

Odour pollution is quite singular because caused by many different substances present in pretty low concentrations (in the order of ppbs) and its hedonic tone could only be measured empirically by a panel of experts.

The main compounds with an odorous impact are those containing sulfur, but also some types of terpenes, which are generally emitted in low concentrations. Instrumentally, their presence and quantities can be measured via IR spectroscopy: either with NDIR sensors pre-calibrated for certain substances or with an FTIR spectrometer which can detect a wide range of substances. Hydrogen sulfide is one of the main constituents of landfill odorous gas, so it can be chosen as a marker: if detected, it is highly probable that also all the other minor substances typical of landfill odorous gas are present.

Landfills are characterized by a diffused emission, unlike chimneys and leaks from broken pipes and valves which instead are punctual emissions. The most unpleasant odours usually arise from active landfills until the waste is covered, whereas biogas (produced by anaerobic fermentation) is released both by active and decommissioned landfill sites. Because of the latter, every landfill (inactive ones included) must be monitored regularly and properly managed. The best case is when the biogas is recovered, so that it can be used for energy production. A typical collection system can recover up to the 70% of the biogas produced in the landfill. The remaining part goes in the atmosphere and has negative odorous and environmental impacts. It can also be dangerous for the plant operators because of its flammability, that could cause in-plant fires.

Public environmental protection agencies, such as ARPAE, are subjected every year to the integrated environmental authorization (AIA), a procedure with a conformal character to fulfil to the principles of integrated pollution prevention and control (IPPC) dictated by the European Union since 1996. Every plant though has its own specific thresholds of emissions to comply with and special authorizations and concessions offices exist to draw up their monitoring plans. For this, ISO standards and technologies listed in the so called “best available technologies document” (BAT) are used. If a technology is not listed in this document (which is updated every 8 years) could not be taken in consideration from possible stakeholders. This means that Sniffirdrone, to become popular in this field of application, should be standardized and added to the BAT.

Sniffirdrone could also help to reveal possible inhomogeneity of the materials arranged in the landfill, therefore it would be useful for deciding how to optimize the installation of biogas collection systems.

3.3 USER JOURNEY AND CRITICAL FUNCTIONS

A tool of utmost importance for the development of solutions that genuinely address user needs and aspirations is the user journey. In our project, we developed user journeys for the 2 opportunities that we found most useful and feasible. Respectively:

Precision plant protection

1. Periodical monitoring with arrival of the drone pilot in the desired area
2. Calibrate the e-nose on the molecules released by a specific pathogen
3. Detection of the disease marker molecules on some field zones (showed in the output 3D map)
4. Further diagnostics on target plants with specific instruments (by going directly in that specific area)
5. Precise treatment based on the collected data

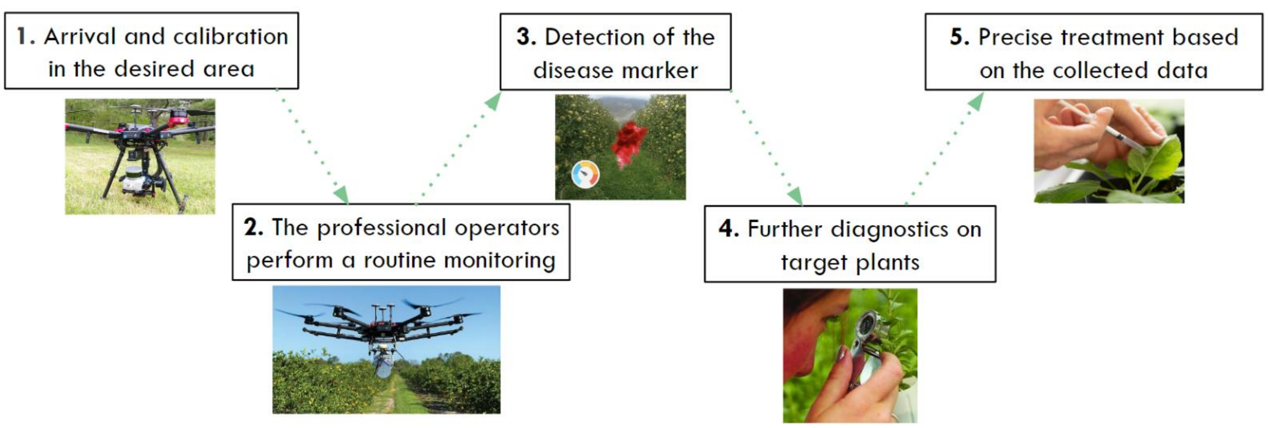


Figure 8. User journey in precision plant protection

Landfills monitoring

1. Complains and reports from citizens nearby a landfill about bad smells
2. Calibrate the e-nose on the volatile molecules released by a specific waste disposal site
3. ARPA inspection: odors and gas monitoring
4. Observation of the 3D map and detection of odor plumes and sources
    a. state that the reported odour does not come from the landfill;
    b. state that the reported odour comes from the landfill à intimate the landfill manager to take corrective actions and send a report to the relevant

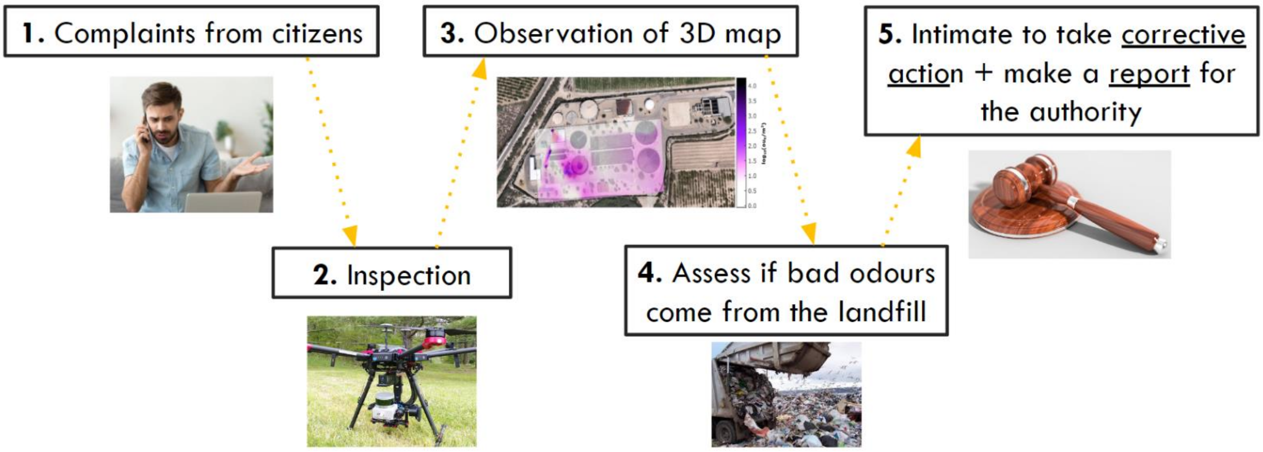


Figure 9. User journey in landfillds monitoring

3.3.2 Critical Functions

Subsequently, we focused on exploring the critical issues of the two solutions mentioned above by identifying research questions, that is, all inquiries pertaining to the feasibility of integrating technology into a given context, providing answers that help determine the possibility and manner in which integration can occur.

After collecting the research questions, we ranked them in in the following cartesian planes in order to get a clearer picture of the situation with respect to the information we already had and the missing information, and also placed them in more or less important quadrants.

Figure 10. Critical functions diagram – Precision plant protection

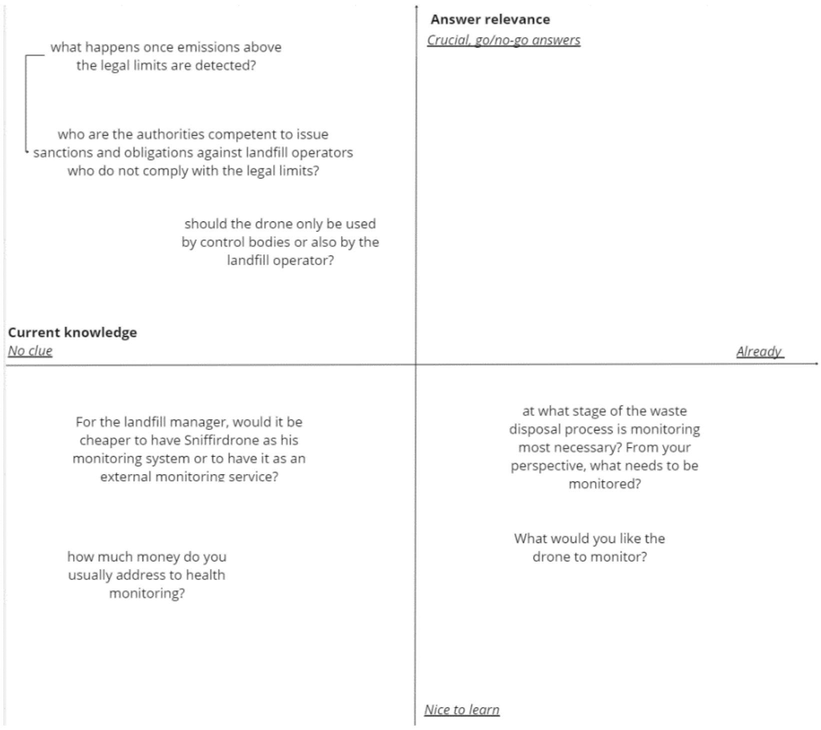


Figure 11. Critical functions diagram – Landfillds monitoring

3.4 VISIT AT THE RESEARCH PARTNER SITE IN BARCELONA

During the two days at the Research center in Barcelona, where the Sniffirdrone technology has been developed, we were presented by Prof. Gálvez the complete picture of the technology development happened.

A drone, also called RPAS (Remotely Piloted Aircraft System) or UAS (Unmanned Aerial Systems), is classified as small if the maximum takeoff weight (MTOW) is less than 25 kilograms and it does not flight above 100 meters high. Fixed wings versions were a choosable possibility: they glide form a high launch point, so they don't require powerful batteries and don't present the downwash problem. Despite this, the rotary wings version was preferred because of its more flexibility and control in movements. The possible applications envisaged by the research team are volcanic research, landfill emission monitoring, chemical monitoring in industrial sites (leaks identifications for example), early fire detection, residential emission monitoring (such as from chimneys), ship emission monitoring, added substances quantity monitoring in precision agriculture, urban air quality check.

Four of the gas specific sensors are of the electrochemical type: they produce an electric potential signal when the gas they are designed for gets in contact and reacts with a specific sensible membrane inside the instrument. On the other hand, the fifth one is an NDIR (optical) sensor, which is the standard type used for CO_2 detection and works by measuring the absorption by the sample of infrared light of specific wavelengths. In the e-nose part, the MOX nonspecific sensors have a metal oxide surface which is maintained at a temperature of 200-300 °C and on which redox reactions of the gases in the sample with the oxygen occur. These reactions cause the sensor to change its electrical resistance and so to produce an electric signal. The 16 MOX sensors present differ from each other for the metal oxide nature and the specific working temperature, which induce different chemical reactions and so different electric signals for the same sample. There is also a photoionization detector (PID) which is totally nonspecific (ionizes almost all the molecules in the sample by a UV light), but allows to get high precise measures of the concentration of the gases in the range of 10 ppb to 10 000 ppm. It is good to use in combination with the gas specific sensors, but it cannot analyze compounds with high ionization energy.

Figure 12. Electric nose

Figure 13. DJI Matrix 600

Figure 14. Mini drone prototype

As concerns the downwash problem, which is proportional to the weight carried by the drone, other ways to face it consist either in sampling the air with horizontally protruding tubes, for which a length of around one meter would be sufficient, or in mounting the gas analyzing chamber on top of the drone instead of on the bottom. In this latter case, there is no need of long sampling tubes and indeed, the air would be directed into the sensor chamber by the sucking action of the fans. This could be an efficient way of operating and the research group is testing it. For now, such a concept has been put in practice with smaller drones, which were shown to us and whose photo is reported below.

The research team is working on increasing the endurance, battery and control autonomy, flight range and MTOW of the drone, but also reducing the size of the gas analyzing chamber from 96 mL to 0,025 mL thanks to nano sensors and conforming with current EU regulation in the field of aerial traffic and drone piloting. A good note to know is that currently privacy protection laws apply only to drones with cameras mounted on, not to those equipped with chemical sensors. Future prospectives are to mount on the drone more equipment useful for other applications (e.g. a LiDAR) and to make different sensors modules easily interchangeable for a versatile adaptation of the technology to different scenarios. We were shown the actual real Sniffirdrone (not in operation), so that we could figure out better its size, weight and high technological level.

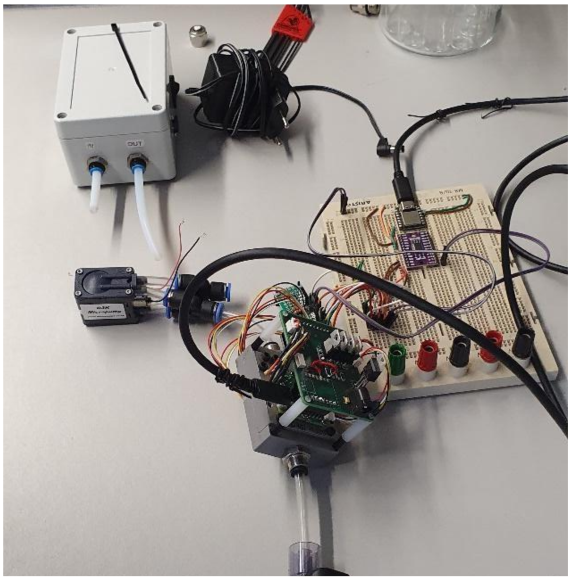
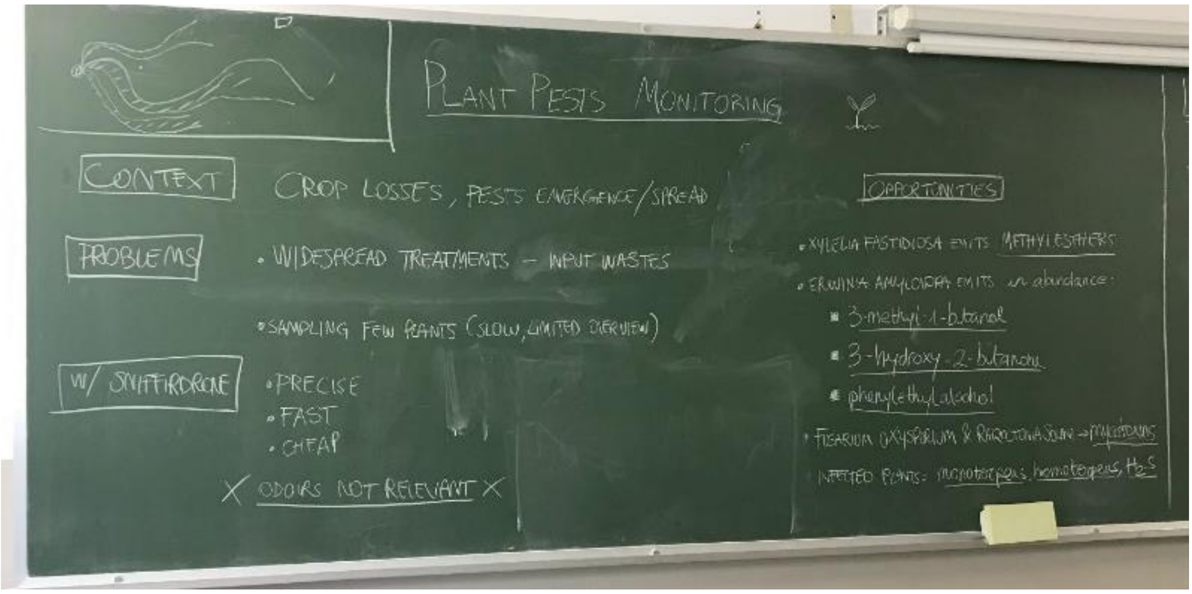


Figure 15. Miniaturized electric nose

Figure 16. Odour Bag

We presented to the researcher Prof. Gálvez our application ideas for Sniffirdrone to which we have converged: plant status monitoring and landfill emission monitoring.



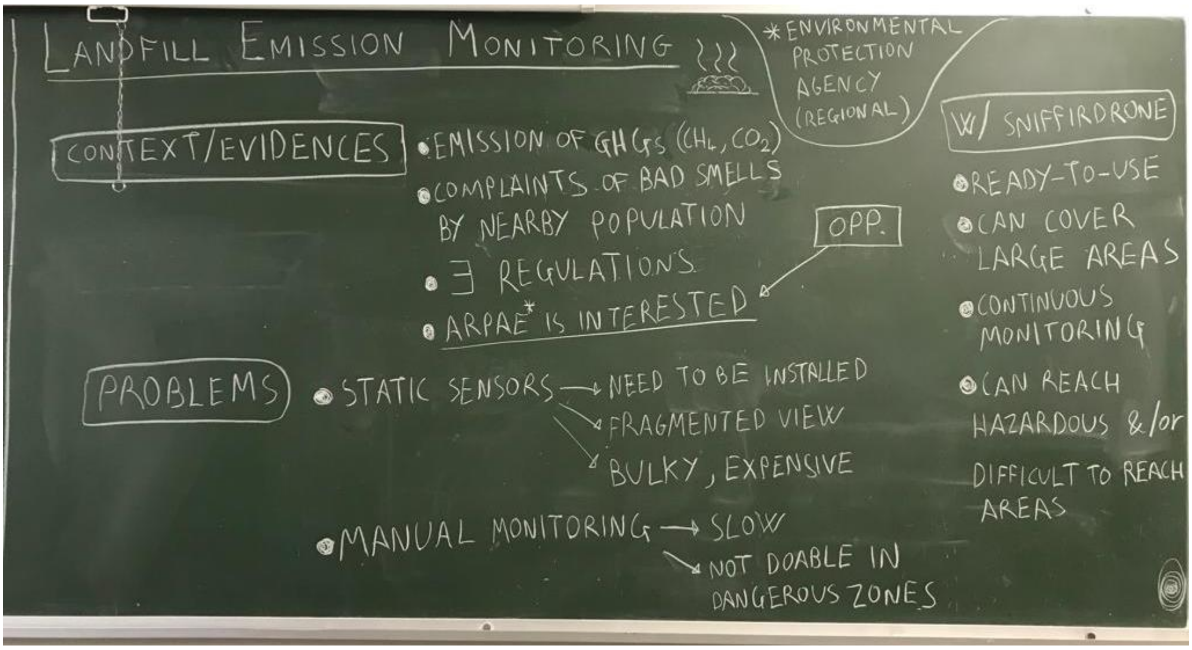


Figure 17. Our presentation workflow in Barcelona

Professor Galvéz confirmed that the former would be really hard to develop because of all the research needed behind and the very low concentrations of the chemical signals compared to the sensor's detection limits. He suggested that, with the technology as it is, the most feasible one is the latter, because it is in a similar scenario of a WWTP so the gas to analyze and their concentration ranges are almost the same.

3.5 USER PERSONAS AND SECOND MILESTONE

Once identified the problems and the needs of the possible users and stakeholders in the two application fields, it is important to be able to aware the developers of the technology about these situations and with just cold and objective facts the message will not pass clearly. A good story instead, which essentially is made of facts charged with emotions, is a powerful communication tool that can really make the listeners feel the real severity of the situation and empathize with users in a more natural way.

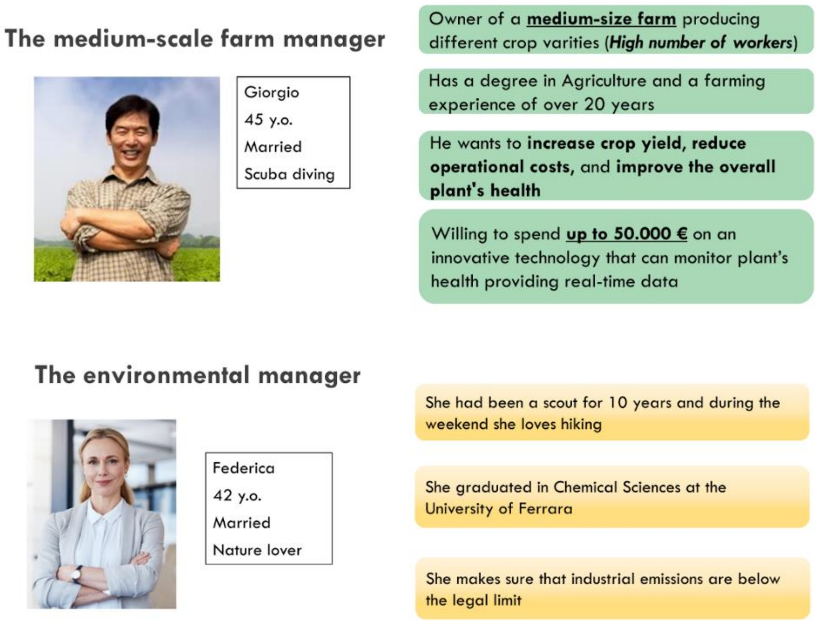


Figure 18. User Personas

Giorgio is an experienced farm manager with a medium-sized farm in the countryside of Bologna that produces a large variety of crops and has a high number of workers. Giorgio's goals are to increase crop yield, reduce operational costs and improve the overall health of his plants. He is willing to spend up to 50.000 on an innovative technology that can monitor his plant's health providing real time data. Giorgio would be able to buy more than one drone, organize training courses for his staff and care for the drone maintenance.

Federica is the manager of ARPAE Bologna who everyday receives many reports for bad odours from people living nearby industrial plants, but she and her technician team do not manage to resolve all of them properly because of the lack of technology present on the market. She feels sorry for the complaining citizens and the high difficulty in identifying the industries to ask for corrective actions stresses her a lot. She looks for a more efficient monitoring system which would allow her and her colleagues to locate quickly and precisely the actual sources of the bad smells reported. Sniffirdrone fits perfectly with this scenario because it brings together in one tool all the technologies they currently use, so it can really help Federica to obtain proofs of the guilty industrial plants, especially where many of them are present.

At the second Milestone, the final stage of the design phase, we presented the two personas just described and their relative user journeys that they would experience whether they used Sniffirdrone technology to face their problems.

2.8 CONCLUSIONS OF THE DESIGN PHASE

The goal of the design phase was to converge to a single opportunity and through the interviews conducted we came to two main insights:

1. ARPAE awared us about their real need for a technology as Sniffirdrone with regard to odour scouting. This because their current static e-noses do not allow them to detect odour trails and odour sources. Sniffirdrone instead can and, thanks to this capability, it would be of paramount importance to ARPAE as it would enable them to identify the culprit of odorous emissions by providing objective evidence. Through our technology, ARPAE could compel the culprits to take corrective actions and at the same time notify them for the issue of penalties.

2. Plant status/plant pest monitoring represents a field with great potential, but at present a lot of research is needed and the technology is not yet ready for this use since it cannot measure such low concentration levels.

Immediately after the morning milestone, we had a meeting with the ARPAE Modena team, who confirmed the interest and usefulness of such technology in this area, but pointed out that landfills are only a small part of the market and are of little concern in the Emilia region, while all the various production industries such as the ceramics industry, the textile industry, composting plants or livestock farming are actually more relevant. They also highlighted the difficulty in figuring out what the source of the odour is, hence, we decided to let us drive by the big interest shown by the agency and so to converge to landfill emission monitoring or better **odour scouting** (hunting specific odours emitted by unknown sources). With a little bit of sadness, we gave up on designing plant status/plant pest monitoring because of the many obstacles discovered. Although it was the most innovative and impactful, we began to follow the application in which a high practical interest is needed.

PHASE C – PROTOTYPING

The purpose of the prototyping phase was to develop a system that could rapidly and accurately identify the source of odors in the air, addressing the limitations of current technologies used by environmental protection agencies. In this paragraph, we will discuss the experiment we designed to prove the feasibility of our concept and present the results obtained.

4.1 EXPERIMENT DESIGN AND DATA COLLECTION

4.1.1 Production and Distribution of CO2

In order to validate the feasibility of our concept, which aimed to develop a drone-based odor monitoring system for rapid source identification, we designed an experiment involving the production and measurement of CO_2 concentrations. By accurately measuring the intensity of CO_2, we sought to demonstrate the capability of our system to identify and track odor sources in the air. The CO_2 was generated through a chemical reaction between citric acid and baking soda. We carefully mixed the two substances to initiate the reaction, resulting in the release of CO_2 gas. To ensure controlled distribution, we connected tubes to the CO_2 generator and positioned them strategically over a table. The generated CO_2 was then spread evenly across the table's surface through these tubes.

Figure 19. CO2 production

4.1.2 Arduino and Sensor Setup

For data collection, we utilized an Arduino breadboard and an air quality sensor MCU-811 CCS811. The Arduino served as the main control unit, while the MCU-811 CCS811 sensor was responsible for measuring the intensity of CO2 concentrations. The sensor was connected to the Arduino, allowing us to capture real-time data on CO2 levels. This setup provided accurate and reliable measurements throughout the experiment.

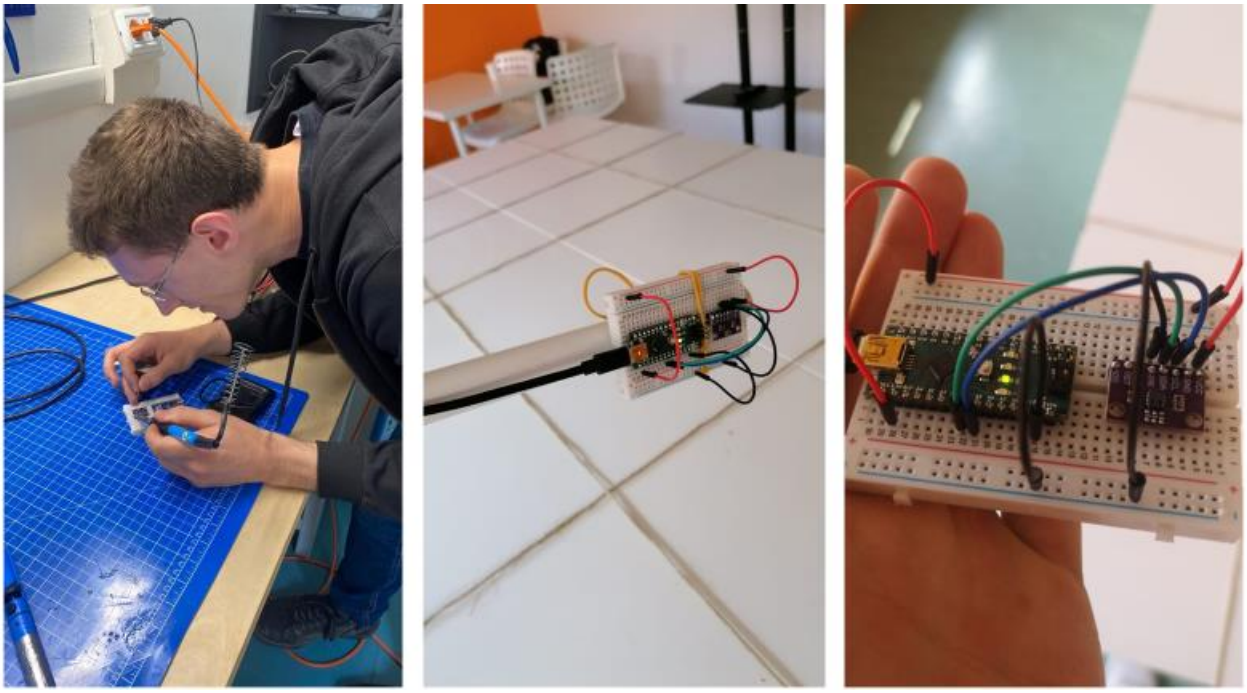


Figure 20. Arduino breadboard with air quality sensor

4.1.3 Experiment Procedure

The experiment took place in an empty room to minimize external influences such as human breath or wind, which could affect the distribution of CO2. To track and analyze the CO2 concentrations across the table, we created a grid pattern. The table's surface was divided into squares measuring 15 centimeters each. This grid allowed us to systematically monitor the CO2 levels in different areas of the table.

To ensure comprehensive data collection, we moved the sensor continuously in a strip pattern over the table, following the grid lines. This movement enabled us to cover the entire surface while collecting two measurements per square. Additionally, we incorporated three holes in the table, strategically positioned at different locations. Each hole was connected to a tube, allowing CO2 to be released at distinct points during the experiment. This setup enabled us to assess the concentration variations and odor spread in the vicinity of these release points.

Figure 21. Setup of the experiment

4.2 ANALYSIS OF RESULTS

During the experiment, we collected data on the intensity of CO_2 measured in parts per million (ppm) and the concentration of organic volatile compounds (TVOC) at various time intervals. The collected data is presented below:

t(s)	ppm	TVOC
1	1086	104
2	1350	236
3	3203	480
4	3443	463
5	2829	370
6	3443	543
7	4106	543
8	3962	843
9	3553	963
10	5041	1145
11	6684	876
12	6921	647
13	7992	873
14	3880	447
15	2581	332
16	2320	292
17	1782	210
18	1571	178
19	1465	162
20	1401	152
21	1364	146
22	1351	144
23	1330	141
24	1261	131
25	1465	162
26	1782	210
27	2251	312
28	2251	445
29	2996	2879
30	2996	1682
31	2280	1069
32	1827	388
33	1544	174
34	2460	152
35	4692	146
36	3110	138
37	1530	126
38	1196	121
39	1153	114
40	1141	112
41	1130	111
42	523	119
43	748	126
44	796	499

PEAKS

Figure 22. Collected data

Upon analyzing the dataset collected during the experiment, several key observations can be made. Firstly, it is evident that the concentration of CO_2, measured in parts per million (ppm), varied over time. The values ranged from a minimum of 523 ppm to a maximum of 7992 ppm. This wide range suggests that the experiment successfully captured varying intensities of CO_2 in the air.

Furthermore, the recorded measurements of total volatile organic compounds (TVOC) also displayed fluctuations throughout the experiment. The TVOC values ranged from a minimum of 104 to a maximum of 2879. These variations in TVOC concentrations provide additional evidence of the presence of odorous compounds in the air.

To better understand the significance of these measurements, it is useful to compare them with established standards. According to established guidelines, the recommended maximum allowable concentration of CO_2 in indoor environments is typically around 1000 ppm (parts per million). Exceeding this threshold can lead to poor air quality and potential health concerns.

In our experiment, the measured CO_2 concentrations surpassed the standard values in numerous instances, reaching levels as high as 7992 ppm. These findings indicate the potential presence of elevated CO_2 levels in areas with odor-related issues. By identifying and mapping such areas using a drone-based odor monitoring system, environmental protection agencies can target their efforts more effectively and mitigate potential risks to public health.

Additionally, the correlation observed between proximity to the CO_2 source and higher intensity measurements supports the hypothesis that our prototype successfully detected and tracked odor trails. This finding provides a crucial proof of concept for the feasibility of a drone-based system to swiftly and accurately pinpoint the source of odors over large areas.

4.3 2D AND 3D MAPPING

The key component of our technology is the generation of a 3D map that accurately represents the distribution and intensity of odors in the monitored area. This dynamic map consists of a grid of points, each corresponding to a specific location in the scanned area. The color of each point on the map indicates the intensity of odors detected at that particular location.

In our experiment, instead of working directly with odorous substances, we focused on measuring CO_2 concentrations as a proxy. This approach allowed us to showcase the potential of our system for rapid source identification. The 3D map serves as a powerful tool in this process, providing valuable insights into the areas where odor sources may be present.

The color scheme employed in the 3D map conveys important information. Points displayed as transparent (none) indicate that no significant odor intensity was detected at those locations. White points represent areas with odor intensity close to the average level in the air, suggesting limited chances of identifying the odor source. Yellow points denote higher intensity levels, indicating that the drone is getting closer to the potential source. Finally, red points represent areas with the highest concentration of odorous substances, suggesting a high probability of locating the odor source in those regions.

This 3D map is a critical tool for efficient and effective source identification. Unlike static e-noses that require numerous trials and calibration, our dynamic map provides real-time information and immediate guidance for the drone. By directly following the scent patterns displayed on the 3D map, the drone can swiftly track and locate the source of the odor, significantly enhancing the capabilities of environmental protection agencies in identifying and mitigating odor-related issues in open and wide environments.

While our experiment focused on CO2 measurements, we believe that with a more sophisticated electronic nose (e-nose), we can achieve similar results for a wide range of odorous substances. The 3D map serves as the foundation for this technology, enabling rapid detection and tracking of odors, thus revolutionizing odor source identification and environmental monitoring.

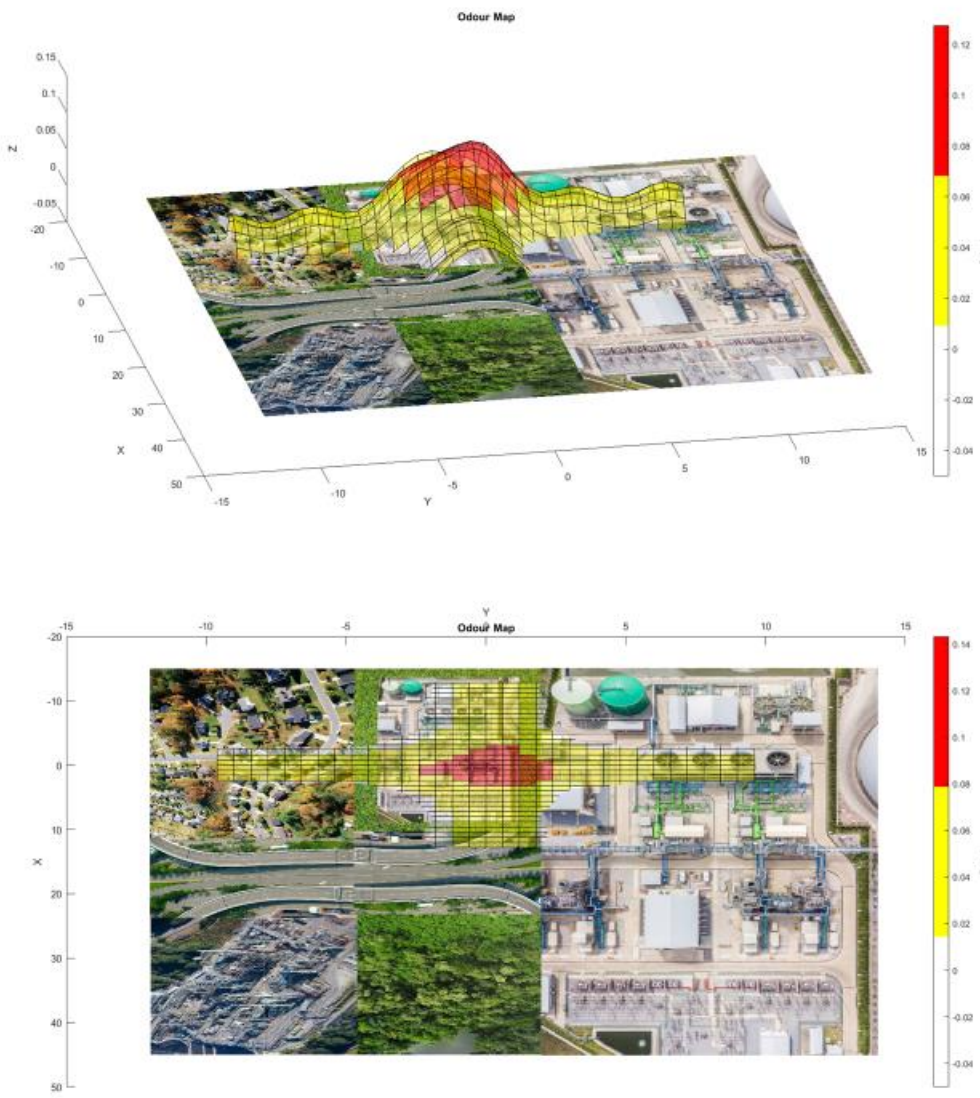


Figure 13. 2D and 3D plot in Matlab

4.4 PROTOTYPING CONCLUSIONS

The analysis of the collected data reinforces the viability and significance of our drone-based odor monitoring system. The recorded concentrations of CO2 and TVOC, along with their variations over time, provide valuable insights into the presence and distribution of odor-causing compounds.

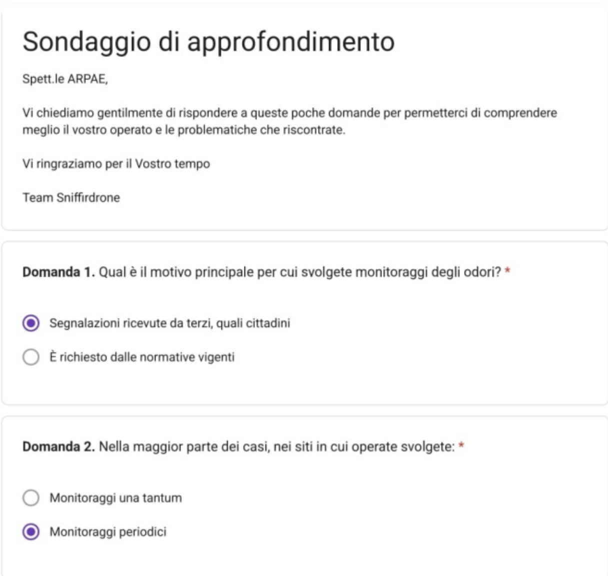
By surpassing established standards for indoor CO2 concentrations, our findings underscore the potential health implications associated with odor-related issues. The successful correlation between proximity to the CO2 source and higher intensity measurements confirms the ability of our prototype to detect and track odor trails accurately.

With the aid of 3D mapping, we have visually represented the collected data, highlighting the concentration patterns of CO2 in the experiment area. This demonstration further emphasizes the system's potential in enabling environmental protection agencies to identify and manage odor sources more efficiently in open environments.

In conclusion, the prototyping phase of our project has yielded valuable insights and confirmed the feasibility of our drone-based odor monitoring system in odors scouting application. By continuing to refine and develop this technology, we have the opportunity to significantly contribute to environmental protection efforts and address the challenges associated with odor pollution in various scenarios.

4.5 MARKET CONSIDERATIONS

In the very final part of our path, we have gained insights into the key cost factors associated with Sniffirdrone technology. To better understand the real needs of ARPAE we had them fill out a small in-depth questionnaire (in Italian), the answers are below:


Sondaggio di approfondimento

Spett.le ARPAE,

Vi chiediamo gentilmente di rispondere a queste poche domande per permetterci di comprendere meglio il vostro operato e le problematiche che riscontrate.

Vi ringraziamo per il Vostro tempo

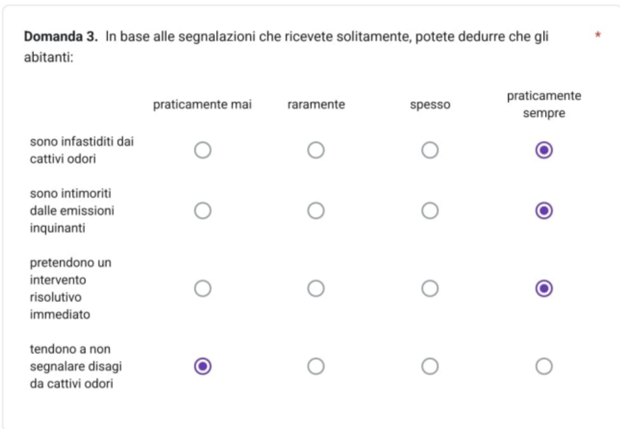
Team Sniffirdrone

Domanda 1. Qual è il motivo principale per cui svolgete monitoraggi degli odori? *

- ● Segnalazioni ricevute da terzi, quali cittadini
- ○ È richiesto dalle normative vigenti

Domanda 2. Nella maggior parte dei casi, nei siti in cui operate svolgete: *

- ○ Monitoraggi una tantum
- ● Monitoraggi periodici


Domanda 3. In base alle segnalazioni che ricevete solitamente, potete dedurre che gli abitanti: *

	praticamente mai	raramente	spesso	praticamente sempre
sono infastiditi dai cattivi odori	○	○	○	●
sono intimoriti dalle emissioni inquinanti	○	○	○	●
pretendono un intervento risolutivo immediato	○	○	○	●
tendono a non segnalare disagi da cattivi odori	●	○	○	○

Domanda 4. Quanto ritenete rilevanti queste difficoltà che potreste riscontrare nel monitoraggio degli odori?

	non rilevante	poco rilevante	rilevante	molto rilevante
Individuare la sorgente del cattivo odore	○	○	◉	○
Calibrare correttamente gli strumenti per rilevare gli odori	○	○	○	◉
Reperire sul mercato strumenti per rilevare accuratamente gli odori	○	○	○	◉
Il tempo impiegato dagli attuali strumenti per rilevare gli odori	○	◉	○	○
L'attendibilità dei dati forniti dagli strumenti	○	○	○	◉
Stabilire le giuste azioni correttive per risolvere il problema identificato	○	○	○	◉

Domanda 5. Quanto desiderereste migliorare questi aspetti in futuro?

	non necessario	sarebbe abbastanza utile	sarebbe molto utile	necessario
Poter svolgere monitoraggi più rapidi a parità di dati ottenuti	○	○	○	◉
Ottenere dati più accurati in termini spaziali potendo così avere un'idea più chiara della distribuzione degli odori in un'area	○	○	○	◉
Avere dispositivi più maneggevoli da trasportare e adattabili a diversi contesti	○	○	◉	○

Questo modulo è stato creato all'interno di Unife.

Google Moduli

Figure 4. Questionnaire for ARPAE Bologna

The major expenses are incurred during the calibration and machine learning model development processes. Calibration involves comparing instrumental responses with results obtained from a human panel through dynamic olfactometry. Once the technology is fully operational, the ongoing cost of using Sniffirdrone is relatively low.

Regular recalibration of the model is required every 4-5 months to account for signal drift caused by the gradual degradation of chemical sensors over time. The machine learning capabilities of Sniffirdrone enable it to recognize patterns of odors, enhancing its effectiveness.

Given these considerations, we believe that Sniffirdrone can be marketed both as a product and as a service. In the case of a product, the initial investment required may seem significant, but it would offset the current expenses incurred by ARPA due to the calibration of multiple static electronic noses. However, it is important to consider additional costs, such as drone pilot training. Overall, considering the frequent utilization of the technology, we believe that Sniffirdrone would yield tangible cost savings, while also reducing intangible costs such as technician efforts in the field. Furthermore, it would deliver invaluable benefits, such as ensuring accurate results and improving the quality of life for citizens.

Alternatively, in the service model, Sniffirdrone could be sold to third-party providers for one-time monitoring activities, eliminating the need for maintenance costs and pilot training. This approach would provide flexibility to organizations that require occasional monitoring without incurring the full ownership costs of the technology.

FINAL PERSPECTIVES AND CONCLUSIONS

The outcome of our project has paved the way for exciting future developments:

1) The first significant prospect is the potential collaboration between ARPAE Bologna and our research partner in Barcelona, with our team serving as a bridge between the two entities. This collaboration holds significant promise, as both ARPAE and our research partner have expressed interest in exploring future cooperation. Professor Galvéz, however, approached the idea with a balanced perspective, displaying a mixture of enthusiasm and pragmatism. He emphasized the importance of establishing a business framework, where ARPAE demonstrates a willingness to fund the potential partnership, enabling him to bring the technology to Italy and test it in accordance with ARPA Emilia Romagna's specific needs. Such a collaboration would prove mutually beneficial, offering ARPAE the opportunity to assess the technology's effectiveness for their purposes, while providing Augustin with a valuable chance to evaluate the efficacy of his technology across a broader range of contexts.

2) ARPAE Modena has also shown keen interest in maintaining a collaborative relationship with our team and Barcelona. They recognize that our project holds intriguing implications for the agency. However, ARPA Modena has expressed the need for a clear framework of agreement with the University of Bologna. This framework would outline the objectives, technical requirements, and timeframes, enabling ARPA Modena to evaluate the feasibility of the proposed collaboration.

3) Following the completion of our third milestone, we had a productive call with Emilio Tropea, the open innovation manager of CRIF. Emilio informed us that he is collaborating with a startup involved in the drone and electronic nose sectors. While no concrete plans emerged from this initial discussion, Emilio expressed interest in assessing the total addressable market for the service we have developed. He said that he would evaluate the potential market size and arrange a meeting with the startup's chief. This development hints at promising opportunities on the horizon.

To sum up, the outcome of our project has generated significant interest and potential avenues for future collaboration. The prospects of partnering with ARPA Bologna, ARPA Modena and the startup aligned with CRIF have opened up exciting possibilities. With a clear framework and continued efforts, we are optimistic about the fruitful collaborations that lie ahead.

CBI.ATTRACT has been quite an adventure. Embarking on this journey, we had little idea of what lay ahead, but we knew it would be different and exciting. What truly made the difference was the team spirit of each other's travel companions. Even though we didn't have a clear destination in mind, we all pushed forward together, united in purpose.

Throughout this adventure, we discovered that the journey itself matters more than the destination. It's the ups and downs, the challenges we faced, and the small victories along the way that truly shaped our experience. We learned to think outside the box and took on a project that none of us felt fully prepared for. However, we were all ready to contribute our knowledge, realizing that our collective effort was essential for success.

In taking part in this multidisciplinary project, we discovered the value of collaboration and teamwork. We witnessed the magic that happens when diverse perspectives come together, and we saw firsthand how our different skills and backgrounds complemented one another. The synergy within our team was remarkable, and it allowed us to achieve more than we could imagine.

Above all, this adventure taught us the importance of stepping out of our comfort zones. It required ambition and bravery to push beyond what was familiar and take risks. Through this, we experienced personal growth and discovered new possibilities we might have otherwise overlooked.

As we conclude our journey with CBI.ATTRACT, we carry with us the memories of the challenges we overcame, the successes we celebrated, and the bonds we formed. We have grown individually and collectively, changed by this transformative experience.

Thank you.