Technology for Social Innovation

Group 3 - AHEAD

ALERTOOTH

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1. Introduction

The present work is an EU-ATTRACT[1] based project which aims to explore ways to apply the discoveries and breakthroughs that emerge from these institutions to address problems in areas like healthcare, air and water pollution, environment, food safety and social inequality.

EU-ATTRACT is an international consortium comprised of CERN, UPC, IED, ESADE, the European Molecular Biology Laboratory, Aalto University and several other research centers around Europe.

In particular, the present work is part of the AHEAD program[2], which is based on a CERN research project: Smart Wall Pipes and ducts (SWaP)[3], a generic manufacturing technology to produce 3D metal components with embedded sensors. More expert domain information about this technology can be found in the Appendix.

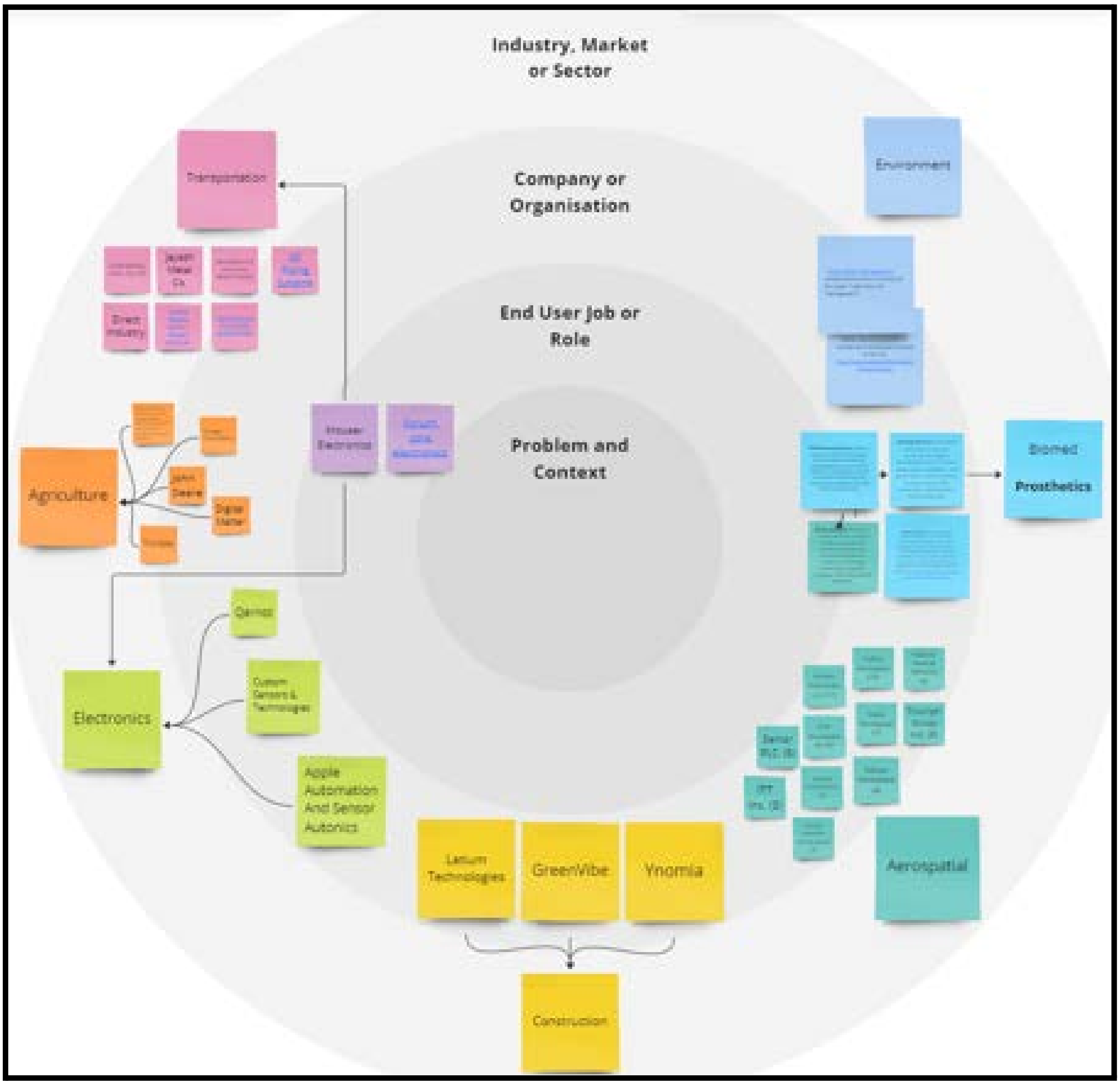
The document is structured as follows: initially, we describe the brainstorming process, then we follow with the exploratory phase, to continue with the decisive phase, which lead us to the description of the final idea. Ultimately, we have the conclusions and the reflection of the student learning process.

[1] https://attract-eu.com/
[2] https://phase2.attract-eu.com/projects/ahead/
[3] https://phase1.attract-eu.com/showroom/project/smart-wall-pipes-and-ducts-swap/

2. Brainstorming

During the most early development phases of this project, our objective was to research different industries where we believed that the chosen technology could be of use. Based on that, our initial keypoint was to look for sensor appliances in different industries, from which to extract if the AHEAD technology would be a fit. The main fields that we extracted information on where the following:

1. **Automotive - Transportation**
    - Utilizing SWaP technology for manufacturing vehicle components with integrated sensors to enhance vehicle diagnostics and performance monitoring.
2. **Biomed**
    - Employing SWaP technology to create advanced surgical tools and implants with embedded sensors for real-time data during medical procedures.
3. **Construction**
    - Using SWaP technology to produce structural components with embedded sensors for monitoring the health of buildings and infrastructure.
4. **Agriculture**
    - Utilizing SWaP technology in agricultural machinery and irrigation systems to embed sensors directly into equipment and piping. These sensors could provide vital data for soil moisture levels and crop health monitoring, optimizing water usage and improving yield predictions.
5. **Environment**
    - Developing piping systems with SWaP technology for environmental monitoring, specifically in water management for leak detection and quality control.
6. **Aeroespacial**
    - Employing SWaP technology to manufacture static dissipative tubing with embedded sensors for aerospace applications. These sensors could monitor electrostatic charges, improving safety by preventing static build-up in critical fuel and hydraulic systems.


Industry, Market or Sector
Company or Organisation
End User Job or Role
Problem and Context
Transportation
Environment
Agriculture
John Deere
Electronics
Custom Sensors & Technologies
Apple Automation And Sensor Autonics
Biomed
Prosthetics
Aerospatial
Latium Technologies
GreenVibe
Ynomia
Construction

3. Initial Phase - Research and Rejection

After the initial brainstorming process, the following three ideas where the most highlighted ones, and the chosen options to present to both the researcher and the professors' team:

Bird Ringing

Figure: Ordinary bird ring example

The idea was to embed GPS trackers into the ordinary bird rings to be able to monitor the activity of birds, focusing specifically on the migration. Currently, bird rings are metallic static rings that show information about the place where they were captured, type of species, gender, age… and other parameters.

However, only when the bird is recaptured again, we are able to know where it is, leaving a huge void of geolocations in between the captures. Obviously, a wide range of different GPS tracker devices for the birds are already on the market, so that investigators can know their migration paths and some other information in real time. Despite that, the main problem is the size of these devices, and the way they are placed into the animals' body, which in most of the cases is quite invasive:

Figure: Current state of GPS-tracker devices example on a bird

Therefore, our proposal was to offer the possibility to miniaturize these trackers into the aforementioned ordinary static bird rings, reducing the impact for the birds when wearing and getting them installed, finding this approach to have an undoubtedly social impact in biology and Earth's species.

To accomplish this goal, we got in touch with many ornithologists and associations applying bird ringing technology (for instance: EURING (European Union for Bird Ringing), the Spanish Association of Ornithology (SEO Birdlife) and its regional associations).
Dr. Stephen Baillie, President of EURING and chair of the Eurasian African Bird Migration Atlas project, was particularly helpful in obtaining response to all of our inquiries. He explained us about the current state of the art of bird tracking devices and shared priceless knowledge, both by email and his scientific research[4].

Finally, the most important part of the gathered information was provided by the Institut Català d'Ornitologia, who was really interested in our idea. Particularly Raül Aymí, Oriol Baltà and Gabriel Gargallo, researchers of the institution, with whom we did an online interview that was truly helpful and instructive.

The main challenges that our idea had were:

- The connection between the bird ringing device.
- The battery / energy supply for the device.
- The size and weight: *"tags need to weigh a small fraction of the bird's body weight for welfare reasons. This constraint would be even greater for a ring - moderate size rings weigh 0.5 - 2g, the largest up to 5g - any device would have to not add substantially to the weight and would require it to be distributed evenly around the ring (to prevent it tilting on the leg and chafing)".*

[4] Geen, Robinson, and Baillie, "Effects of Tracking Devices on Individual Birds – a Review of the Evidence."

Antennas

When it comes down to the many ideas that the group had researched on, one of the chosen ones to start pursuing was the standing out proposals on the telecommunications field, including, most of the times, solutions addressing communication issues involving antennas' integration.

A relevant topic of research, collaborating with UPC professors Xavier Hesselback and Josep Paradells, from the Telematic Engineering Department, was the endless and useful applications in regards to the Wireless Sensing Networks Technologies. This technology is mainly used to gather information from the physical world using sensors, allowing to act upon it through actuators. Their purposes include improving resource management efficiency, promoting sustainability, and enhancing human life quality.

Opportunistic networking supports the mobility of nodes to ensure information transfer despite intermittent connectivity. It uses nodes as data carriers, transporting information until a connection is available to relay it, ensuring interoperability, flexibility, and scalability.
At the moment of looking for information, the most common applications involving sensor network applied were:

- **Medical Teleassistance:** People with health problems (e.g., the elderly, disabled, etc.) can benefit from the use of sensors that measure their biometric parameters, among others, to allow for permanent remote monitoring. This way, accurate diagnoses can be made, and alarms can be triggered in case an emergency situation is detected.

Fig. 2.2. Wireless sensor node to be fitted at the wrist (orange box) for patient identification, monitoring and location. The black box at the top of the image is used as a wireless router to create a backhaul network used for communication and as a reference for location in the hospital

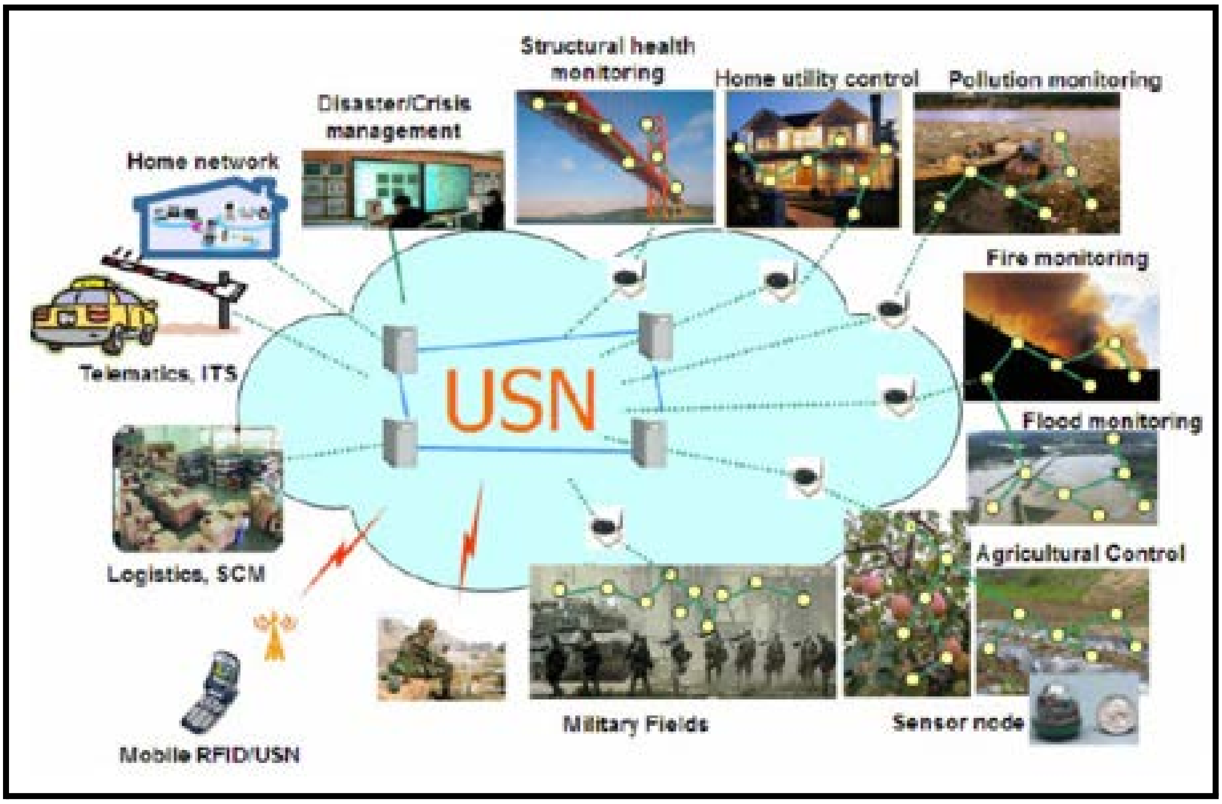
- **Environmental Monitoring:** The small size and high autonomy of sensors make them ideal for monitoring the environment. Sensors can be easily camouflaged or even placed on animals.

- **Preventive Monitoring:** Both in infrastructures and mechanical systems, sensor networks can be used to continuously monitor parameters that predict the collapse of a bridge or the failure of a part. For this purpose, vibration, displacement, or temperature sensors are mainly used.

- **Building Automation:** A home or office is a place where various sensors, actuators, and devices that need to be controlled can be found. With the development of wireless sensor networks, all solutions can be unified into a single system, facilitating improvements in performance and cost.

- **Meter Reading:** Gas, water, and electricity supply companies have been trying to remotely read meters located at the customer's home for many years. These networks should be able to interact with the user's equipment to control services.

- **Smart Cities:** Management of equipment, green areas, waste collection, public transport, sewage, road traffic, and lighting, to name a few. Sensor networks can be used to monitor proper functioning and control the irrigation of green areas, save on lighting in areas without people, plan waste collection based on container occupancy, or identify available parking spaces.



So, once again, even though exploring a specific field from the many we had initially, we were left with multiple choices. At that point, we focused our efforts on the ones we felt had more potential, such as the Vehicular Adhoc Networks (VANETs) or the city pollution monitoring through lampposts.

VANETs are a key component of Intelligent Transportation Systems, promoted by government regulatory initiatives. They collect and share data from roads and other vehicles, providing information such as emergency notifications, traffic warnings, road conditions, and weather forecasts. Unlike other networks, VANETs are not limited by power availability or processing capacity, enabling efficient real-time communication and enhanced road safety.

That, apart from the already existing emergency optimal-path calculation system, opened up the chance of proposing a method to communicate remote isolated villages or areas, so, whenever a transport came to pick up o deliver goods, litter, or to attend an emergency, they could establish connection with the local server, to then transmit that information to other nodes, enabling intermittent communication to the rest of the world.

The main proposed idea was to print the desired sensor into a microcontroller, placed on top of the automobile or lamppost head. The sensor would be combined together with an RF antenna, feeded by electrical power supply, generated by the car motion or using the same electric power system in case of the lamppost.

Unfortunately, the feedback received was not super positive. All in all, our approach to the solution of the problem was not well defined nor focused on a particular group of affected customers, oppositely super broad, and we were lacking information on the innovation, as most of this technology was already invented or been used, so there were small improvements on our proposal.

While discussing it with researchers, the structural level monitoring came out as the most interesting approach of the ones we had searched about, and consequently discarded our previous ones in favor of it.

Basically, the problem resides on how infrastructure health status is monitored, having to execute expensive and time consuming processes during audits. Our approach pretended to print a 3D piece including vibration, displacement, or temperature sensors used in building monitoring, to prevent and detect anomalies before the incident occurrence.

These would be thrown inside the concrete or building material during the construction, and, by using a device, such as a mobile, one could power the sensor by means of RF energy to register the levels read by it, which would improve the process in great time and manner.

Prosthetics

Our initial foray into the world of prosthetics was ambitious. We envisioned a future where sensors were seamlessly integrated directly into 3D printed prosthetic limbs, transforming them from passive replacements to active partners in movement and rehabilitation. This research, while ultimately discarded, laid the groundwork for exciting possibilities and provided valuable lessons for future exploration.

The project commenced with a valuable interview with Jón Reyr Jóhannesson, an industrial designer at Ossur, and a leading force in prosthetic development. Jón gave us some insights on “how the industry nowadays does research and development in the field of prosthetics”. These indications pointed towards the transformative power of sensor technology by monitoring and analyzing various aspects of daily usage.

Pressure distribution, a critical factor in comfort and long-term use, was a prime target. Imagine sensors embedded within the prosthetic socket that could map pressure points in real-time. This data could then be used to personalize the prosthetic fit, minimizing discomfort and preventing potential skin breakdown. Additionally, gait analysis stood to benefit immensely. Sensors could track movement patterns, identifying areas for improvement and informing targeted therapy programs.

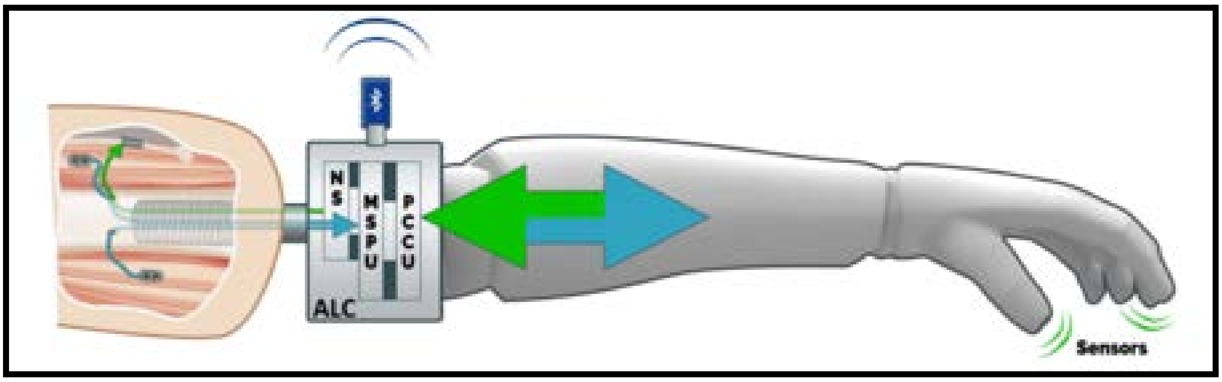
Muscle activity was another exciting area of exploration. By monitoring residual muscle signals, we envisioned the development of more intuitive control systems, allowing for a more natural and responsive prosthetic experience.

In the process, we came across significant articles, such as the one redacted by Joan Sanders, bioengineering professor at the University of Washington, and his team, aiming to ease patient discomfort with research that could help build better sockets. They have developed a device that tracks how much a person’s limb swells and shrinks when inside a prosthetic socket. The data could help doctors and patients predict how and when their limbs will swell, which is of great use to build smarter sockets.


The portable device tracks how much a person’s limb swells and shrinks when inside a prosthetic socket. *Joan Sanders, U of Wash.*

Worthy of note is the research put forward by the Swedish Research Council in a scientific article on 'Embedded Systems for Prosthetic Control Using Implanted Neuromuscular Interfaces Accessed Via an Osseointegrated Implant', describing a new embedded controller for prosthetic limbs that utilizes a technology called OHMG.

This system offers several advantages, including bioelectric signal processing, prosthetic control, and sensory feedback. The authors compared the performance of standard control methods with their own pattern recognition algorithms and achieved promising results. Additionally, they were able to successfully implement a neurostimulator for tactile sensation restoration. Overall, the research demonstrates a potentially valuable prosthetic control system with promise for real-world applications and further research.



Artificial Limb Controller (ALC). The system is composed by three modules: Neurostimulator (NS), Mixed Signals Processing Unit (MSPU) and Prosthetic Control and Communication Unit (PCCU). An external module can be plugged on the side of the system to achieve Bluetooth communication. Myoelectric signals are acquired from the implanted epimysial electrodes and then digitally processed to decode the motor intention of the user. In parallel, sensors on the prosthesis are periodically read and their output converted into stimulation pulses to the nerve via cuff electrode.

Furthermore, concerns arose regarding the long-term durability of embedded sensors. The constant stress and strain placed upon prosthetics during daily use raised questions about the sensors' ability to withstand the rigors of everyday life.

Another critical consideration involved data security and user privacy. The idea of collecting sensitive data about a user's movements and muscle activity raised ethical concerns. Implementing robust security measures and ensuring user control over collected data became paramount.

Despite these challenges, the research yielded valuable insights, and the growing interest within the field of prosthetics for incorporating sensor technology was undeniable. We learned about the immense potential benefits of monitoring various aspects of prosthetic use, highlighting the path towards a future of personalized care and improved user experience.

While 3D printed sensors were not the ultimate answer in this instance, the research served as a springboard for further exploration of sensor integration in the biomedical field, which proved to have a huge social impact potential, underscored the importance of collaboration between designers, engineers, and medical professionals in pushing the boundaries of prosthetic technology. The journey also highlighted the need for careful consideration of the technical, ethical, and practical challenges associated with new technologies.

4. Decisive Phase - Tooth

Our decisive phase took place during the CERN stay. There, after narrowing down the aforementioned 3 ideas, and after presenting them to our researcher, we did not receive really good feedback from her.
She, at least, provided us some lead to chase, by indicating that biomedical applications seemed a good field to investigate on, if the purpose and implementation was well found.

At that point, we looked for multiple choices, finding in dental health our last point of broad research. It was in this sector where we could identify potential social impacting issues where the AHEAD technology could be used through sensor monitoring implementation:

Jaw Movement - Bruxism

Bruxism, characterized by the repetitive clenching or grinding of teeth, manifests in two forms: sleep bruxism (SB) and awake bruxism (AB). It affects approximately 10% to 13% of adults (SB) and 22% to 31% (AB), with even higher prevalence among children, ranging from 40% to 50%. The condition can lead to a variety of symptoms, including aching jaw muscles, hypersensitive teeth, extensive tooth wear, and even damage to dental restorations.

Historically, the monitoring and management of bruxism have relied on external devices, such as bite guards equipped with pressure sensors. These devices, though somewhat effective, require nightly application and are not discreet, often leading to user discomfort and low compliance rates.

Building upon research initiatives from notable institutions such as the National Center for Sensor Research at Dublin City University and the Department of Dental School at Trinity College Dublin, there has been a shift towards integrating sensor technology within dental devices. The initial implementation involved embedding sensors in bite guards to monitor jaw pressure and movement continuously.

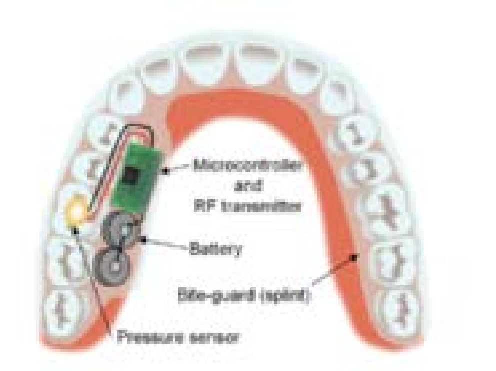


Fig. 1. Conceptual drawing of the proposed device.

To further this advancement, we proposed to integrate sensor technology into a compact, 3D-printed tooth. This approach would allow for real-time, continuous monitoring of bruxism and jaw movements without the need for cumbersome external devices. The embedded sensors within the 3D-printed tooth would be capable of detecting both the occurrence and intensity of bruxism episodes, with data transmitted via Bluetooth to a mobile application for immediate analysis.

The integration of sensor technology directly into a dental prosthesis represents a significant innovation in patient care within dentistry. This technology enables proactive management of bruxism, potentially preventing the progression of the condition and associated complications, such as TMJ disorders and severe tooth wear. Moreover, the discrete nature of the integrated device promotes higher patient compliance and comfort.

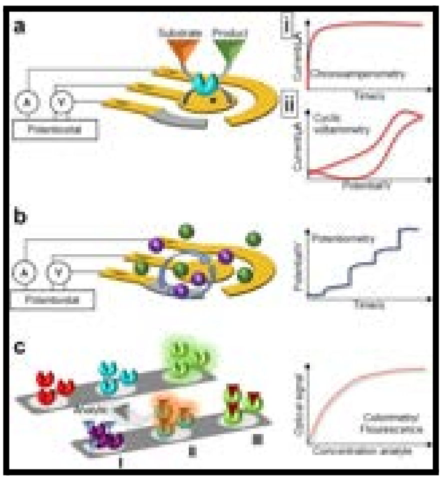
Oral Health

Salivary biomarkers are suitable for screening multiple unusual systemic conditions. More significant for dentistry, saliva can help assess oral cavity diseases like periodontal infections or caries risk assessments.

Single isolated samples often offer little information and might even be misleading. However, monitoring salivary parameters can throw valuable data. Hence, wearable intraoral sensors seem to be a promising tool.

For real-time monitoring of salivary parameters over several hours, the establishment of wireless communication and long-distance data transmission between the intraoral sensor and the readout device (e.g., smartphone) is still challenging. Nowadays, the best and most energy-efficient strategies include the application of Bluetooth low energy (BLE) and near-field communication RFID (radio frequency identification).

Sensor formats like flexible polymer foils on mouthguards, pacifiers, dentures, vacuum-formed oral appliances, or silk-based dental tattoos have been developed.



Schematic illustration of the most common biosensors suitable for detecting salivary analytes. a) Optical biosensors b) Amperometric biosensors monitor electrochemical reactions via measurable currents. c) Potentiometric biosensor

- Optical approaches such as fluorescence and colorimetry (Fig. 2a) provide relatively simple readout formats.
- In general, electrical or electrochemical transducers (2b) are capable of quantifying analytes in sensors with a simple format, where multiple of them can be integrated in a single and small-footprinted chip for multiplexed analysis.
- The same set of electrodes can also be operated as potentiometric transducers (Fig. 2c). Despite the higher complexity for sensor fabrication, ultrasensitivity is gained

When coming to the detection, calcium elevates in saliva also due to oral dehydration and increased protein concentration in diabetic patients. There is no ion-selective wearable sensor available for measuring in real time, as interferences from other ions and ionic strength differences are difficult to analyze, but could be in the future. The most common approach is an electrochemical sensor, although other research groups performed measurements using ion chromatography, piezoelectric sensors, or customized ion-selective sensors as PoC devices.

Fluoride is the most important chemical element in preventive dentistry, but the low concentration may cause problems for sensors development. There has been no sensor monitoring salivary fluoride in situ in real time. Modified ion-selective electrodes seems to be the most common approach.

All in all, our reading through the paper was that real-time, long-term, and continuous intraoral measurement needs further investigation as only few well-functioning sensors have been developed until today, with enzyme-based sensors being an appropriate approach. Until now, there is no sensor that measures reliably beyond hours for any analyte **other than glucose**.

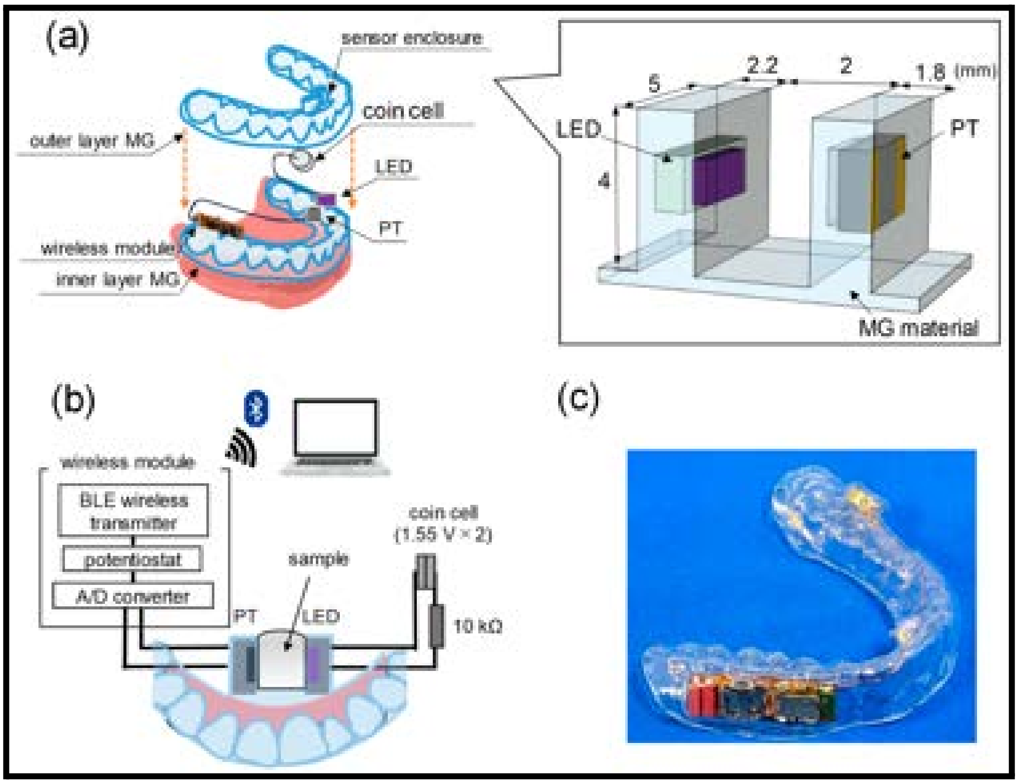
So, that gave us an opening to future implementations on oral health monitoring and treatment, which, with the appropriate sensor, materials and prototyping, could be a valid option for our final product.

In terms of oral health detection with sensors, a different and insightful approach was also found. This was focusing on salivary turbidity, which is a promising indicator for evaluating oral hygiene. This study proposed a wearable mouthguard-type sensor for continuous and unconstrained measurement of salivary turbidity.

The sensor evaluated turbidity by measuring the light transmittance of saliva with an LED and a phototransistor sealed inside a double-layered mouthguard. The sensor was also embedded with a Bluetooth wireless module, enabling the wireless measurement of turbidity. The proposed mouthguard-type sensor has promising potential for the unconstrained continuous evaluation of oral hygiene:

Phototransistor, LED, wireless module, and coin cells sealed inside a double-layered MG. The PT and LED were installed facing each other on the lingual surface of the incisor. This sensor evaluated the salivary turbidity by measuring the transmittance of light emitted from the LED through the saliva flowing in the gap between the LED and PT.

Plaster dental models were used as the base for vacuum-forming the inner and outer layers of the MG. A 3D-printed dummy part was incorporated to create space for sensor elements such as a turbidity sensor and LED. The outer layer was reshaped locally to ensure proper alignment of components. Sensor elements were connected using enameled wire and sandwiched between the layers.



The wireless module for the MG-type sensor functions as an A/D converter, potentiostat, and wireless transmitter using Bluetooth Low Energy. A constant voltage of 800 mV was applied to the PT using the wireless module, and the output current was evaluated as an output representing turbidity.

In conclusion, in vitro and in vivo turbidity measurement results of saliva samples showed similar results with the MG-type sensor as with optical measurements with a spectrophotometer, indicating that the MG-type sensor is capable of measuring salivary turbidity. In addition, the in vivo measurement experiments demonstrated wireless unconstrained with the fabricated MG-type sensor.

This part was a key point when imagining how we could create and propose a sensor for the final idea design, and from these papers' research we extracted the main components and structure used when building mouth monitoring sensors.

Allergy

One method of avoidance to food allergies is to monitor food with point of care (POC) biosensors that can detect known allergens. These detectors are categorized according to their sensor mechanism, such as optical, electromechanical, and electrochemical biosensors:

- **Optical biosensors:** measure surface property changes when an analyte is bound to a sensor chip and forms a target-receptor complex on the sensor, using colorimetric or fluorescent detection. Surface Plasmon resonance (SPR) is widely used for allergen screening because it enables label-free, real-time. and highly sensitive detection.
- **Electromechanical biosensors:** one major challenge is that the microbalance resonant frequency and sensing layer requires that antibodies, DNA complementary sequences, and aptamers are immobilized on the transducer surface. To address this, quartz crystals are used to enhance the amount of immobilized molecules, while nanoparticles increase the sensor surface area and sensitivity.
- **Electrochemical biosensors:** easy miniaturization, lower cost, and the potential to incorporate additional POC settings like wireless food allergen monitoring. Provides semi-quantitative or qualitative data based on an electrochemical transducer. There are four types: amperometric, potentiometric, impedance, and voltammetric biosensors.

The complexity of food allergies and our poor understanding of their causes hinder detection methods. There are multiple and almost endless biosensors developed for food allergen detection.

While researching for it, we found out that there are already prototyped or existing POC technologies, but most of them implemented into handheld or smartphone devices. The paper, however, gave us the idea of how and which sensors were designed to measure a certain protein and the different ways for implementing it.

Ultimately, but this being the most important research, was the study evaluating the possibility of use of saliva for the detection of IgE and IgG1 in the diagnosis of food allergy.

Samples of serum and saliva were collected and subjected to the indirect immunoenzymatic assay (ELISA) for the detection of specific immunoglobulins for food.

The methods currently available for detecting FA are still invasive, causing discomfort to the patient, often high costs, and are restricted to one food per test. In addition, the gold standard test requires hospital environment and trained staff, and may trigger life-threatening reactions, leading to anaphylactic shock in the patient. Moreover, this variety of methods only evaluates the presence of IgE class specific antigen antibodies.

The results demonstrated that, when comparing the levels of specific IgE and IgG1 immunoglobulins in the serum and saliva for the foods tested, no statistical difference between them are found for most foods.

In this context, it was found that the use of saliva for the detection of IgE is more sensitive to diagnose CMPA alone because it has a higher amount, however IgG1 also showed efficiency in the diagnosis of food allergy through saliva.

These findings indicate that the detection of IgE and IgG1 in saliva proves to be as efficient as in the serum. The use of the salivary technique for use in the diagnosis of food allergy is suggested.

5. Decisive Phase - Allergy

Coming down to make a decision towards our ultimate and definitive technology approach, we believed, after reading through the above mentioned immunoglobulin article (thoroughly explained in the appendix), that allergy had to be our final product solution, although the same proposal could be applied to the other explained problems.

We decided that it was better to implement a generic device approaching the allergy problem, rather than embedding different protein detection sensors. With the first, we were just focusing on a broader collective by detecting overall allergy reaction levels, leaving an opening for future specific protein detection for particular allergies at the same time.

Objective: What do we want to solve? Social impact

In exploring the societal implications of food allergies, the innovative tooth-mounted sensor, "Allertooth," offers a promising avenue to mitigate the significant economic and healthcare strains these allergies impose. Globally, food allergies affect approximately 1% of adults and 2% to 2.5% of children (Allergy UK, 2015), underscoring a widespread health concern. Economically, the burden is profound, with annual costs in the U.S. alone reaching approximately €22.8 billion. This total includes €4.0 billion in direct medical expenses and an additional €18.9 billion shouldered by families (Allergy & Asthma Network, n.d.)..

Traditional therapies, while available, are often costly, underscoring the urgent need for cost-effective alternatives like Allertooth. This device could potentially reduce the frequency of emergency medical interventions, thereby lessening the financial load on healthcare systems and significantly decreasing annual management costs.

For individual families, the financial relief could be substantial. Families typically face out-of-pocket expenses amounting to 31% of their food allergy-related budget going towards the higher costs of safe food alternatives. The sensor’s capability to provide real-time data about potential allergens enables better-informed dietary choices, which could reduce the reliance on expensive emergency measures and adrenaline autoinjectors, which cost between €143 and €682 per twin-pack in the U.S.

As we look to the future of managing food allergies, Allertooth stands out as a key technological advancement. It offers a sustainable, patient-centric approach that not only addresses the immediate dangers of allergic reactions but also contributes to the long-term management of the condition. By incorporating such innovative technologies into comprehensive allergy care strategies, there is potential to significantly enhance the efficacy and economic viability of managing this health issue.

A use case scenario

"Petra is a twenty three year old girl that is allergic to nuts. She goes to the ice cream shop to buy ice cream. There she orders an ice cream that she is ensured to not have nuts or any other allergen she is allergic to. However, the serving spoon is contaminated from the previous serving and traces of nuts end up in Petra's ice cream. She eats the whole ice cream before she starts noticing the consequences of the nuts as an allergic reaction."

In this situation, a continuous real time food allergen detection mechanism would help Petra to know about the nuts in its ice cream just in the first bite she takes, allowing her to stop eating the ice cream and therefore minimizing the negative effects of the food allergic reaction.

Our solution. Prototype. Technology

General description - Allertooth

Allertooth is a tooth-mounted inlay food allergy detector. It is a 3D-printed device that uses AHEAD technology to embed sensors during printing, allowing a custom fit for different teeth. It connects to your smartphone via a Bluetooth Low Energy (BLE) transmitter and detects your immunoglobulin levels from saliva samples, providing real-time data on your possible allergic reaction. This information helps you manage your allergies and adjust your response based on the severity. It relies on piezoelectric nanogenerators to generate the electric energy supply from the chewing motion.

Tooth inlay

The main idea is to have a device that is discrete and the least invasive for the user, reading for basing our product on a tooth inlay ("Inlays & Onlays")[5]. An inlay is similar to the traditional dental filling and fits inside the top edges of the tooth, called the cusp.

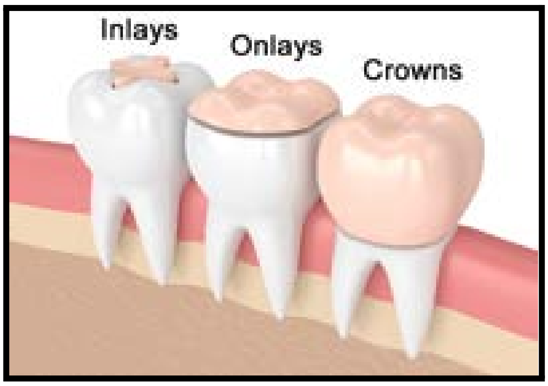


Figure: Tooth inlay, onlay and crown

[5] https://balotadentistry.com/inlays-onlays/

As it can be seen in the Figure, the tooth inlay is the least invasive tooth mounted add-on, in comparison to the more invasive ways like onlays or crowns.

The inlay will be 3D printed using the AHEAD technology (*AHEAD - ATTRACT Project Phase 2*, n.d.)[6] with ceramic materials, which provide good properties such as its natural appearance, the avoidance of allergic reactions, a better comfortability than with metallic materials, and being biocompatible (*4 Types Of Ceramic Dental Crowns*, n.d.)[7].

During the process, we reached out to odontologists, by asking questions and doubts in regards to the creation and production of the inlay, the needed material to 3D print, and the feasibility of our idea. Summing it up, they didn't see it undoable, but they made us reconsider the initial battery approach that we had, which could lead to leaks and toxic problems.

In addition, they made us reflect on the fact that, even though it was really useful, we were still being invasive to the tooth, and preferably we should install it on unhealthy rather than healthy ones.

One important added thing to take into consideration was the need of overall outer node structure checks, to know if it was big and robust enough to hold the perforation, avoiding to break the dent into pieces.
Additionally, they gave us insights on the dental pressure that we apply when chewing, which is quite high, and could break the sensor, so it was another factor to be aware of.

Food allergy detection

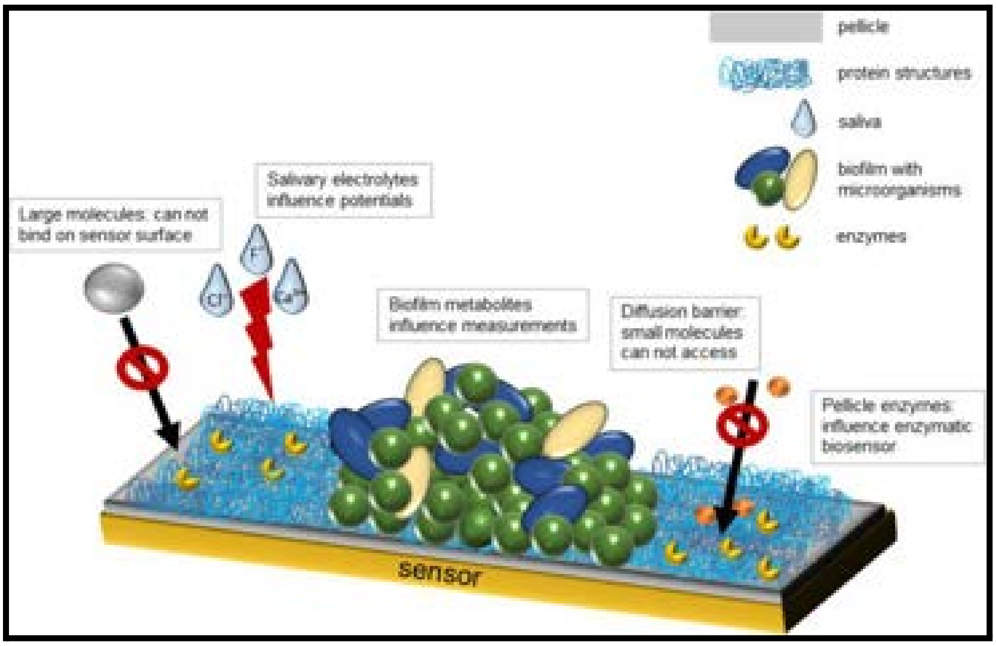
As seen before, the food allergen detection is based on the immunoglobulins (igE, IgG) biomarkers testing, which monitor immune response to infections. This detection of the immunoglobulin levels will be carried out by a nanobiosensor. As seen before, Nunes et al[8] showed a study on the usage of the saliva to detect specific antibodies related to food allergies, focusing on IgE and IgG immunoglobulins.

The main technique used for the detection is called ELISA (enzyme-linked immunosorbent assay) which is an immunoenzymatic assay, a laboratory technique used to detect and quantify specific proteins or antibodies in biological samples.

In the context of this study on food allergies, this kind of technique was employed to measure the levels of IgE and IgG antibodies in serum and saliva samples collected from individuals with cow's milk protein allergy. This method involves using enzymes linked to antibodies that can produce a measurable signal when they bind to target molecules, allowing researchers to assess immune responses related to food allergens.

[6] https://phase2.attract-eu.com/projects/ahead/
[7] https://drkorol.com/blog/4-types-of-ceramic-dental-crowns
[8] Nunes et al., "Detection of Serum and Salivary IgE and IgG1 Immunoglobulins Specific for Diagnosis of Food Allergy." https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6469776/

The results showed promising potential for using saliva as a diagnostic tool for food allergies, with significant findings related to cow's milk, fish, and papaya.



However, some considerations are also needed to take into account. Due to its heterogeneity, saliva metabolite measurement is challenging as the presence of bacteria, epithelial cells, and leukocytes can affect proper monitoring. Sampling standardization still seems to be an unsolved problem, as the concentration of the ingredients depends on the flow rate, the gland, gender, time of the day, the stimulus, and several other factors.

Thus, the variation in the sampling volumes and the influence of external factors like food and drinks is huge. Furthermore, the wide range of saliva viscosity and, therefore, the dilution of compounds due to stimulation of salivary flow is a crucial problem when considering sensor development.

Hence, it is essential for the design and placement of a wearable device that the fluid varies in consistency in different regions of the mouth. Moreover, the influence of the temperature should be addressed when monitoring intraoral metabolites.

More details on the study on how the detection of food allergies is carried can be found in the Food allergens detection subsection of the Appendix.

Mobile phone connection

The sensor read levels will be sent to the mobile phone of the user through a BLE[9] (Bluetooth Low Energy) transmitter. These values will be processed in a simple mobile phone application, that will be in charge of doing all the necessary calculations and notifications. We will be considering the following severity levels of the specific food allergy:

- **High**: high level of immunoglobulin, indicating an anaphylactic shock. In this case, the application will automatically call the emergency services.
- **Medium**: in this case, an alert will be sent to the user so that he can react in time by stopping to eat or drink, or appropriately taking the needed medicine or EpiPen.
- **Low**: the mobile will throw a simple alert to the user, so that he/she can be aware of the incoming risk about the ingested food.

Energy supply

In order to supply energy to the device, feeding the sensor and bluetooth transmitter, our solution proposes to include piezoelectric nanogenerators to recollect electric energy from the chewing and speaking motion.

Piezoelectric materials can convert mechanical stress into electricity, and electricity into mechanical vibrations, thanks to the appearance of the electric charge accumulated within the material due to the mechanical loading.

Yuan et al [10] show the usage of these piezoelectric nanogenerators in animals' bodies to harvest energy from the motion of different organisms such as heart, lung and diaphragm, proving the existence of biocompatible nanogenerators for energy supply of Implantable Medical Devices (IMDs).

Due to health and security reasons (although batteries are increasing more and more in safety), we chose and preferred to have an energy harvesting technique that uses no battery, as the device is placed inside the patient's mouth. A capacitor will then be in charge of storing the generated energy of the piezoelectric nanogenerator, so that the device can continue working even if the user is not chewing.

More notes on the articles that support the piezoelectric nanogeneration of the energy supply are included in the Energy supply subsection of the Appendix.

[9] "Bluetooth Low Energy. transmitter" https://en.wikipedia.org/wiki/Bluetooth_Low_Energy
[10] Yuan et al., "Biocompatible Nanogenerators through High Piezoelectric Coefficient 0.5Ba(Zr0.2Ti0.8)O3-0.5(Ba0.7Ca0.3)TiO3 Nanowires for In-Vivo Applications."

6. Prototyping

Introduction

The prototyping phase of the project was particularly stimulating when thinking about the feasibility of our product. We asked ourselves countless questions, exchanged ideas, and reviewed methods before settling up for a strategy.

Initially, the challenge was the measurements, as it was difficult to reproduce a realistic 1:1 scale of our product; the prototype would not have been seen clearly and miniaturizing the components was an added obstacle.

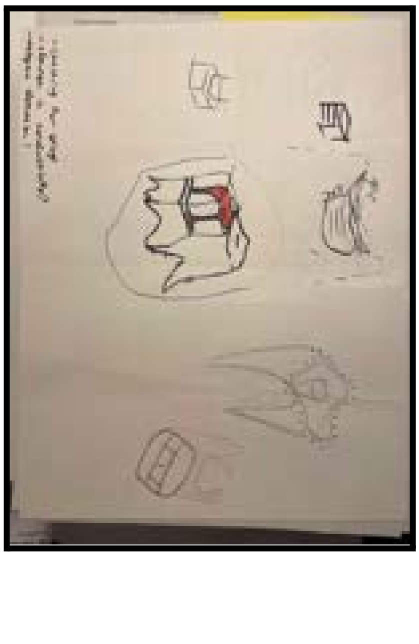
Therefore, we iterated our options and processes many times before obtaining our final physical augmented scale result. In addition to our physical model, we have also developed a digital prototype using an augmented reality animation representing the final product.

Both prototypes served different functions, as the physical was used to display the design of the inlay and how it would realistically look and fit in a tooth, whereas the virtual showed the building process to generate interest overall.

Ideation and Sketching

When approaching the prototype, we first sketched out models of molars, later beginning to put out visual representations of how this piece would look like on the tooth. We wanted the piece to be completely opaque, matching the color of the person’s teeth to make it the least visible possible.

As for the shape, we did not have that much freedom, because we prioritized functionality. Nonetheless, we took the existing inlay ‘forms’ and decided to simply stretch the ends to have a slicker look and to adapt and stick better to the tooth shape.

The Strategy

For the prototype assembling phase, we decided that the piece itself would not be camouflaged with the tooth model, but be transparent rather, so that people could see the pieces within it. At this point, we had settled on the looks, but needed a plan on how to execute our vision.

Initially, we thought about simply buying a tooth model from a local or even online store, as it was the fastest and cheapest option, but were not able to find stores that sold tooth models in our area, therefore resorting to asking some dentists for providers of their models. Most of the offices were kind enough to order them for us directly, although shipping times were too long and the deadline was getting close, so it was a risk we were not willing to take. We ended up simply 3D printing the tooth model.

In terms of the inlay itself, we began brainstorming on possible materials to make the piece, as it was supposed to be transparent, hard enough and not malleable, but malleable enough to take the shape of a mold.

In the end, we ended up using hot glue, as it was the perfect option to display our idea. We could mold it into the needed shape, it could get solid after not so long, and was transparent enough to show the sensors placed inside.

Once the tooth model was ready, we covered the top part with a thin film, so that, after the glue had hardened and gotten the shape of the concave part of the tooth, the prototype piece could be an object that people could grab, look at, and place back again, solely for demonstration and exhibition purposes (obviously, the definitive model would not be removable, and fixed into the tooth's inlay instead).

Execution

When approaching the execution of our prototype, we wanted to be as efficient as possible, therefore we downloaded an already existing model from the internet. Afterwards, we just placed it in Blender to slightly modify the concave part, where the inlay would fit. We sculpted it just a little bit in order for our inlay to be as symmetric and aesthetically pleasing as possible, later creating realistic bone textures that were placed on the model.

Next, we proceeded to make the inlay in Blender as well. It was modeled to fit the concave part of the tooth, and then simply placed where it should have been. For purposes of the render and poster, we gave it a plastic material texture to see through.

The next step was the sensors. We had some trouble in finding accurate models that we could download to make our system visual and understandable. In the end, we downloaded some assets and, modifying some others, we obtained the first definitive image (1). At his point, we had our 3D models and our renders (2).

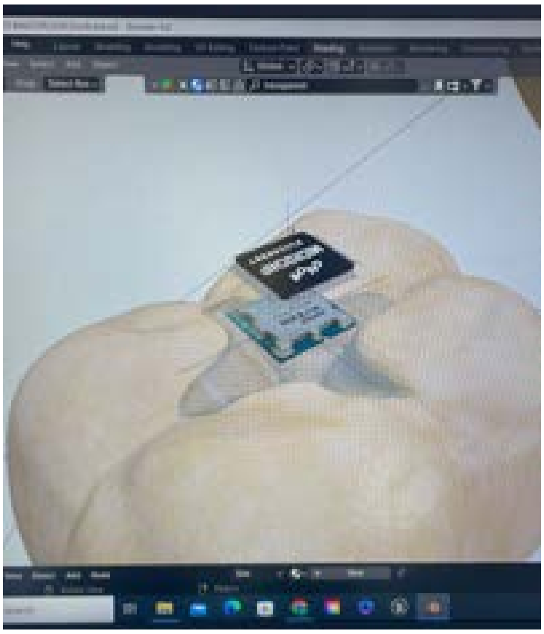
In regards to AR visualization, it was quite straightforward. We simply put the models we had into Adobe Aero, played with the scale and settings, and made a short animation involving the sensors moving up, down, into and out of the inlay. When exporting it, Adobe Aero generated a QR code which we then used at the stand, enabling people to scan and see the dynamic model through their phones.

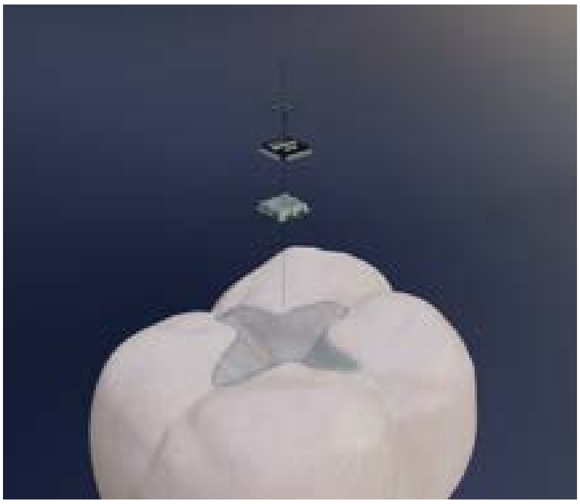
Regarding the physical model, the first step was naturally 3D printing the tooth asset, which was a quite straightforward process, as its present dimensions were real scale. We only had to scale the model, adjusting its height to 24 cm so that we could have a visible augmented object, afterwards inserting the electronic pieces (3).

Once printed, we visited the IED workshop labs and proceeded with the hot glue experimentation. We previously bought plastic film, although we were recommended to use oven paper as it was heat resistant. We also visited a ‘Punto Limpio’ near the UPC facilities, in which we were able to find a motherboard (4), from which the electronic pieces were obtained (5). Once all the materials were collected, we started with the assembly, placing one layer of the oven paper on the top of the tooth, making sure it adhered as much as possible (6).

Next, with the glue gun, we started by consequently putting glue in between the electronic pieces we had taken apart until we had three layers of sensors surrounded by hot glue. We refined the shape and waited for it to harden (7). Right after, we removed the oven paper from underneath and retrieved our piece. At this point, we could take it out and place it back again, and, even though it was not as symmetric as we wished, it still fitted and looked like an inlay with ‘sensors’ inside and accomplished our interactable objective.

In conclusion, our physical and virtual prototypes were a success. They clearly showcased the product's structure and how it would work. Both of them were interactable and managed to generate interest (8). If we had had more time, we would have probably enhanced the AR experience, as it could have been more demonstrative and explanatory.

1) 

2) 

3) 

4) 

5) 

6) 

7) 

8) 

7. Reflection of student Learning

Throughout our project journey, we encountered numerous challenges in defining our problem statement. Initially, the broad scope of potential applications presented difficulties in narrowing down our focus. As we progressed through the stages, refining and concretizing our problem became increasingly complex.

The abundance of potential fields where AHEAD technology could be applied posed a significant challenge. We could not stop finding new applications and varied information, which instead of helping, just opened up new discussions. After proper consultation and feedback from the coordination team, we had to narrow down our focus to a specific area and deliberate, because we found ourselves divagating most of the time. That helped us to improve in terms of input analysis and decision making.

Seeking guidance and knowledge from experts proved to be quite a rough task. Despite our efforts to reach out to individuals for assistance, we encountered challenges in establishing connections and obtaining valuable input, receiving low to none response, and not useful ones when we got them. When the team saw that there were no improvements, it increased frustration levels, but at the same time it helped us in staying together and cheering ourselves up.

Reading through scientific papers has not been an straightforward task either, as they are full of technical concept, references and indications with which nobody is used to, but with the help of internet and consultation of terms, we were able to fully understand the most technical aspects of it, allowing the team to imagine how to adapt and apply the technology to our solution.

While the overall goal of AHEAD technology is often to improve efficiency, TeSI aimed to prioritize social impact. This distinction required a shift in mindset and approach, as we needed to focus on identifying solutions that addressed societal challenges, whereas a lot of the possibilities found at the beginning were focused on efficiency, and therefore economic improvements, so a lot of good leads had to be discarded.

A big difficulty for us initially was to focus on our problem statement and customer focus (the individual or community whose needs we wanted to address). We were never able to define them using two or three sentences when asked about, because we were so obsessed with the solution. After properly setting our target, having a customer-centric approach guided our decision-making and solution development processes, allowing us to think about solutions that truly made a difference for the customer and had an overall society impact.

In conclusion, our solution aims to revolutionize food allergy management through Allertooth, a discreet tooth-mounted sensor that provides real-time allergen detection, empowering individuals to make decisions and effectively manage their food allergies, thereby enhancing safety and well-being. Through a customer-centric approach and a focus on social impact, Allertooth represents a significant step forward in addressing the pressing challenges of food allergies and improving the lives of individuals affected by them.

Appendix

SWaP technology info and interviews info from Chrysoula:

Smart Wall Pipes and ducts (SwaP)

For SWaP, the breakthrough character and aim of the project's initial phase is the combination of advanced manufacturing methods, in the form of Selective Laser Melting (SLM) and AerosolJet Printing (AJP), to create a new generation of smart fluidic elements for cooling systems.

3D printing of metal parts with embedded sensors. So far, specifically thermal sensors (RDTs) with → Main application (focused so far): measurement of fluid parameters for thermal management systems, specifically hydraulic circuits used in cooling systems.

More specifically: generic manufacturing technology (so that it can be applied to any market) to produce 3D metal components with embedded sensors, through the combination of different AM methods.

Researcher interview

Why was this needed / Which is the novelty in this product/technique?

Measurement of sensing properties of circulating fluids, such as temperature, pressure, flow rate should be performed directly in the fluid flow with sensors directly in contact with the fluid.However, in practice, this is not done like this due to: hard to reach measurement areas, lack of space, limitations of total mass to the system. The current process of sensor integration *(referring to the current cooling systems at CERN)* requires modification of both the sensor and the piping system and extra materials/components, which add mass and volume to the system at a higher risk of leaks due to the use of additional fittings. Also, the size of the component to be integrated into the piping system limits the number and the position of the sensors that can be used for the cooling system.

Therefore, the novelties that this product/technique provides us:

- ***Freedom of design*** to allow for the fabrication of complex shapes

- ***Weight reduction*** (reduces material and energy consumption. Improves ease of handling or simplification of support structures)

- ***Reduction of assembly steps. Short time production.***

- Production does not require highly complex infrastructures

Drawbacks:

- The temperature of the SLM process
- The surface roughness
- The complexity to connect the sensors or to create the sensor connections during the fabrication process.
- Although the reduction of the time production that it achieves, AM is not suited to achieve high volume and low cost production → it is more aimed at addressing small to mid-scale volumes of complex parts with high added value.

- Ask for more resources (papers, articles, examples of applications of the technology) related to the technology.

Chrysa will ask the coordinator if she can share the presented slides with us. Apart from that, we can search info on the Attract prototype and phases, not a lot of additional examples or related papers info. given.

- Sensors only monitor temperature or can we use other types of sensors?

Chrysa explained that they are working mainly on temperature sensors, but that is not a constraint. We should be exploring different types of applications and uses ,including using different types of sensors (i. e. pressure, fluid flow,...), also pipes adapted for different fluids (note that fluids include liquids and gasses), and also not only for pipes but for other kinds of components with sensors embedded in them.

- Has this technique already been applied to some product fabrication / has already been used / commercialized?

Not really, it has been used on some tests, mostly stainless steel pipes with temperature sensors used in fluid cooling systems at CERN.
Additionally, one of the project's key partners – Thales Alenia Space (TAS) – is studying how the sensor-equipped pipes could be employed in the International Space Station's pressurized modules and NASA's future Lunar Gateway space station. TAS also plans to install the pipes in two-phase mechanically pumped fluid loops, which are a type of thermal control system used in its telecommunications satellites.
Outside these two it seems that is not elsewhere (...?)

- Does it need to be a pipe, could this technique be applied to other kinds of supports done with AM (3D printing technique)? On the official summary it says that it is a technology for 3D printed segments of pipes, can it be generalized to 3D printing of microchips? Can the 'pipe segments' be printed in other shapes and forms?

Yes, of course. It is our duty to explore different approaches, and there are no constraints other than a printable 3D design. We should be asking different industries and stakeholders about needs, materials, characteristics, usefulness,...

- Which base materials (properties) does this technique/approach support?

Not really mentioned, she has just talked about using stainless steel, the internal sensor integration and the weight reduction it implies, maybe we need to specify more instead of being generic on this matter.

- Could also be used for gases with probably other kinds of sensors integrated?

Of course, all types of fluids are in scope, and the sensor that may fulfil our needs better

- How expensive is it? / Could it be used to print big surfaces at a cheap price?

In principle in the article it is said that "Although the reduction of the time production that it achieves, AM is not suited to achieve high volume and low cost production → it is more aimed at addressing small to mid-scale volumes of complex parts with high added value." Plus Chrysa said that they are focused on the technology at the moment and not on the economic efficiency apparently. They are not able to specify costs yet.
More focused on high-value components… probably it is not going to be really cheap. So yes probably for small parts or in areas / fields with high value components.

- How thin / small can "the print" be to apply this technique?

N/A

- AJP (used for the printing of the integrated sensors) is made for really small sensors. The AJP is done with ink. ONLY really small components and thicknesses (almost 2D things) → used for chips, electronics… For the AJP -> polymers, contactive materials (?) ink?, conductors, semiconductors…
- With the SLM 3D printing we can print on stainless steel, titanium… and it is also being tried in copper and others…About the sizes of the products being able to print with it → (?) not sure. Seems also for small components (but bigger of course than with the AJP technique).

- How are the sensors deposited between 3D printing operations?

The printing of the pipe is done horizontally, stopping after having the first half printed, embedding the sensor inside it, to later finish the other half. In between, there's the sensor integrating part. The main idea is to electrically isolate the sensor using resin casting → this is usually a manual process.

Sometimes, if encapsulating is needed, a polymer automatic adding method is used instead.

Food allergens detection

A summary of the articles related with the food allergies detection is included in what follows.

1. Detection of serum and salivary IgE and IgG1 immunoglobulins specific for diagnosis of food allergy[11]

The text discusses a study that explored using saliva to detect specific antibodies related to food allergies, focusing on IgE and IgG immunoglobulins.

Results showed promising potential for using saliva as a diagnostic tool for food allergies, with significant findings related to cow's milk, fish, and papaya.

Description of a technique for detection of allergens (ELISA: Enzyme-linked immunosorbent assay) to measure the levels of specific IgE and IgG antibodies that are present in response to particular allergens. Note that we could integrate this technique into a biosensor.

In this case, saliva samples collected from individuals with food allergies were tested for the presence of IgE and IgG antibodies against various food items using indirect immunoenzymatic assays like ELISA. By comparing the antibody levels in serum and saliva samples, researchers can assess allergic reactions to different foods non-invasively through salivary testing.

IgE and IgG are types of immunoglobulins, also known as antibodies, produced by the immune system in response to foreign substances like allergens.

Researchers can detect allergens in saliva by using techniques like ELISA (enzyme-linked immunosorbent assay) to measure the levels of specific IgE and IgG antibodies that are present in response to particular allergens. In this case, saliva samples collected from individuals with food allergies were tested for the presence of IgE and IgG antibodies against various food items using indirect immunoenzymatic assays like ELISA. By comparing the antibody levels in serum and saliva samples, researchers can assess allergic reactions to different foods non-invasively through salivary testing.

An immunoenzymatic assay, such as ELISA (enzyme-linked immunosorbent assay), is a laboratory technique used to detect and quantify specific proteins or antibodies in biological samples. In the context of this study on food allergies, an indirect immunoenzymatic assay was employed to measure the levels of IgE and IgG antibodies in serum and saliva samples collected from individuals with cow's milk protein allergy. This method involves using enzymes linked to antibodies that can produce a measurable signal when they bind to target molecules, allowing researchers to assess immune responses related to food allergens.

[11] Nunes et al., “Detection of Serum and Salivary IgE and IgG1 Immunoglobulins Specific for Diagnosis of Food Allergy.” https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6469776/

How ELISA works: (can be integrated into a biosensor)

In an immunoenzymatic assay like ELISA, enzymes are linked to antibodies in a way that allows for the detection and quantification of specific proteins or antibodies in a sample. Here's how it works:

1. **Coating Phase**: The first step involves coating a microplate with capture antibodies that specifically bind to the target molecule (e.g., IgE or IgG antibodies). Any target molecules present in the sample will bind to these immobilized capture antibodies.

2. **Detection Phase**: After washing away unbound substances, enzyme-linked detection antibodies are added. These secondary antibodies recognize and bind to different epitopes on the target molecule (IgE or IgG) than those bound by the capture antibody.

3. **Substrate Addition**: A substrate solution containing an enzyme-specific substrate is then added to trigger a reaction if there is binding between the detection antibody and its corresponding antigen (target molecule).

4. **Signal Production**: If there is binding between the enzyme-linked antibody and its target antigen, an enzymatic reaction occurs leading to conversion of colorless substrates into colored products which can be measured spectrophotometrically at specific wavelengths.

5. **Quantification**: The intensity of this color change directly correlates with the amount of target molecules present in the sample, allowing researchers to quantify their concentration based on standard curves generated from known concentrations.

By measuring this signal produced by enzymatic reactions upon binding events within each well of a microplate, researchers can determine levels of specific proteins or antigens such as allergen-specific IgE and IgG immunoglobulins accurately within biological samples like serum or saliva.

Can we trust saliva as opposed to serum?

It was observed that 100% ($n = 36$) of the participants presented cow's milk allergy through the indirect ELISA, detecting IgE or IgG in serum and saliva. When serum IgE and IgG concentrations were compared, there was no statistical difference ($p > 0.05$) in 12 of the 14 foods evaluated. The same amount ($n = 12$) of non-significant differences ($p > 0.05$) was observed in the comparison of the 14 foods under IgE and IgG contractions in saliva. In the verification of the average values of IgE present in the serum and saliva of the foods, only cow's milk, fish and papaya showed statistically significant differences ($p < 0.05$).

2. Sensors for in situ monitoring of dental health parameters in saliva [12]

- Monitoring salivary parameters can throw valuable data. Hence, wearable intraoral sensors seem to be a promising tool.
- Real-time monitoring → For real-time monitoring of salivary parameters over several hours, the establishment of wireless communication and long-distance data transmission between the intraoral sensor and the readout device (e.g., smartphone) is still challenging. Nowadays, the best and most energy-efficient strategies include the application of Bluetooth low energy (BLE) and near-field communication RFID (radio frequency identification).
- Material → The sensors can be covered effectively with materials commonly used and approved in dentistry, such as vinyl polysiloxane impression material.
- Challenges & materials → formation of a pellicle on sensor surfaces, the text highlights the importance of selecting appropriate coatings to minimize electroactive interferences. It also emphasizes the role of nanomaterials in enhancing sensor sensitivity and mitigating biofouling. Furthermore, the text suggests the use of protective permselective antimicrobial and anti-adherent coatings to prevent the accumulation of salivary proteins, such as mucins and proteolytic enzymes, which can compromise sensor performance. These coatings need to be carefully chosen to ensure effective protection without interfering with sensor functionality.
- Real-time, long-term, and continuous intraoral measurement needs further investigation as only few well-functioning sensors have been developed until today. The use of enzyme-based sensors seems an appropriate approach. Until now, there is no sensor that measures reliably beyond hours for any analyte other than glucose.

[12] Timpel et al., “Sensors for in Situ Monitoring of Oral and Dental Health Parameters in Saliva.” https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10560166/

3. Nano-biosensor platforms for detecting food allergens – New trends[13]

- Monitor food with point of care (POC) biosensors that can detect known allergens. These detectors are categorized according to their sensor mechanism, such as optical, electromechanical, and electrochemical biosensors.
- Review of different biosensors developed for food allergen detection.
- They speak a lot about different already prototyped or existing POC technologies, but mostly implemented into handheld or smartphone devices, but it's useful to get an idea of how sensors are designed to measure x protein and the different approaches that we can have for implementing it into the veneer/crown.
- Recent advances include the combination of microfluidic technology with immunosensors, genosensors, and cell assays. ELISA and microfluidics have been combined in a single POC device that uses an optical immunosensor with custom features. A miniature optical POC device has been developed by combining microfluidics and aptamer-conjugated quantum dots to detect.

4. Mouthguard-Type Wearable Sensor for Monitoring Salivary Turbidity to Assess Oral Hygiene[14]

- Focus on oral hygiene.
- Details on the specific built sensor device and technology for transmitting the measurements (Bluetooth wireless module).
- The wireless module for the MG-type sensor functions as an A/D converter, potentiostat, and wireless transmitter using Bluetooth Low Energy. A constant voltage of 800 mV was applied to the PT using the wireless module, and the output current was evaluated as an output representing turbidity.
- The energy supply is obtained by a coin cell (battery).

[13] Neethirajan et al., "Nano-Biosensor Platforms for Detecting Food Allergens – New Trends." https://www.sciencedirect.com/science/article/pii/S2214180417301137
[14] Ichikawa et al., "Mouthguard-Type Wearable Sensor for Monitoring Salivary Turbidity to Assess Oral Hygiene." https://www.mdpi.com/1424-8220/24/5/1436

Energy supply

1. Biocompatible Nanogenerators through High Piezoelectric Coefficient 0.5Ba(Zr0.2Ti0.8)O3-0.5(Ba0.7Ca0.3)TiO3 Nanowires for In-Vivo Applications[15]

- Existence of biocompatible nanogenerators for the energy supply of implantable medical devices (IMDs).
- Convert tiny mechanical energy in the environment such as low frequency movement, air flowing, animal's motion and heart beating into electrical energy. Piezoelectric NGs have been implemented in animals' bodies to harvest energy from the motion of different organisms such as heart, lung and diaphragm.
- Abundant and natural in vivo biomechanical energy, such as bone strain, acceleration during locomotion, motion of respiration and heart contraction. If these mechanical energies can be harvested, it will contribute greatly to solving the challenge of powering IMDs.
- Compared with the other energy technologies such as battery, NG can power the IMDs for quite a long time because it can continuously convert the mechanical movements into electricity.
- Results:
    - Experimental result shows that the NG could generate 0.12 nA current continuously with little attenuation in 2 hours' working.
    - By periodically pressing the back of the rabbit, the partly packaged NG could give an output current of 0.13 nA.
    - Furthermore, this device could be driven by the slow walking of a rabbit and generate about 0.1 nA current.

[15] Yuan et al., "Biocompatible Nanogenerators through High Piezoelectric Coefficient 0.5Ba(Zr0.2Ti0.8)O3-0.5(Ba0.7Ca0.3)TiO3 Nanowires for In-Vivo Applications." https://onlinelibrary.wiley.com/doi/10.1002/adma.201402868

2. Review of materials for energy harvesting[16]

- Explanation and review of piezoelectric materials.
- Piezoelectric materials utilize the inherent material property of piezoelectricity for energy harvesting. Piezoelectricity represents the appearance of the electric charge accumulated within a material due to the mechanical loading.
- Energy harvesting method considers the conversion of environmental energy into electricity, which can be used for powering wireless or remote electronic devices and circuits. While the concept of this conversion is the same as large-scale renewable energy generation, such as wind turbines, the quantity of energy generated is significantly smaller.
- Energy harvested in this way is generally in the range of tens of microwatts to a few watts.
- The principle of energy harvesting can be utilized to replace small energy sources, such as batteries. While batteries are inexpensive, they have a limited amount of energy and must be replaced or recharged on a regular basis. Unlike batteries, the energy harvesting process is renewable and does not require environmentally harmful disposal.

[16] Anic et al., "The Review of Materials for Energy Harvesting."
https://ieeexplore.ieee.org/document/9635169