Multisensorial Portable Device for Augmented Reality Experiences in Museums

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Abstract: - This paper presents a portable device capable of enhancing the augmented reality (AR) experience to the full five senses through the stimulus of touch, taste, and smell. While most of the existing solutions for this type of devices lack portability or fail to explore all the five senses at once, in this work we introduce a new portable device that adapts to the users' smartphone or tablet to provide a full five senses experience. This is part of a mobile five senses augmented reality system for Museums (M5SAR) project, which aims at developing an AR system to be a guide in cultural and historical events and museums, complementing or replacing the traditional orientation given by a guide, by directional signs or maps, while enhancing the users' experience adding by new senses to the museums' objects. The proposed device communicates via Bluetooth with an App (out of the scope of this paper) and is responsible for generating the stimuli that reproduces three senses: touch, taste, and smell, while the senses of sight and hearing are already reproduced through the users' smartphone or tablet, allowing to explore all the human senses. The proposed hardware is powered by a rechargeable battery, giving the module portability to be used during a visit to the museum. It uses a microcontroller for the core unit, which receives instructions from the mobile application, running on the user's smart device, and acts respectively, activating the physical interfaces to deliver the five senses experience to the user.

Key-Words: Augmented reality, multisensorial display, portable device, five-sense experience, museums.

1 Introduction

This work is part of the M5SAR project. The complete system consists of a smartphone application (out of the scope of this paper) and a physical device (the present work) hence referred as "gadget" or "portable device", to be integrated in the smartphone to explore the 5 human senses: sight, hearing, touch, smell, and taste. The device should be portable and small, but it adds touch, smell and taste experiences to the complete augmented system, to improve and augment as much as possible a museum visit, i.e., to see, hear, touch, feel and experience all the interesting objects that exists.

Traditional AR systems return sensorial feedback for only two senses – sight and hearing. Unlike those, multisensory media focuses on providing immersive communications and enhancing the user's quality of experience [1].

The existing systems related to augmented sensing experiences are big hardware systems, far from being portable. By developing the new augmented reality device, the first big challenge will be to integrate a visitor's smart device (tablet or smartphone) in a compact new device that allows the user to have these five sense experiences. The second big challenge will be to integrate, in a portable and small device, all the hardware needed to allow the five sense experiences. The device should integrate physical interfaces, which will be responsible for creating the stimuli that reproduces the three senses of touch, taste and smell. The remaining senses, sight and hearing, should be reproduced in the user's smartphone or tablet, connected to the device.

Moreover, the device should be flexible enough to adapt itself to different sizes of users' smartphones or tablets. It should be powered by a rechargeable battery, which gives the module the ability to keep the system running during the museum visit.

2 Background

It is a generally accepted fact in psychology [2] that the more informational channels we use, the better the transmitted information will be perceived. Still, many existing multimedia systems in use today are focused only on two senses (sight and hearing). It is difficult to digitally convey compelling sensations for the other senses, which might explain this absence. Even though there have been a series of attempts to achieve this, almost none of those were embraced by developers, product designers, manufacturers or consumers. In this analysis, the focus will be on the three human senses that are not generally stimulated by technological devices and commercial products, which are the senses of touch, taste and smell.

2.1 Singular Sensorial Systems

One example broadly used are vibration motors that stimulate the sense of touch through haptic feedback. It has been in use for years and it was mostly introduced by videogames and mobile phones. The first videogame to use haptic feedback was the 1976 arcade racing game "Fonz", developed by Sega, which had vibrating handlebars during collisions [3]. Newer generation consoles now include built-in haptic feedback features in their controllers, like Sony's DualShock technology, which is a standard feature in videogame controllers nowadays.

However, most people are probably familiar with the technology thanks to the mobile phone industry, which has also been incorporating the tactile feedback for years, either for notifications or, more recently, as a touch response in touchscreen keyboards to help mimic a real mechanical button, aiding users to hit their targets faster and more accurately.

Electrovibration is another existing way to create sensations of touch, although not yet present on the consumer market. It works by controlling electrostatic charges on the surface of the touchscreen, this way varying the friction between the surface and the user's finger [4].

Ultrasounds have also been used to reproduce tactile sensations. The authors in [5] have developed a prototype that uses ultrasonic air pressure waves to create contactless vibration feedback. Still, research on this area is just beginning, and initial steps have been made to start combining ultrasonic haptics with newer display technologies, creating better mid-air interactions and displaying visual elements wherever the user needs them [6].

The use of air as a mechanism to stimulate our sense of touch is also in the haptic feedback category. One of the earlier uses of this technique was a wind display called the WindCube [7]. Other virtual reality applications have since then been using similar approaches to enrich their experiences. Disney Research, however, introduced a different system called AIREAL [8]. However, these technologies are not yet distributed to the consumer's market.

An interesting approach to mechanical haptic feedback is using pneumatic tactile displays, which use air chambers between layers of acrylics and latex to create simple shapes and buttons [9]. In terms of tools for development and academic research, there is some interesting hardware available in the market, like the Geomagic's line of haptic interfaces [10]. Although these technologies are certainly interesting, some of them would be impractical on a mobile device.

Another way to stimulate the sense of touch is through thermoreception, or perception of temperature, although sometimes this is categorized as an extra sense to the traditional 5 human senses. The application of thermal feedback in devices is not exactly new [11], but with the dissemination of Peltier devices (thermoelectric modules), more studies and experiments have been conducted.

However, the usage of Peltier devices on mobile applications is problematic from the point of view of efficiency and energy consumption, which is likely one of the main reasons why this technology is not yet present in everyday consumer products.

As to reproduce the sense of smell in a small or portable digital device, there have been some academic studies and even a few commercially available products. In terms of techniques, there are also some different options available, like pushing a flow of air through a scent filter or recipient, vaporizing an aromatized solution, pressurized scented cans, heated or evaporative diffusers, ultrasonic scent atomization, among others. The first combination of smell with video was back in 1906 when a cinema owner diffused a rose scent in the audience during a screen of the Rose Bowl [12]. After that, a few attempts were made to release digital scent technology to the market, but none of them seemed to have gained traction. A peculiar prototype is the Smelling Screen, which combines a display with four fans to carry the scent and work together at different settings, to change the odour's point of origin on the screen [13]. Recently, the Ophone Duo allows the user to send a photo tagged with a specific odour to another person with the device [14].

Finally, there is the sense of taste, the least explored of all senses and probably the hardest to digitally stimulate. Most studies and projects on this topic try tricking the brain by using other senses like sight and smell, to recreate thoughts and activate existing memories of food flavours. There is some research however, on a real digital taste interface that attaches to the user's tongue via two silver electrodes, to produce sour, bitter and salty sensations [15]. Further research demonstrated that by combining other influential factors, like temperature, enabled the system to produce a wider variety of results, for example sweet and minty tastes [16].

2.2 Multisensorial Systems

There are not many examples of systems that combine together multiple senses to offer a more immersive sensorial experience. The most similar devices available are probably the ones used in 4D movie theatres or shows, which, besides the 3D films, allow you to experience physical effects synchronized with the movie, such as rain, wind, temperature changes, strobe lights, vibrations, smells, fog and chair movements, among other things. However, these are usually expensive to install and maintain, therefore are limited to special venues like amusement parks. Still, if classified based on the three uncommon generalized senses touch, taste and smell, these systems only use two of them.

In the virtual reality (VR) consumer market, there have been also some developments, as the example of the FeelReal VR Mask, presented in 2015. It is a multisensory gaming interface, which enables the user to experience different smells and simulated effects of wind, heat, water mist and vibration. It is also compatible with some existing VR headsets like the Oculus Rift [17].

The Museum of Food and Drink (MOFAD), in New York, also developed a very interesting odour interactive display, called The Smell Synthesizer. It allows the visitors to press different buttons that release chemicals associated with the smell of certain elements, and by pressing different buttons at the same time, different odour combinations will be perceived as something else [18], working with a logic of primary odours, in an analogy to primary colours. For example, by releasing both maple and butter odours, the users supposedly associate that to the smell of pancakes.

However, their multisensory approach was not exactly integrated into a single system, and the taste aspect of it was recreated separately using gumball machines. These dispensers then release to the visitors, candy-like pellets with peculiar flavours such as tomatoes, porcini mushrooms and parmesan cheese.

3 Concept Design

The objective of this work is to develop a portable device, capable of providing a complete five sense experience when used in conjunction with a mobile device running an application (out of the scope of this work). The focus pertains on the design and construction of the device or gadget, considering that it is meant to be coupled with the user's mobile device. This means it should be flexible enough to adapt to different mobile devices, light and small enough so that it could be comfortably carried by a person during a typical museum visit, and, obviously, able to reproduce compelling stimulus for the three senses, touch, taste and smell, at the appropriate time, when instructed by the application via wireless commands.

The initial objectives and design requirements can be summarized as: to be a portable device that can reproduce touch, taste and smell contents; the dimensions should be small, with a maximum size of 7x7x25 cm for each part (two parts, one on each side of the mobile device); it should also be lightweight; capable of adapting easily to multiple sizes of mobile devices; able to reproduce sensations of touch such as wind, heat, cold, and vibration; able to generate 3 to 5 different odours; able to recreate sensations of taste with 3 to 5 different flavours; to have a wireless communication between the device and the application; a simple communication protocol to activate sensorial interfaces; and finally, a battery powered operation to allow portability.

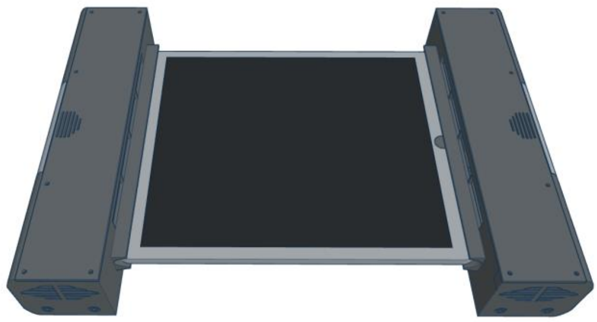

Fig.1 – Initial concept of the prototype

Figure 1 presents a sketch of the proposed portable device. The system consists of two similar hardware parts, placed on each side of the user's device where the mobile application is running, and it is connected at the bottom through the adjustable supports.

A microcontroller is the core unit of the device. It receives instructions from the mobile application and acts accordingly, controlling the remaining hardware of the portable device to allow the five-sense experience. The communication between the device and the mobile application is possible through wireless communication using a Bluetooth interface. The communication between the remaining interfaces will be wired. The physical output interfaces will be responsible for reproducing the multiple sensorial stimulus for the three senses. The left and right hardware parts are very similar to each other, and they should have the same modules, components and connections, with one main difference, in which only one has a Bluetooth communication interface. The side that has the Bluetooth module (left) will have the master microcontroller, and the slave microcontroller will be on the other side (right). In terms of software and hardware, they are similar, and the firmware running on both microcontrollers can be mostly the same code.

3.1 Touch Stimulus

Different types of possible touch stimulus were analysed for the touch sense reproduction. However, considering the state of the art, availability, complexity, dimensions and price of all these technologies, only three were selected for this device. For example, electrovibration technology would be incredible to represent textures of museum objects that people are not allowed to touch, however it is not yet disseminated in the consumer market and appears to exist only in a research and development stage, which makes it not feasible. The three types of touch stimulus selected are thermal touch, vibration and air flow.

Starting with temperature, the objective is to have the user somehow experience sensations of heat and cold through the portable device. With that in mind, the direct contact seems to be the ideal approach for a portable device; by changing the temperature on the device's handles, the user could immediately feel the temperature sensation in their hands.

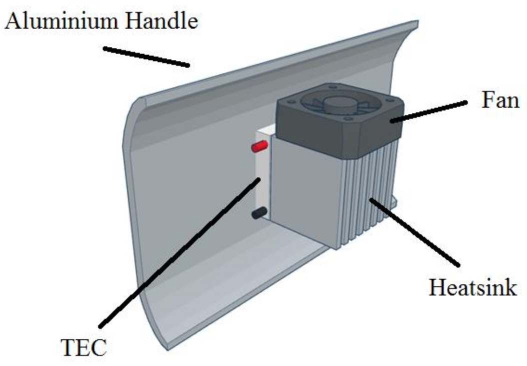

Fig.2 – Thermal module design.

Luckily, nowadays, thermoelectric cooling modules (TEC), also known as Peltier devices, are easily available at accessible prices. A Peltier module uses the Seebeck effect to create a solid-state active heat pump. It has two sides, a hot side and a cold side, and it transfers heat from one side to the other, through the consumption of electrical energy, depending on the direction of the current.

Therefore, by using and tuning heatsinks (Fig.2) on one or both sides of the device, it is possible to generate a desired temperature on a specific side. Since they can be used both for cooling and heating just by reversing the electrical current, it seems practical to use them, in order to save space and money. In terms of desirable temperatures for the touch sense, the range between 0ºC and 40ºC seems like a good selection, which is safe for the user, yet still sufficiently noticeable to convey the intended sensations.

Vibration is another way to represent another stimulus related to the sense of touch. One particularly useful application would be aiding the user to navigate through the museum using vibration pulses, since we have a left and right side of the portable device. If following a predetermined path or route, the system can subtlety indicate which way the user should go, without the need for a visual representation, but instead using a vibration signal, either on the left or on right side of the device. Other possible features include generating the feeling of shock, trepidation or certain vibration patterns that can be designed to better represent a specific object, action or scenario. The vibrations can be easily obtained through vibration motors, with one on each side of the device, independent and as close as possible to the handles, to increase the noticeability of vibrations.

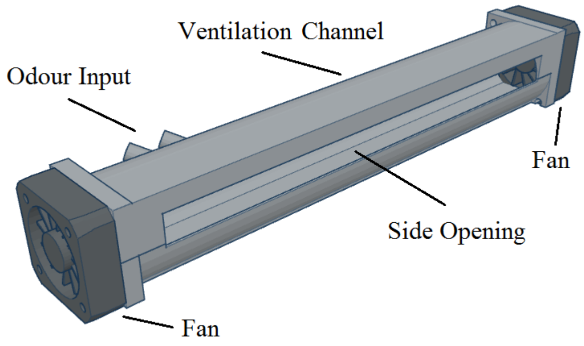

Fig.3 – Air channel design.

Still regarding the sense of touch, there is also the possibility to use an airflow to recreate the idea of wind or a small breeze in a certain given scenario. Size is also not a problem, since there are fans as small as 15x15 mm, and they are quite easy to use and control the flow, if necessary (via PWM). An interesting concept is doing something similar to the Smelling Screen. The airflow or wind sensation is obtained using a ventilation system with four fans and two air channels, two fans and a channel on each side of the device. As proposed in [13], the cooperative work of these four fans can cause a sense of wind directed to the user's face, and by varying the speed of each one individually, it can generate an airflow coming from different points of origin.

The ventilation channels (Fig.3) consist on a tube with a fan on each end blowing air inside, with a longitudinal opening on the side of the tube. This way, the air that is forced inside will collide at a certain point in the channel and be forced to exit the side opening on that location. By varying the speed of the fans and their relations between each other, different points of origin and flow rate are possible.

3.2 Taste Stimulus

There are not many solutions available for the sense of taste, and the main option found is using electronic vaporizers, also known as electronic cigarettes. The working principle is always the same: The tank, which also includes the heater, takes a special liquid called "e-liquid", which contains a mixture of propylene glycol, glycerol, water, flavourings and nicotine, among other chemicals [19]. Obviously, for the museum application, the liquid would be nicotine free, which is also easily available in every vaping store, with a wide variety of flavours.

The device should thus be developed with four vaporizers, two on each side, providing a total of four different flavours per visit. To guarantee the hygiene of the system, each visitor would receive with the device a disposable tube to connect to the flavour outlet, and at the other end the respective mouthpiece to sample. This means that there will be two taste outputs per side of the device, and to let the user know which one to use, they should have an output indicator like a small LED nearby.

This system also has the advantage of being easy to replace flavours and not being completely necessary to develop the flavours themselves, since food grade aromatizers are easily found and commercially available.

3.3 Smell Stimulus

There are a few different odour releasing techniques available. The most common include pushing a flow of air through a scent filter or fragrance recipient, vaporizing an aromatized solution, pressurized scented cans, heated or evaporative diffusers, and ultrasonic scent atomization, among others. The solutions that require airflow to carry and release the fragrance into the environment are usually done with micro air pumps, or compressed air reservoirs. However, this presents a problem, because micro pumps can be quite noisy, which is not desirable at a museum. A pressurized container would also be a problem, because of the necessary space required for it.

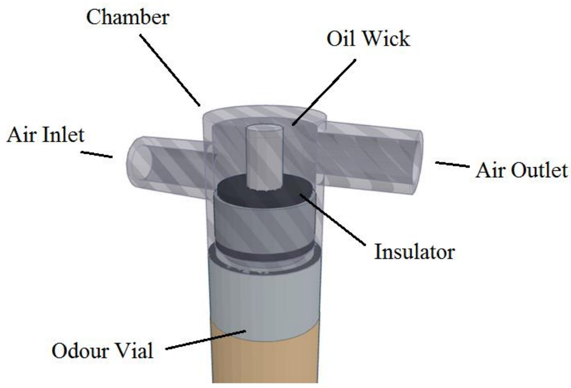

Fig.4 – Fragrance chamber design.

To generate the necessary air flow, once again the design of choice were fans, specifically for the smell module alone, pushing the air through an odour reservoir chamber (Fig.4) and then releasing it to the ventilation channels of the air stimulus system, with the air fans rotating at slow speeds to not over dissipate the fragrance.

The objective is to incorporate four different fragrances on the portable unit and two different odours on each side of the device, and then release the aroma to the ventilation channel of the wind/breeze module, to disperse it to the ambient.

4 Device Development

Considering the concept requirements for this project in terms of size, sensorial interfaces and practicality, a sketch for the structure was designed with round edges, a lower height of 52mm and also a reduced width of 57mm, to improve comfort while holding the device. The length is kept at 250mm. The idea is to design the 3D model of the entire structure, considering all components and interfaces to be used, their dimensions and positions. All requirements should be respected, such as having the thermal system and vibration motors near the handles, the wind/airflow output to the inner side of the module, over the user's mobile device, the taste output on the bottom part of the portable unit, a place for the electronic board, a space for the battery and an easy way to access and replace the odours and flavours.

Figure 5 shows the final 3D model, without covers, for the portable device. It consists of two sides attached together via the adjustable supports. Another design consideration is the fact that the prototype will be 3D printed, therefore the 3D model has to be carefully designed to avoid certain problems. To optimize the use of space, the inside volume was separated into two floors: In the top floor goes the thermoelectric module, the holder for the odour vials, the supports for the micro fans for the aroma dispersion, and the ventilation channel.

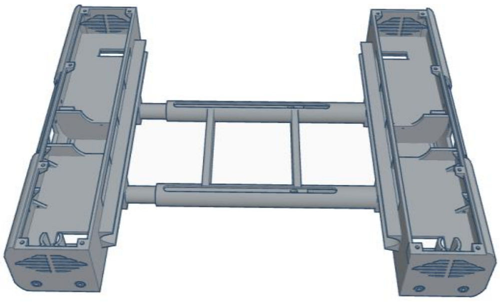

Fig.5 – 3D model for the portable device's structure.

The middle section is an empty area that will serve as an air duct for the Peltier heatsink forced airflow. The bottom floor will be composed of two compartments, one for a battery with a size of up to 100x30x13mm, and the other is meant to be an easy access to the odour and flavour reservoirs. By opening the cover of this area, the fragrance vials or taste vaporizers can be easily replaced.

4.1 Sensorial Interfaces

Starting with the temperature module, the selected approach was the use of a Peltier module. Even though they can produce heat and cold, they are generally used for cooling applications. This way, the thermal sensation module only needs one critical component, the TEC module that generates both heat and cold, and conveys such thermal sensation to the user through an aluminium handle.

One way to do the power inversion is by using a transistor bridge using MOSFET's, however this will add more heating losses, a need for heat dissipation, and decrease the overall efficiency of the system, which could be excessive for a battery powered device. Therefore, the chosen solution was to use a DPDT (Double Pole Double Throw) relay wired in a polarity reversal configuration. This will require two outputs from the microcontroller, one for the relay, which selects between cooling and heating, and another one to activate the Peltier itself. The relay only inverts the wires, it does not have an off position, which is why a second output for the TEC module is needed. The selected Peltier is a TES1-3104 module, it has a 3.8V nominal voltage, 4A rating, a maximum temperature difference of 68ºC (DTmax), a maximum refrigerating power of 12.5W (Qmax) and a size of 20x20mm.

The TEC module also has a heatsink fan that turns on at the same time as the Peltier, to help the interior side to stay near the ambient temperature, so that the exterior handle can reach higher or lower temperatures. Both the relay and the Peltier device and fan are powered by switching transistors.

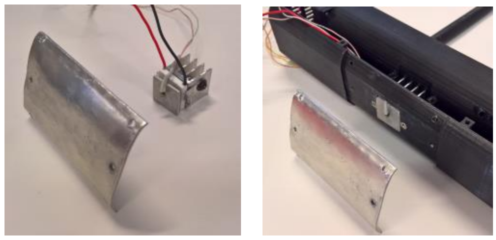

Fig.6 – Thermal module assembly.

The temperature reading of the handle is done via a 100k NTC thermistor, which is placed between the outer side of the Peltier and the haptic handle (Fig.6), configured with also a 100k pull-down resistor, and the middle node later connected to an analogue input of the microcontroller. It is also critical to obtain the correct proportions of the heatsinks, and since the inside space will be limited. it will be difficult to get a heatsink with the desired specifications. Another important detail is the fact that the aluminium handle outside also serves a heatsink. For that reason, it should be as small as possible, otherwise that side will get closer to the ambient temperature and, instead of the cold side getting cold, the hot side will get even hotter, possibly overcoming the maximum 80ºC allowed for the thermoelectric module.

The vibration system simply consists of a small vibration motor fixed to the structure next to handles of the device, one on each side, in order to allow for all those previously mentioned navigation functionalities. By sending different vibration patterns it will be possible to create different sensation scenarios, similar to video games. Just like the thermal system, the motor will be activated from a switching transistor. The selected motor has a 3.3V operating voltage and 90mA rated current, with the dimensions of 12x6x3.6mm. However, if more intense vibrations were necessary to convey stronger sensations, another motor could be considered.

The airflow or wind sensation is based on the Smelling Screen prototype [13], using a ventilation system with four fans, two in each side of the device. By varying the speed of each individual fan, it is possible to control the air flow point of origin on the screen of the user's device. The electronic circuit for the fans' driver is straightforward, two fans (on each side) are activated by two switching transistors. The fans in use have a 12V operating voltage, 0.44W consumption power, and a 30x30x10mm size.

Taste is probably the most difficult sense to stimulate digitally, so the chosen solution is to use an electronic vaporizer to recreate different flavours.

For this prototype, only the heating element is required since the battery and controller will be part of the design. The clearomizer is the most common type of vaporizer, consisting of a clear polycarbonate plastic or Pyrex glass tank, which allows to see the level of the liquid inside. The liquid is absorbed by silica wick and delivered to the heating coil. The selected ones for this prototype are shown in Figure 7 and have a liquid capacity of 1.6ml. The electronic driver is quite similar to the wind system circuit; the vaporizers, which are basically just resistors, are connected through switching transistors. These vaporizer resistors are typically very low, which means that currents are also relatively high.

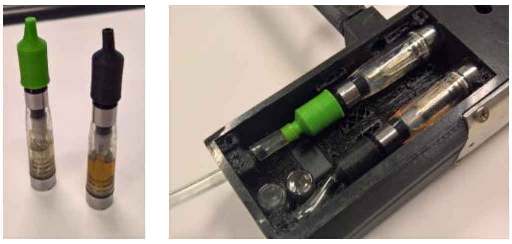

Fig.7 – Clearomizers assembly.

Since energy consumption is important for portability reasons, the selected clearomizer has a 1.8Ω heating resistor, 5V nominal voltage, which translates to a power of 13.89W and current of 2.77A. The clearomizers have a threaded pattern connector on their base that will be the system used to plug them in and out of the prototype, which also allows a simple and quick replacement of the tank or flavour if desired.

The selected system for the smell module was the use of a forced flow of air through an aromatized container, which is then inserted into the fan ventilation channels. It basically consists of an oil wick air freshener, where the oil fragrance in a small bottle is absorbed by the wick to the top of the chamber. This chamber, depicted in Fig.4, has an air inlet and outlet, and when the smell system is activated a small fan will push the air through the chamber inlet and exit through the outlet, directly into the ventilation channel (Fig.3). There are two fragrance bottles, two chambers and two inlet fans in each side of the device, therefore creating a total of four different smells in the portable device. This fan can be as small as 20x20mm and still generate a sufficient airflow to carry and disperse the aroma.

The electronic driver is similar to the one used for the taste system, the only difference being the use of two micro fans instead of vaporizers, which are both activated by switching transistors. The fragrance vial being used is a small glass flask, similar to perfume samples, and the chamber is 3D printed in flexible material. The fans have a 5V operating voltage, 0.2W consumption power and a 20x20x10mm size.

Fig.8 – Portable device assembled with a tablet.

The finished prototype is shown in Figure 8, with an Asus Zenpad 3S 10 tablet, which has a size of 240.5x163.7mm. One the frontal bottom side, the air inputs and the taste outputs are visible.

4.2 Communication

The communication between the user’s device, either a smartphone or a tablet, and the portable multisensorial device is done via Bluetooth. The Bluetooth interface for the portable gadget is a HC-05 Bluetooth Serial Module, which creates a simple wireless serial bridge between the devices. The app running on the user’s device will communicate with the master device, sending commands through its own Bluetooth interface, to the HC-05 Bluetooth module, which then redirects those serial instructions to the master microcontroller through a wired UART link. This HC05 module has a low power operation of 1.8V to 3.6V, average consumption of 50mA, a UART interface with programmable baud rate and an integrated antenna.

Once the serial communication is made transparent between the device and the application, the focus falls on the communication protocol to activate the reproduction of the desired sensations. Depending on the desired sensation, the parameters that the command instruction will need as inputs.

5 Results

To check the sensorial interface perceivability of the portable device prototype, several different tests were performed to the individual interface systems. Since these are sensorial stimulus, some can be difficult to quantify. For that reason, some tests were executed with users, where they classify the intensity of the stimulus they felt.

5.1 Tests

The first one is the thermal system since temperature is something quantifiably. The first test was executed with an external thermometer on the haptic handle, when a cold instruction for 10ºC was requested for 60 seconds, with an 100% power PWM. The initial ambient temperature was 24ºC. The second test followed the same settings, but with a heat instruction instead of 35ºC for 60 seconds, with an 30% power PWM. The handle was resting for a few minutes until it reached the initial ambient temperature of 24ºC as before. Both results are presented in Figure 9.

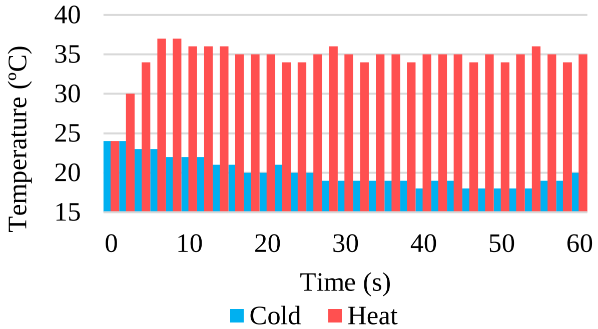

Fig.9 – Temperature test results.

The results presented in the graph show that the temperature never reached the desired set point of 10ºC during the 60 second test. In fact, it probably never would, since the lowest temperature achieved was 18ºC, and near the end of the graph the temperature starts rising again. Another noticeable issue is the fact that the temperature decreases very slowly, and the system needs 40 seconds to reach the lowest point of 18ºC. Regarding the heat test, the results in the graph show that the behaviour of the thermal system in heating mode is quite different than the cooling mode. It is possible to see that the system presents no problems reaching the desired temperature of 35ºC, being also relatively faster at achieving a determined temperature, taking less than 6 seconds to reach 37ºC.

The vibration system is hard to quantify. For this reason, the portable device was handled to a group of ten users in a laboratory environment. The vibration instruction was sent, with the pattern of left handle 5Hz intermittence vibration for 5 seconds, then a 2 second rest, followed by a right handle 5Hz intermittence vibration for 5 seconds. The subjects were asked to rate the level of intensity they felt, from 1 to 5, 1 being "weak" and 5 being "extreme". Results are presented in Fig.10.

The airflow interface was also tested by users' feedback. The same sample group of ten subjects was used, this time with a wind instruction in the device for 10 seconds, with the origin of airflow being the top right quadrant. The subjects were informed to keep their faces 20 to 30cm away from the gadget's tablet, to simulate a normal use. The results are also presented in Fig.10. It was requested for the subjects to qualify the intensity of the airflow they felt in a scale from 1 to 5.

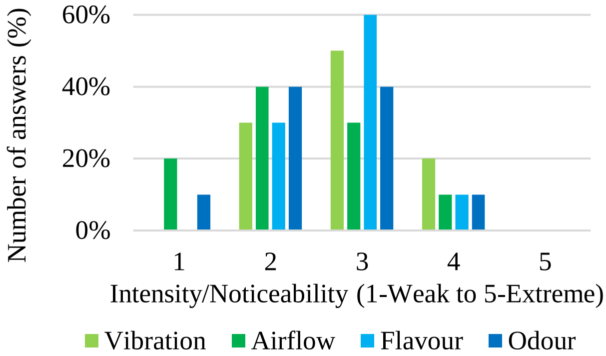

Fig.10 – Subjective interfaces test results.

The taste module is yet another interface that cannot be quantified, therefore relies on the users' feedback. The test was conducted with the same sample group and consisted of simply sending a taste instruction of the flavour "red fruits" for 25 seconds, which consists of three tasting periods, considering a five second on/off intermittence. The subjects were asked to suck on the disposable tubes whenever they saw the LED of the taste output indicator light up. They were then asked to qualify the intensity of flavour they perceived in a scale 1 to 5; the results are presented in Fig.10 as well.

A test was also conducted for the smell system. The same sample group was used, this time with a smell instruction in the portable device, for 10 seconds with the odour of pine tree. The subjects were informed to keep their faces 20 to 30cm away from the gadget's tablet, to simulate a normal use, as it was done in the airflow test. Next, they were asked to qualify the intensity of the fragrance in a scale from 1 to 5, from "weak" to "extreme". The results are also shown in Fig.10.

Regarding the power supply, since the sensorial interfaces are not yet completely tested and finalized, it was not possible to have a real museum visit and verify what would be considered normal consumptions, in order to select an appropriate battery. However, an estimation can be calculated based on the interfaces nominal values and a given museum visit scenario. For this, it was considered a visit of one hour, where the thermal handles were used for 3 minutes, the vibration for 2 minutes, the airflow for 5 minutes, the taste for 2 minutes and the smell for 3 minutes. Since each portable device's side has its own battery, only the side with the Bluetooth module needs to be calculated. With an estimation of all the interfaces added together, excluding drivers and LEDs for simplification, it was achieved a total energy consumption of 1.581Wh for a visit with this interface usage pattern. The individual modules estimated consumption is represented in Fig.11.

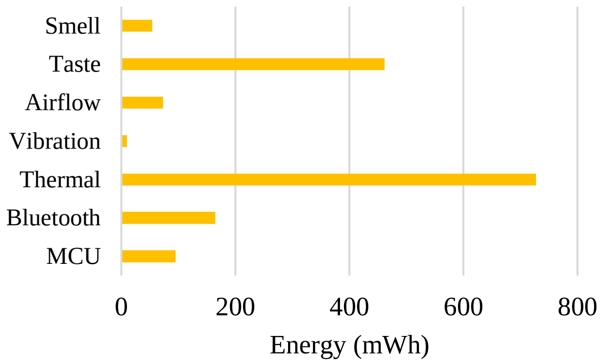

Fig.11 – Energy consumption estimation.

Considering that the battery would have a nominal voltage of 3.3V, this would correspond to a required capacity of 479mAh, which is relatively low for the wide range of batteries available commercially.

5.2 Discussion

Upon the analysis of the results it was found that the cold temperatures were not cold enough. The probable cause is the heatsink being too small. Because of the limited available space only allowing a 20x20x20mm heatsink with forced ventilation, this seems to be under the required specifications. On the other hand, the heat mode works well, which was expected, because it is easier to generate heat instead of cold, since most power losses are reflected that way.

The vibration system proved to be sufficient. This might be enough to send or left or right indication notifications to the user when following a specific route, however it is possibly too weak to convey convincing stimulus of shock or trepidation in a given storyline scenario.

The first results on the airflow system show that the airflow is slightly weak and this may be a consequence of this design, since the fans are already small, and there are multiple air collisions, with lost flows along the way, before reaching the user.

The taste system seems to work relatively well. Although the vapour travels through the disposable tube before reaching the user, the flavours still proved to be to be noticeable enough.

The smell interface seemed to be too weak to be noticed by some users, despite the majority of subjects reporting smelling the odour. This might be related to the airflow system design. On the other hand, the aromatized container together with the oil wick chamber seemed to work well, activating the scent release immediately.

Nonetheless, future tests should be conducted with a larger number of subjects, in order to have more solid results.

The battery estimation results were also quite positive. Despite a few losses that are not being considered here, these results show a relatively low power consumption.

6 Conclusion

For a prototype developed as a proof-of-concept, this device has fully accomplished its purpose, allowing to validate the main idea, and also allowing feedback from the end-users about the use and implementation of the real device. In this regard, the analysis of the problems found allow to find possible solutions to correct those problems, and solutions on how to improve the portable device when designing a future prototype version. Regarding other finishing details, since the sensorial interfaces are still in need of change, designing a final PCB is yet to be done, and the selection of the appropriate battery as well. The ergonomic design aspect might also be improved through user experience feedback.

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