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Design and Development of a wearable Olfactory Display

Tesi di Laurea Magistrale

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AI MIEI GENITORI

Abstract

The technological and engineering progress permitted the design and the realization of artefacts and prototypes with high technological content. The fields of action are among the most varied and diversified and are not linked only with research or industrial production. Lately, more and more often, the technology is at the service of man and medicine, giving life to a very fruitful close collaboration. In particular, the aspect regarding the virtual reality is finding multiple uses: from its use in the field of training and medical study for a better learning of the practical aspects and an important integration of the theoretical aspects, passing through multimodal experiences, up to everything that deals with psychotherapy and physical rehabilitation. The multisensory aspect is very important and allows to improve the experience of use and to obtain a much more faithful reproduction of reality compared to a traditional use experience. In this thesis project an olfactory display device will be developed which, connected to a virtual reality application that regulates and controls its functioning, allows the patient to interact with aromas and essences contained in pods housed in the device. The device for therapeutic purposes is addressed mainly to people suffering from post-traumatic stress disorder, Alzheimer's patients or it is indicated for aromatherapy. After an analysis of the state of the art and the principles concerning the interaction with the sensory organs involved, the construction of the prototype, the design choices made and the 3D printing process of the components involved are illustrated, as well as their assembly. Subsequently, the construction costs and the other possible design choices rejected during work are analyzed. Everything related to the software part, the interactive interface of Unity, its design and its control system and communication with the prototype will also be described. A quick survey on the experience of use has allowed users to provide feedback on the prototype, positively assessing its intuitiveness and ease of use and emphasizing the main aspects to be improved. What has been deduced in particular is that the experience of using such a device, given the complexity of the diffusion of essences, is still rather limited and that many problems concerning mainly the management of perfumes at present must still be solved.

Riassunto

Il progresso tecnologico e ingegneristico ha permesso la progettazione e la realizzazione di manufatti e prototipi ad alto contenuto tecnologico. I campi di azione sono tra i più svariati e diversificati e non sono solo legati alla ricerca o alla produzione industriale. Ultimamente sempre più spesso la tecnologia si mette al servizio dell'uomo e della medicina dando vita a una stretta collaborazione molto proficua. In particolare, l'aspetto riguardante la realtà virtuale sta trovando molteplici utilizzi: dal suo uso nel campo dell'addestramento e dello studio medico per un migliore apprendimento degli aspetti pratici e una importante integrazione degli aspetti teorici, passando dalle esperienze multisensoriali fino a tutto ciò che ha a che fare con la psicoterapia e la riabilitazione fisica. L'aspetto multisensoriale è molto importante e permette di migliorare l'esperienza di utilizzo e di ottenere quindi una riproduzione molto più fedele della realtà rispetto a una esperienza di utilizzo tradizionale. In questo progetto di tesi verrà sviluppato un dispositivo olfattoforo che, collegato a una applicazione di realtà virtuale che ne regola e controlla il funzionamento, permette al paziente di interagire con aromi e essenze contenute in cialde alloggiate nel dispositivo. Il dispositivo per scopo terapeutico è indirizzato principalmente a persone che soffrono di disturbo post traumatico da stress, malati di Alzheimer o è indicato per l'aromaterapia. Dopo un'analisi dello stato dell'arte e dei principi riguardanti l'interazione con gli organi coinvolti, viene descritta la costruzione del prototipo, le scelte di progettazione fatte e viene illustrato il processo di stampa 3D dei componenti coinvolti oltre che il loro montaggio. Successivamente vengono analizzati i costi di costruzione e le altre possibili scelte di progettazione scartate in corso d'opera. Verrà descritto anche tutto ciò che riguarda la parte software, l'interfaccia interattiva di Unity, la sua progettazione e il suo sistema di controllo e comunicazione con il prototipo. Un rapido sondaggio sull'esperienza d'uso ha permesso agli utenti di fornire un feedback sul prototipo, valutandone positivamente l'intuitività e la facilità d'uso e sottolineandone i principali aspetti da migliorare. Ciò che si è dedotto in particolare è che l'esperienza di uso di un dispositivo del genere, data la complessità della diffusione delle essenze, è ancora piuttosto limitata e che molti problemi riguardo principalmente la gestione dei profumi allo stato attuale devono essere ancora risolte.

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Chapter 1

Introduction

Over the last decades, the technological progress played an important role in the generation of new ideas and in the development of new things which changed deeply our everyday life. Let's think for example at computer that are more powerful on respect on years ago, or at the mobile phones which turned, from devices used only to call or text, to smartphones which can do a lot of things and they are small PCs that facilitates our life, or let's think at the evolution of microprocessor, that are continuously decreasing their size and continuously increasing their power so that could be implemented in different objects, or let's think also to cars that evolved from mechanical to interconnected and integrated with safety electronical systems. The possibility to sustain a lot of computational effort in very little space, is particularly useful to Virtual Reality systems. VR technology requires rendering of three-dimensional graphical structures created in a digital environment with low latency between real-time and simulated data to present accurate visuals. User experience with VR is very dependent on how real and robust the interactions with virtual environment are and the expected growth of the VR market shows that companies are willing to invest further into these systems. The usage and the improvement of the VR is mostly pushed by entertainment purposes but there are also many professional fields that can use the potential of this system. For example, it could be very important in the medical field, for simulations of surgery or for rehabilitations purposes, and it is used also in the mechanical field to visualize mechanical pieces or to see in advance the assemblage operations.

1.1 Objectives

The objective of this thesis is to present a device that can diffuse different scents linked on what the user sees in the Virtual Reality and give a device applicable for the rehabilitation to patients subjected to post traumatic stress disorder or other diseases as Alzheimer or loss of sense of smell and taste. The physical device is designed to be inexpensive, lightweight and comfortable to wear. The VR environment is easy to use and addressed to people even not keen on the use of technology. In the future few equipment of different brands could be implemented so that this device could be adaptable on what is connected to.

1.2 Thesis Organizazion

Chapter 2: This chapter discusses the developing technologies related to Virtual Reality and how they are used in medical field to be a solution for different treatment methods. Medical problems that are treatable with VR are explained. Further applications related to the topic are analyzed. Principles of Virtual Reality and in particular the multimodality are shown.

Chapter 3: This chapter contains the explanation of the sensorial aspects of sight and olfact. The technology related to this field are listed. The state of the art regarding the particular applications is illustrated.

Chapter 4: The main ideas behind the choices made in the creation of the prototype are presented in this chapter. The list of the components, their description and the particular design issues are depicted.

Chapter 5: In this chapter the focus is posed on 3D printing process, from the passages to generate the proper files to the particular settings regarding time and printing velocity, reviewing the pros and cons for each setting.

Chapter 6: In chapter 6 the attention is posed on the assembly operations and the order followed to mount the prototype focusing in particular on the critical passages and on the cost evaluation of the prototype made.

Chapter 7: What concerns the virtual reality interface aspects in this project, the key concepts taken into account, the interaction between the virtual reality and the board, and all of the issues regarding the dedicated application are presented.

Chapter 8: In this chapter are presented other possible alternative solutions and the reasons of the different choices made during the design phase. The single main components are reviewed and their aspects highlighted.

Chapter 9: This chapter is related to the Sistem Usability Scale protocol, a simple and immediate method to evaluate the effectiveness and ease of use of the prototype considerated. This represents the part of this thesis where other people enter in contact with the device presented. Moreover the feedback given by the users allowed to understand the criticalities of the product.

Chapter 10: Here possible improvements and future works are listed and these represent the starting point for future improvements or continuation of work in the direction taken.

Chapter 2

Research Field Background

The concept of reality and virtuality has been discussed since long time ago, from the early ages of humanity. In the Ancient Greece the philosopher Plato explained “The Allegory of the Cave” [35]. In this theory there are prisoners locked in a cave since childhood and they observe the shadows of figures on the cave wall created by the puppet master through the light of fire. The prisoners think what they observe as reality, but it is because they have never seen anything out of the cave. If one of them discovers how to go out of the cave, he will understand that what thought as reality, was only a reflection of it. This can explain how our reality can be manipulated through delusive information that we acquire but, in our scope, we can use them to make us think the things are real.

If we think a moment, all the sensory information that we get from our senses as hearing, touching, sight, smelling and gustation, are processed in the brain which is an organ with no direct contact with the outer world. The sensation of feeling is the processed information by the brain after the mechanical inputs got by the senses. The combination of all this it is how we perceive the world. Although, we have yet to understand the brain completely, there are also ways to implement new sources of information to achieve various methods of sensing through sensory augmentation. For example, there is a product designed by David Eagleman which translates sound-waves into patterns of vibrations trough a wearable vest for the people with hearing disabilities in his research project VEST, versatility extra sensory transducer [17]. It is also tested that in a brief time, a deaf subject began to understand words that are presented to them through vibrations from the device. This revolutionary innovation suggests that we have the capacity to understand sensory information through non-biological accessories that we are not born with. Since we can program our brains for new type of learning methods, suggestion of using virtual information to manipulate our perception is not that far from this topic. We tend to imagine ourselves in unreal situations or fantasies to have a sense of comfort, happiness, anxiety and various feelings time to time which can also be described as a virtual production of our brains. Therefore, creating a virtual world is something that is natural to us and today we can utilize the technology to achieve our requirements. All the actions that we do to interact with the world can be simulated through electro-mechanical devices and a digital world can be visually generated for us to observe. When recreation of the reality can be performed in an accurate manner through technological devices, our perception can be exploited for any required purpose.

2.1 Definition of Virtual Reality

The term Virtual Reality (VR) was popularized in the late 1980's by Jaron Lanier, one of the pioneers of the field. At the same time, also the term Artificial Reality [27] came up. 1982 the term cyberspace was coined in a novel by W. Gibson ("Burning Chrome") [20]. The Encyclopaedia Britannica describes Virtual Reality as *"the use of computer modelling and simulation that enables a person to interact with an artificial three-dimensional (3-D) visual or other sensory environment"* [1]. Furthermore, it states that *"VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information and are worn as goggles, headsets, gloves, or body suits"* [1]. An important term is presence or telepresence, which can be described as an illusion of "being there" [1]. This illusion is enhanced using motion sensors that pick up the user's movements and adjust the view on the visual display accordingly, usually in real-time; the user can even pick up and manipulate virtual objects that he sees through the visual display wearing data gloves that are equipped with force-feedback modules that provide the sensation of touch [1]. Virtual reality usually refers to a technology designed to provide interaction between a user and artificially generated environments. This interaction is supposed to be more natural, direct, or real than pure simulation technologies or other previous technologies, for example those, which are based on passive mechanical phantoms. However, the simple definition of Virtual Reality derived only from its technical components and devices is not complete and, thus, not very useful, because it fails to provide an explanation for varying degrees of the Virtual Reality interaction experience.

2.2 Virtual Reality in Medicine

In the following sections it is illustrated the use and the various applications of the virtual reality in the medical field. First it is illustrated the implementation in the training practical phase then its use in the rehabilitation paths and then the conclusions.

2.2.1 Need for Training in Medicine

Recent years have brought about a drastic change in patient awareness and sense of adverse effects in medical care. The combination of this process with an increasing focus on patient safety has put traditional educational paradigms in the medical area to the test. Especially in the surgical domain, the time-honoured concept of theoretical education followed by supervised clinical practice is becoming less and less acceptable [53], wherefore innovative and complimentary methods of teaching medical knowledge are being sought. Further concerns are rooted in the high cost of teaching in a clinical environment [10]. The level of costs, complexity, risks, and time exposure of the training process increases with the fidelity of the objects (Fig. 2.1).

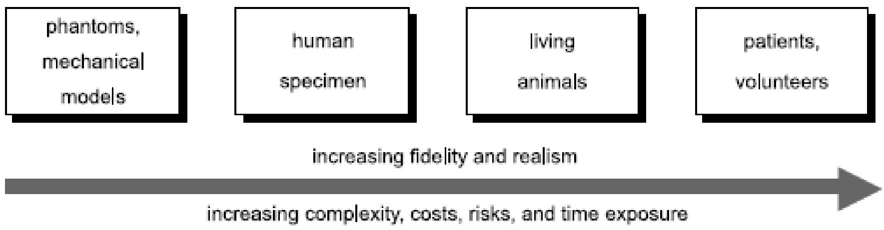


Figure 2.1: Practical limitations in medical education

Increased awareness of patient safety has for instance been stimulated by studies on surgical or medical errors, and associated health care costs. Studies carried out at the turn of 2000's in US pointed out that medical errors cause the deaths of about 44000 patients in US hospitals per year, more than highway accidents, AIDS, or breast cancer in the USA, and caused an additional 8.8 billion dollars of direct health care costs. Other studies made in Canada in 2000 [5], Australia [58] and for several European countries [31] stated the same results. Even if the exact numbers of surgical errors are not easy to obtain, about half of them occurs during surgical interventions, of which 75% are preventable [29]. A cause identified of such considerable numbers of chirurgical errors is the rapid growth of medical knowledge and the very fast turnover of new technologies, which makes it hard for practitioners to keep up. Possibly the most significant change in recent times has been the advent of minimally invasive surgery (MIS) in the late 1980's. This technique minimizes the damage of healthy tissue during interventions on internal organs. An example of this procedure for laparoscopic interventions is depicted in Fig 2.2.

The relatively large cuts in open surgery are replaced by small incisions, through which optical and surgical instruments are inserted. Reduced tissue damage and careful selection of the entry points results in a major gain in patient recovery after operation as well as reduced scarring. The price for these advantages is paid by the surgeon who loses direct contact with the operation site. Visual information is acquired via endoscopic cameras and displayed on a monitor, thus impairing normal hand-eye coordination. In addition, much of the manipulative freedom usually available in open surgery is lost. Therefore, performing operations under these conditions demands very specific capabilities of the surgeon, which can only be gained with extensive

Figure 2.2: Laparoscopic Intervention

training. Nevertheless, MIS procedures have been replacing traditional approaches in several areas. Taking all these points into consideration, the need for improved medical training and continuing education becomes apparent. The VR so can be largely used as anatomy atlases and surgical training environments; nowadays, novel VR technologies exist that display the anatomical information via auditory and haptic modalities additionally to the visualized data. The user under training can hear the sound or feel the touch from the digital body in a similar way as one would perceive it from the real interaction. This can enhance the performance, allowing the VR system to be used for advanced applications such as surgical training.

2.2.2 VR in Rehabilitation, Psychotherapy, and Surgery

VR in combination with rehabilitation robotics can not only relieve exhausting therapy sessions of physical therapists. It can also motivate patients to train longer in an exciting artificial environment while being supported by the robot. An example is the gait rehabilitation robot Lokomat, developed at the Balgrist University Hospital, Zurich, Switzerland, that can be combined with different VR scenarios (Fig. 2.3). Moreover, VR applications can be used in psychotherapy, for example for phobia treatment such as fear of spiders [24], post traumatic stress diseases, closed rooms [6], open spaces or fear of flying [7]. The VR system simulates the real conditions in which the user is confronted with the phobic stimulus (Fig. 2.4). One of the advantages of VR is the ability to vary the degree of the different situations and the immediate termination of the procedure. VR applications are quite successful in phobia treatment; however, they should only be used in addition to traditional approaches. Intra-therapeutic augmen-

Figure 2.3: Lokomat Robot

tation, e.g. intra-operative navigation, can assist physicians during therapy or surgery. Also, diagnostic and pre-therapeutic planning can be enhanced by 3D-reconstructions and graphical animations of the individual patient.

Figure 2.4: Spider phobia VR treatment

2.2.3 Benefits and Chances

There are several benefits of applying VR technology to medicine. VR is more comprehensive than books and cadavers. It is also time and case independent, as the users can train and repeat medical skills at any time they want. Surgeons can practice treatments in extreme situations without taking a risk for the patient, as no patients are directly involved. Procedures are observable and reproducible, and performance can be recorded and used for assessment or evaluation of the treatment. Moreover, augmented information can be displayed to assist the treatment or decision making. Medical applications can benefit from VR in several areas. VR in medicine aims to optimize cost, improve quality of the education and therapy, allow long and efficient training sessions, and increase safety.

2.3 Principles of Virtual Reality

VR comprises two main components: the user environment and the virtual environment (Fig. 2.5). While the user interacts with the VR system, the two environments communicate and exchange information through a barrier called interface. The interface can be considered as a translator between the user and the VR system. When the user applies input actions (e.g. motion, force generation, speech, etc.), the interface translates these actions into digital signals, which can be processed and interpreted by the system. On the other hand, the system's computed reactions are also translated by the interface into physical quantities, which the user can perceive with different display and actuator technologies (e.g. images, sounds, smells, etc.). Finally, the user interprets this information and reacts to the system accordingly.

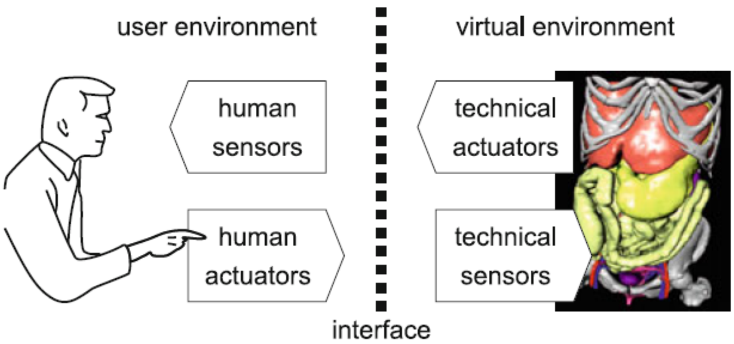


Figure 2.5: Bidirectional exchange of information in VR systems

2.3.1 Importance of Multimodality

In VR applications, the exchange of different physical quantities between the user and the virtual environment occurs via different channels or modalities. Such modalities can be sound, vision or touch. Communicating with multiple modalities is called multimodal interaction. Multimodal interaction allows several types of modalities to be simultaneously exchanged between the user and the virtual environment. The goal of applying multimodal interaction is to provide a complete and realistic image of the situation, to give redundant information, for example, for safety reasons, and to increase the quality of presence. Multi-modality plays an important role also in our daily life. In most daily situations, we interact with the real environment through multiple modalities, for example, when watching a movie (hearing and vision), painting and moulding (vision and touch), making music (hearing and touch), walking (vision and balance), or ingesting (taste, smell, vision, touch, hearing). Furthermore, multi-modality can influence human behaviours and decisions. For example, the decision to buy a product may depend on the optical appearance or tactile property of the product. Or the optical appearance of a meal can influence our subjective impression of its taste. A horn of a car can warn a pedestrian when crossing a street and, thus, support other senses like vision. Multi-modality is important for medical applications. Medical activities often involve multiple senses (e.g. touch, vision, hearing, and smell) especially in diagnosis and surgical treatments. In medical simulations, multi-modality can increase the fidelity of the encountered situations (e.g. by adding the sound of the medical device), making the situation more realistic, which increases the quality of presence and the performance of the VR system. In addition, multi-modality can provide additional instructions or warnings while the user is practicing a surgical or any other task.

2.3.2 Early Steps in Multimodal Displays

The first important multimodal systems were created between the 1950's and 1960's. In 1956 Morton Heilig built the Sensorama (Fig. 2.6), an arcade machine that provided the sensation of riding a motorbike through Brooklyn with also engine vibrations, wind and olfactory effects even if he could only drive on a predefined path with no interaction.

Figure 2.6: The Sensorama simulator

In 1960 Heilig introduced also the first head-mounted display (HMD) with stereoscopic slides, stereo sounds and smell (Fig. 2.7).

In 1965 Ivan Sutherland developed a cathode ray tube (CRT) head-mounted display with a tracking system recording position and orientation of the user's hand [44]. In the beginning of the 1980's, Jaron Lanier was one of the first who designed interface

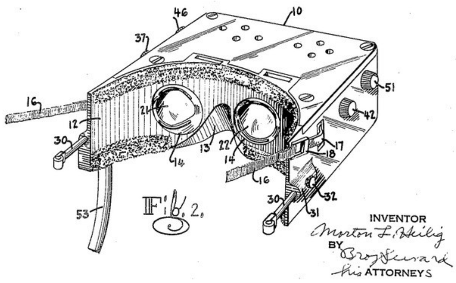


Figure 2.7: The HMD Heiling Patent

gloves (Fig. 2.8) to measure position and orientation of the fingers and hand, which allows a natural way of communicating with the computer using gestures.

Figure 2.8: Modern VR Data Gloves

2.3.3 Multimodal Training Simulation

A very successful application of multimodal techniques, which in fact existed long before the term VR was initially coined, is flight simulation for pilot education. Initial attempts at using simulated environments for pilot education have already been undertaken a century ago at the inception of manned flight. From the early mechanical trainers, flight simulators have grown into highly complex, fully immersive computer-based tools for teaching in aviation (Fig. 2.9). Nowadays, simulator training is an indispensable element embedded into pilot education. Aviation authorities have issued regulations how simulator training hours can be logged. Furthermore, official certification procedures for new simulators have been established. Commercial pilots are even certified for new types of aircraft based on simulator experience alone. Like other VR-based training environments, flight simulators allow practicing complex or emergency situations. The reduction of airplane accidents over the last decades is partly attributed to simulator training.

Figure 2.9: History of flight simulation devices: Early synthetic flight training device from 1910, Link Trainer from the 1930s, Contemporary high fidelity flight simulator

Flight simulation, or vehicle simulation in general, coexisted a long time unnoticed by VR. In the sport field, the VR is largely used for race pilot such as F1 and other motorsports to learn track trajectories and understand the forces they are undergoing during the race (Fig. 2.10).

Figure 2.10: Ferrari F1 simulator

Also, in the field of car design and manufacturing, VR systems are found to be an attractive tool. Development costs can be reduced dramatically, as the designs can be virtually displayed and evaluated which can save manufacturing costs of real objects (Fig. 2.11).

2.3.4 Problems

Increasing use of VR also turned up some problems due to the technology. Sometimes users experience the so-called cybersickness [32] with symptoms of nausea, dizziness, eye-strain, headache, disorientation, or vomiting. The reason of cybersickness is often because from the eyes are coming moving scenes while from the other senses is coming information of static. Of course, the level of sickness depends on the susceptibility of the user. Symptoms can appear during the exposure to the VR and last for hours

Figure 2.11: VR scenarios can improve the ergonomic design of a new car

after the exposure. Technical issues may be one of the reasons for cybersickness. For example, a 15 ms lag in a head-mounted display can already induce cybersickness of the user.

Chapter 3

Sensory Aspects

Since the device proposed in its functioning needs the involvement of the sense of sight and smell, in the next sections of this chapter will be illustrated briefly the characteristics of these human senses and the technologies that are addressed to these topics that make the state of the art. After that, possible uses in particular in the social and rehabilitation fields will be explained.

3.1 Visual Aspects

Visual aspects are crucial in our situation because the system proposed is integrated with video. The computer Graphics is mostly responsible for what we see and for the virtual objects and environment we can interact with. But what is the computer graphics? The computer graphics is the artificial creation and manipulation of the image content. In general, is referred to three-dimensional scene representations in real-time but also the generation of single, high-quality images can be considered. Both cases involve scene rendering that is the generation of artificial images based on a computational model. Regarding our application is useful to distinguish between interactive real-time, used mainly in virtual reality and computer games, and offline rendering applied in the movie industry or in digital architecture. The underlying methods and paradigms in computer graphics cover diverse related research fields, including Photography, Mathematics, Geometry, Mechanics [47], Psychology and Design [21]. The typical application areas exist for computer graphics are Entertainment, Data Visualization, Graphic Design, Marketing and Virtual Environments.

3.2 Visual Sense and Perception

The visual sense plays a key role in the perception of and interaction with our environment. Consequently, in the development of virtual reality setups a large focus has been on providing, analysing, as well as enhancing visual feedback. At the current state, the realistic and real-time display of virtual scenes is a standard feature in Virtual Reality (VR). To better understand some of the concepts related to the visual aspects of a VR setup, the human visual sense should first be examined. Therefore, the structure of the human eye, colour vision, and depth perception will be introduced in the following subsections.

3.2.1 Structure of the Human Eye

The eye is the key sensing element in human vision. Its receptors are sensitive to a part of the electromagnetic spectrum, turning incoming light into electrochemical impulses in the neural system. Signals are sent through the optical nerve and neural visual pathways to the primary visual cortex (as well as other sections) in the brain. The overall structure of the human eye is illustrated in Fig. 3.1.

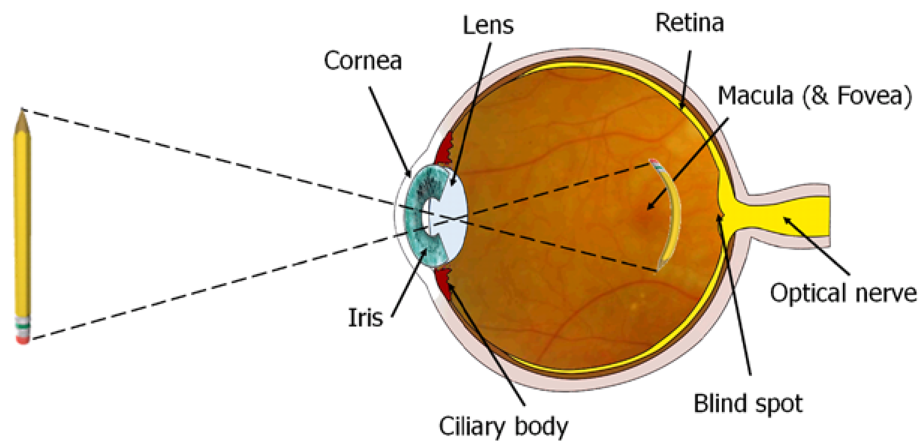


Figure 3.1: Schematic depiction of the structure of the human eye

The function of the eye can be likened to a camera. Cornea and lens provide the refractive power to focus incoming light onto the retina. Note that the geometry of the cornea is fixed, while the shape of the lens is adjustable through activation of the ring-shaped ciliary muscles. Thus, the refractive power of the cornea is constant, while that of the lens can be changed to allow focusing at different depths. In addition to this, cornea and lens also absorb ultraviolet and infrared components of the electromagnetic spectrum. The amount of light entering the eye is controlled via the iris which consists mainly of smooth muscles and changes its shape to adjust the size of its central opening, the pupil. Its function can be compared to the aperture of a camera. At the back of the eye the retina is located, housing the light-sensitive photoreceptors, as well as additional neural cell layers and vessels. There are two types of receptors: the rods and the cones. The cones are key for colour and high-resolution vision. The three types of cones in the retina are sensitive to different parts of the visible spectrum of electromagnetic radiation. The combined response of the cones to light at different wavelengths leads to the perception of colour. Most of them are located in the central region of the eye, the macula, which has a diameter of about 5 mm and it has the highest visual acuity. It exhibits the highest density of cones and is free of vessels or additional cell layers. The diameter of the fovea is about 0.5 mm. It is interesting to note that the fovea only covers a small fraction of the retinal surface but is represented in a disproportionately large area in the primary visual cortex. The fovea is responsible for high acuity vision, used for instance in reading, driving, etc. When an object is focused by the eye, then its image is projected onto this central region. Another special area in the retina is the blind spot, the region where the optical nerve and the vessels exit and/or enter the eye [54] . No photoreceptors are in this area, therefore, the corresponding region in the visual field is not directly perceived in that eye but empty spots are mainly filled-in during high-level processing in the visual cortex. The retina then converts the light in electric signals. These pass through the optic nerve to the brain, which then processes them to create an image.

3.2.2 RGB Colour Space

Mixing together three primaries to create a wide spectrum of visible colours is the underlying principle used in most display hardware (e.g. computer monitors or projectors) as well as in computer graphics. Such a colour space follows the notion of additive mixing of colours. Figure 3.2 presents this idea. In computer graphics colours are defined by a three-dimensional vector composed of the three primary channels, representing the red, green, and blue (RGB) components.

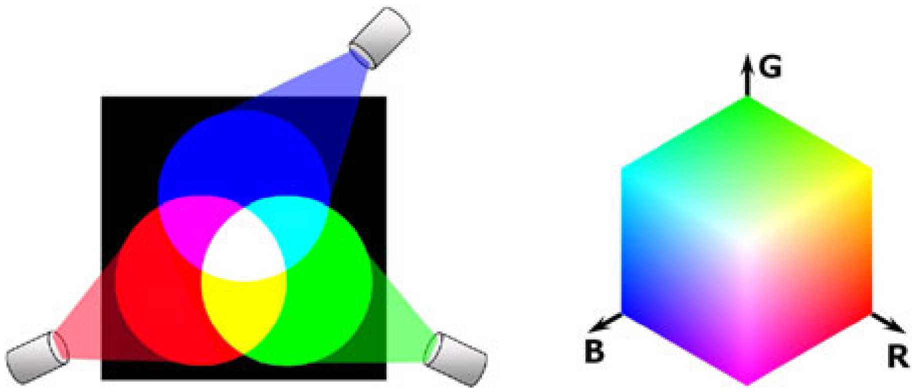


Figure 3.2: Additive color space: Additive mixing of colored light and RGB color space represented as a cube

3.2.3 Depth Perception

The perception of depth is critical regarding immersion and interaction of a VR system. Depth perception is the ability to appreciate spatial relationships and to perceive distances. A key element to create immersion is to provide users appropriate visual cues to give a sense of depth.

3.3 Visual Display Technology

Various hardware exists for the visual display of computer-generated images. Key technological solutions will be presented in the following, with a focus on visual rendering in virtual reality and typical VR display hardware.

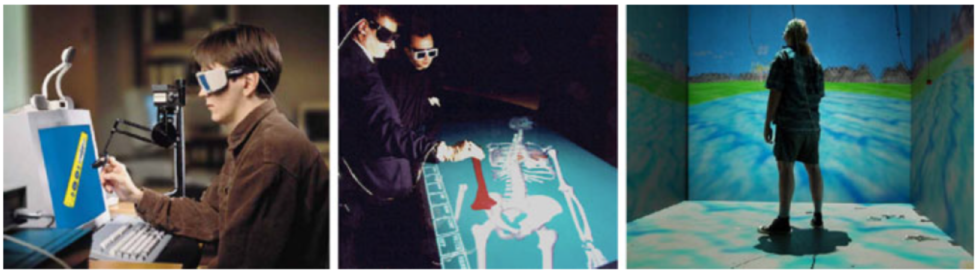
3.3.1 Virtual Reality Displays

The display hardware used in virtual reality systems can be categorized with regard to the attainable degree of immersion. Three main classes exist, which will be introduced in the following.

- **Desktop VR**: The simplest solution for a VR setup is to combine a desktop-based display device, for instance a standard computer screen, with additional components, such as stereoscopic rendering and head tracking (to provide motion parallax). Often a desktop-based haptic interface is also included in such a setting (Fig. 3.3 (a)). It is occasionally questioned whether such setups should be considered as "true" VR or not, since the user is not fully immersed into the virtual world. Nevertheless, gaming applications using even less sophisticated hardware have already shown the potential to elicit a very high degree of immersion. Since the virtual world is viewed through a small window (i.e. the screen), such setups are also referred to as fish-tank VR [46].

- **Projective VR**: A straightforward extension of desktop VR is the enlargement of the display area. This widens the provided field of view, thus, increasing the sense of immersion. Moreover, additional users can participate in the viewing of the presented VR content. Such setups usually employ one or more projectors for displaying on flat or curved surfaces. A typical interface in this category is the so-called Responsive Workbench [26] (see Fig. 3.3 (b)). Stereoscopic rendering and head tracking are usually integrated into these setups. However, in multi-user settings it has to be considered that a correct view needs to be rendered for each viewer [3]. If only the head of one person is tracked, then correct perspective is only generated for this viewer, while the others will experience image distortions.

- **Immersive VR**: The target of immersive displays is to place a user inside of a virtual world, while blocking out cues from the real environment. This is related to the sense of presence, i.e. the feeling of being in the simulated environment. Two key examples in this category are CAVE-like setups and head-mounted displays. In the former a user stands inside a small room, whose walls are used as projection surfaces. The virtual world is displayed on the latter via rear-projection (Fig. 3.3 (c)). In the other immersive display type, a head-mounted setup is worn, which houses small screens in front of the eyes. By tracking head movements of a user, the views of the virtual world are updated according to the changes in viewing position and orientation. These immersive technologies are sometimes considered as being “true” virtual reality interfaces.



(a) (b) (c)

Figure 3.3: Types of virtual reality display hardware setups. (a) Multimodal desktop VR; (b) Projective VR on a Responsive Workbench (courtesy of Bernd Fröhlich); (c) Immersive VR in a CAVE

3.4 Head-Mounted Displays

The second display hardware solution typical for immersive VR is head-mounted displays (HMDs). In these systems a user wears an assembly directly on his head containing small screens in front of the eyes. A further key component is the tracking of the user's head. The view displayed on the screens is updated according to the head movements. The first HMD-based VR system was developed in 1968 by Ivan Sutherland [45]. It used CRT displays and a mechanical linkage for head tracking. The displayed virtual world only consisted of simple wireframe models. Note that in normal usage it had to be suspended from the ceiling due to its weight. Another key element of HMDs is the optical system. It provides magnification as well as collimation, thus, letting the image appear further away than just a few centimetres in front of the eye. Another common element of an HMD is stereo headphones. Figure 3.4 depicts the main components of a typical HMD. Various concerns arise when using an HMD for immersive VR. User comfort plays a critical role in this respect. HMDs are often too heavy and uncomfortable for prolonged usage. Moreover, the head-mounted device is often connected via cables (for tracking and rendering), which limits movement. Nevertheless, some attempts are currently made to provide wireless solutions. Cables are also not visible while wearing the HMD, thus, a user might accidentally trip on them. In fact, since the real environment is fully blocked out, a user also cannot see his own body in the virtual world (unless some form of body tracking is provided) [40]. In this context, using an HMD is usually a single user experience. A further point to consider is the mismatch between the human field of view (about 200 degrees horizontally and

130 degrees vertically) and the usually much smaller one provided by an HMD [16]. A larger FOV of the HMD increases user immersion. In this context image resolution also must be considered. With a limited number of pixels available, a trade-off must be made between the field of view and visual acuity. Moreover, the head-mounted system has to be adapted for each single user. This usually includes the adjustment of the optical system according to the inter-pupillary distance of a user. Another critical point is the unavoidable lag between head movements and the corresponding update of the displayed images. This latency is another potential source of cyber sickness [36].

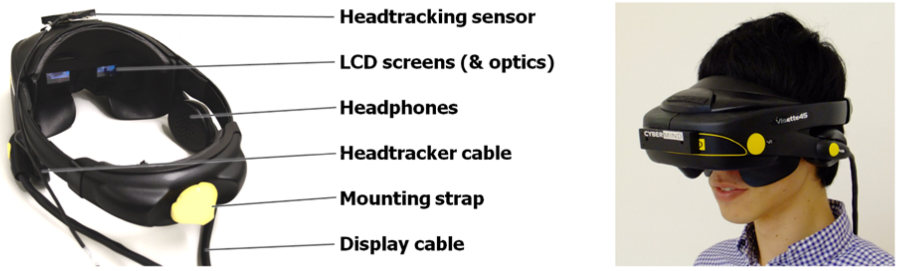


Figure 3.4: Head-mounted displays—key components (left) and user wearing an HMD (right)

3.5 Olfactory and Gustatory Aspects

3.5.1 What Are Olfactory and Gustatory Displays?

Humans both smell and taste information by chemoreceptors that respond to chemical stimuli. The sense of smell (olfactory sense) and the sense of taste (gustatory sense) are functionally coupled. In general, the sense of smell influences the sense of taste. Without the sense of smell (olfaction), the ability to taste (gustation) may be reduced. The provision of olfactory feedback in VR environments can enhance the level of realism of different training scenarios. Gustatory simulations are mostly developed for research purposes or entertainment. Olfactory and gustatory displays enable the artificial representation of certain smells and tastes, respectively. They are less popular in VR systems than visual, auditory, and haptic displays, most probably because their contribution to enhance presence and immersion is believed to be limited. The technical design and realization of realistic, but also practical olfactory and gustatory displays is challenging.

3.5.2 Olfactory Sense and Perception

Our sense of smell detects chemical molecules that are released by substances in our environment. Odorants in form of chemical molecules are dissolved into the ambient air and inhaled through the nose or the mouth (Fig. 3.5).

Humans have about 10 to 30 million olfactory receptor cells located in the regio olfactoria in the nose. An odorant contains different structural elements and can

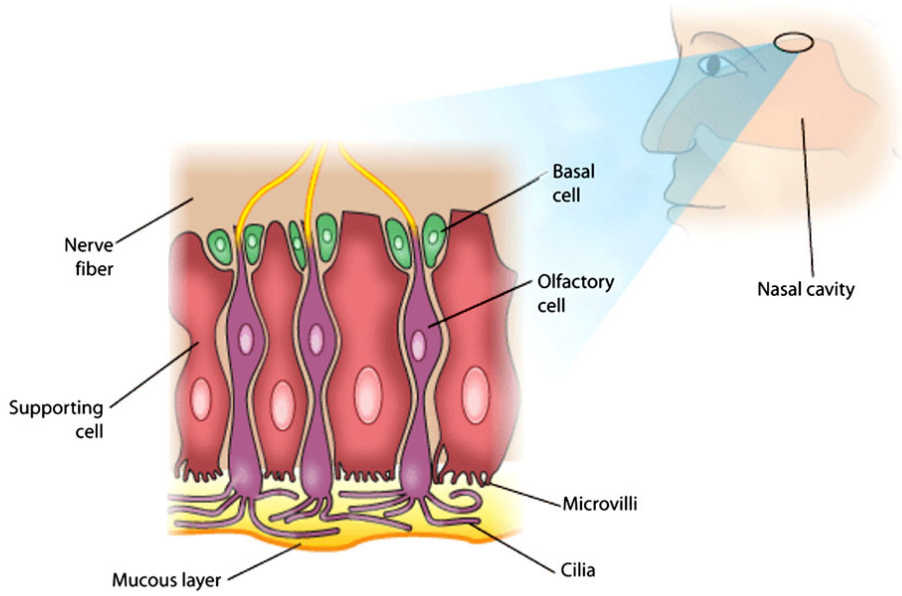


Figure 3.5: Olfactory epithelium

therefore bind to different receptor types. Consequently, an odour is determined by the activity of an ensemble of multiple receptor cells. An odour can consist of hundreds of different odorants. It is assumed that the human can distinguish some thousands of odours. The threshold of perception largely differs between odours. It can be e.g. 1×10e7 molecules/ml air for hydrogen sulphide (bad eggs, faecal matter) or 1×10e14 molecules/ml air for geraniol (rose oil). The perception is highly dependent on external circumstances and may vary among ethnic groups. Practically, the olfactory sense works as a warning system for danger, bad food or hygienics. Odours also have an influence on sexual behaviour, well-being and social relationships (e.g. mutual mother-child identification). Odours can induce salivation and the secretion of gastric juice [13]. Olfaction has been described to have the following characteristics [28]:

- Olfaction is nominal. It has a good absolute sensitivity and an even better-quality discrimination, which is more important.
- It is a near sense, as the odorants need direct contact with the olfactory receptor cells in the nose.
- It is a hidden sense. Olfaction is seldom in the focus of attention but can subjectively influence the attentional and emotional state of the human.
- Olfaction is very subjective as well as emotional and associative, as odours are often associated with emotional experiences.
- It is a special memory, with a strong relation to emotion. It is rather an episodic than a semantic memory.

3.6 Olfactory Display Technology

3.6.1 Design Principles

The simulation of odours is challenging because odours cannot be described by compressed information as it is the case for colours and sound (i.e. frequency, intensity). Odours can be produced by releasing small portions of odour samples in the form of vapor into the ambient environment. A number of primary odours may be combined to generate new odours. So far, the major problem with emitting odours has been that the odour diffuses to a wide area, and that it does not dissipate quickly. Various odour parameters such as flow rate, concentration, duration, and direction need to be characterized. Therefore, technological advances in odour storage, mixing, delivery, and removal are required to produce real-time synthesized odour, which can quickly adapt to the change of the situation in the virtual environment. In summary, the main challenges of the design of olfactory displays are

- the generation of a large variety of different odours,
- the mixture of odours, as odours cannot be reduced to a subset of simple parameters such as possible in visual and auditory displays,
- the storage of odours,
- the precise transport of odours to the nose,
- the maintenance of odours in a desired area,
- the exchange or removal of odours in real-time.

In its most general form, an olfactory display consists of an odour storage, control, and delivery component. Odour components can be stored in a liquid phase, in gel, and solid waxes [9]. The odour liquid can be delivered by using inkjet printer technology or heat-induced methods, whereas the odour gels can be released thermally or electrostatically. Once released, odours can be dispersed using a general air ventilation system [37].

Not many olfactory displays have been developed so far, and most often, the devices have stayed in their prototype version. Next will be presented some of the existing systems. Olfactory display devices can mainly be separated into stationary or desktop devices and wearable or wireless devices.

3.6.2 Stationary Devices

- **iSmell** A digital scent synthesizer called iSmell has been developed by DigiScents, Inc. The device consists of pots of oils infused with different scents (Fig. 3.6). A combination of pots is heated according to the code received from the computer, thereby evaporating those oils. A fan blows the heated vapours out of the pots. The iSmell was claimed to be able to create thousands of everyday scents with scent cartridges of 128 primary odours. These primary odours are blended to generate other smells that closely replicate common natural and man-made odours, but it is unclear if this claim has ever been scientifically proven. However, DigiScents closed in April 2001, without having commercialized the iSmell device [55].

- **Solenoid Valves-Based Olfactory Display** A research group at Tokyo Institute of Technology has developed an olfactory display system, which can blend up to 31 primary odour components. Thus, theoretically, 2×10e9 combinations of smell are possible [33]. High speed solenoid valves are used as selective switches to control the concentration of each odour component. The time period between on/off states of the high-speed solenoid valves is about 1 ms. 32 sample tubes are used in the current system. 31 tubes are filled with different primary odours in liquid form, while one empty tube is used to supply air to the outlet. The vapor of each primary odour is carried out of the tube by a carrier gas. Only one odour component can flow to the output at a certain time. Time division multiplexing technique is used to mix the odour components. The output odour is produced with a cycle time of 1 s.

- **Scent Palette** The Scent Palette (Envirodine Studios, Canton, GA) allows delivering short and longer burst of scents into a virtual environment. The scents are stored in a gel and enclosed in an airtight chamber with compressed air. Four electric fans inside the Scent Palette generate an air stream in order to release the scent into the room [39].

- **Scent Dome** TriSenx Holdings, Inc. (Savannah, GA) has released a consumer olfactory display product called Scent DomeTM. Scent Dome consists of 20 base scents which can generate dozens of aromas by software control [42]. The scents are dispersed out of the top of the scent cartridge by a small fan (Fig. 3.7).

- **Projection-Based Olfactory Display** The projection-based olfactory display (scent projector) delivers localized odours to the human nose through free space by incorporating nose-tracking function rather than scattering scented air by simply diffusing it into the atmosphere. The air cannon in the device generates scanted vortex rings that can travel several meters. A limitation is that the user feels an unnatural airflow when the vortex rings reach the face. To reduce this sensation, a later version of the scent projector used two air cannons, each launching vortex rings [60]. The rings collide at a target point creating a small spot of scents (Fig. 3.8). The user feels the scent as coming with a small breeze. However, the system is not applicable for larger spaces or outdoors, as the firing range is limited and environmental factors such as wind can disturb the delivery of the odour [59].

- **Aroma-Chip based Olfactory Display** An aroma-chip based olfactory display system was developed with the goal that it can easily be used by everyone at home [25]. In this system, a Peltier module controls temperature and, thereby, the gel-sol transition of the temperature sensitive hydrogel of the card type aroma-chip. The hydrogel is mixed with aromatic fragrances, which are released in the sol phase. Interestingly, to drive the release of different odours, dual tone multi-frequency (DTMF) signals were used. These signals, which were on sound tracks of a video tape, triggered the release of different aromatic fragrances.

- **Piezoelectric Perfume Diffusion Technology** Osmooze introduces a piezoelectric perfume diffusion technology. The perfume passes through a needle towards a bevel edged tip. A piezoelectric ceramic disk induces a vibration (200 Hz) of the needle in order to form droplets of odours. A small ventilator blows the droplets into the room. Another approach, the Osmooze GEL technology, allows the storage of odorants in a dry state for small volumes. An air stream passes over the gel cartridge, releasing the odorant into the environment.

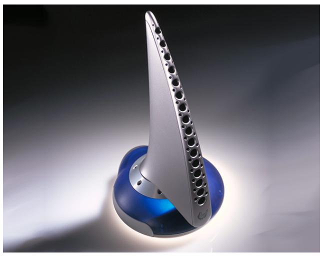


Figure 3.6: iSmell

Figure 3.7: Scent Dome

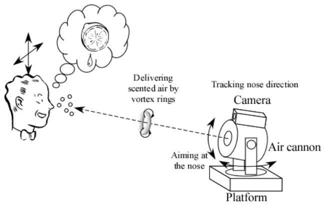


Figure 3.8: Projection-Based Olfactory Display

3.6.3 Wearable Devices

- **ICT Scent Collar** In collaboration with the Institute for Creative Technologies ICT (University of Southern California, USA), AntroTronix, Inc. (Silver Spring, Maryland, USA) has released an olfactory display called Scent Collar or Scent Necklace (Fig. 3.9(a)). In the prototype version, the device can provide four different scents. Each unique scent is contained in an individual cartridge embedded in a lightweight wearable collar that fits around a user's neck [48]. The amount and duration of the scent released are wirelessly controlled via Bluetooth by simulations or games.

- **Sniffman** Another wearable olfactory display "Sniffman" has been developed by Ruetz Technologies (Munich, Germany) and utilized by im.ve, University of Hamburg, to enrich VEs through im.ve's odour-extended VR system. Up to 32 different odours can be released in different concentrations and time intervals [22]. A plug-in controls the synchronization of the smell for example in a VE and sends its commands by radio signal to a device worn around the neck. Different odours are released from an injection nozzle to a heating plate. After evaporation, the odours are released into the air and are then smelled by the user (Fig. 3.9(b)).

Figure 3.9: Wearable olfactory displays. (a) ICT Scent Collar; (b) Sniffman in combination with virtual marketplace

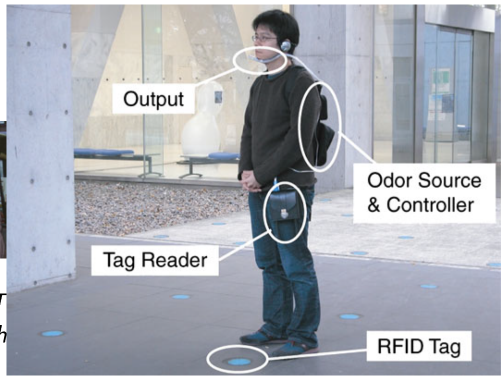


Figure 3.10: Odor field concept using radio-frequency identification (RFID) tag space combined with a wearable olfactory display

- **"Odour Field" Concept** The idea of an "odour field" in a virtual environment is to release odours by a wearable olfactory display depending on the spatial position of the user [60]. The concept of the "odour field" was tested with two prototypes of olfactory displays. The first one transfers odourised air by four DC motor air pumps to the user's nose. One air pump was used for non-odour airflow. Three air pumps were connected to three odour filters which contained the perfume materials. The odour strength was adjusted by controlling the proportion of non-odour airflow to odour airflow. Silicon tubes were used for the connections, because silicon is nearly odourless and nontoxic to humans. By placing the odour presenting unit close to the user's nose, odours could be quickly switched and external disturbances such as wind could be minimized. The wearable olfactory display was combined with a radio-frequency identification (RFID) tag space in order to build an odour field. Tests showed that users can perceive the spatial odour information, however, wind made it still difficult to perceive the odour (Fig. 3.10). The second prototype was constructed to allow the display of many odours while remaining a small, wearable device. The odours were stored in the liquid phase. The inkjet head device of the odour presenting unit released odour droplets directly to the user's nose, where it vaporized (Fig. 3.11). This allowed a subtle control of odour strength. In order to save perfume material and to minimize the amount of odours spread into the environment, the breathing of the user was detected by a respiration sensor. Thus, the perfume material was only released during inhalation. Indeed, the second prototype was evaluated to be superior to the first one in terms of operating life and stability of odour strength presentation.

- **Further Wearable Devices** The ScentKiosk Scent dispenser can release three odours to the user's nose via a tube (www.scentair.com). Exchangeable single scent cartridges facilitate different scenarios. The system can be applied for data visualization or virtual reality applications. However, as the tube lengths are limited, mobility is constrained. Aromajet has developed a small aromadispensing device called Pinoke. The device can be worn but also be placed in front of a monitor (www.aromajet.com). Aromajet provides a kiosk system, which allows a costumer to create different odours [55].

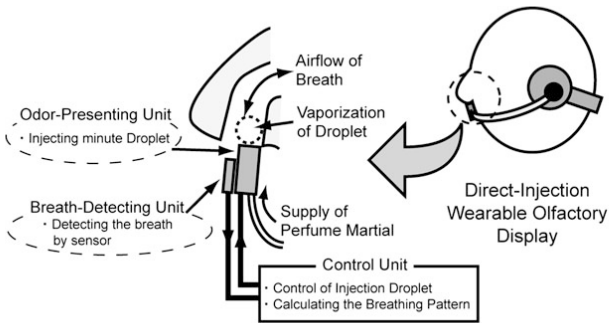


Figure 3.11: Direct-injection wearable olfactory display system

3.7 Applications of Olfactory and Gustatory Displays in Medical VR and in Virtual Reality Therapy

Olfactory displays have not been used much in Virtual Reality Therapy, they are mostly used to increase the level of realism in a virtual environment. The ambient smell of the physical environment can have great importance on creation of a sense of presence in a virtual environment. Without appropriate scents, a user may have reduced virtual experience. For this reason, it is necessary to introduce olfactory stimuli to current virtual reality exposure therapy or cognitive therapy to enhance the presence of patients. However, this application is limited by the high cost and low effectiveness of current olfactory display device. Odours can not only influence mood and vigilance but can also decrease stress as well as increase learning performance [38]. Therefore, olfactory displays can also be applied as therapeutic devices to affect mental stress or treating psychological disorders or phobia as well as for aromatherapy on pain and depression. For example, virtual reality scenarios could enhance the treatment of Post Traumatic Stress Disorder (PTSD) of war veterans, victims of kidnapping or terrorist attacks, as special odours experienced in the traumatic event, can be reproduced, released selectively, and combined with a visual and auditory scenario [39]. In addition to psychological treatments, olfactory displays could facilitate the learning of diagnostic decision making for medical students [9]. Some disorders can be identified based on specific odours of the patient. Medical students could be trained in a VE in order to learn to identify odours that accompany these specific disorders. Moreover, in a tele-surgical environment, where doctors perform operations with a robotic device, odours could be displayed to represent human tissue to enhance the experience [43]. Like odours, tastes can have significant impacts on the emotional state of a human. Therefore, they could potentially be used to treat psychological disorders. However, gustatory displays, but also olfactory displays, have rarely been applied in the field of medical VR to date.

3.8 Potential Application

Smell can alter emotional state and strongly elicit autobiographical memories and associated affect [12]. Compared to memories cued by auditory and visual information, these memories are more emotionally laden, which is known as the Proustian phenomenon [18]. So, it may be beneficial to introduce olfactory stimulation as a treatment to VRT. In PTSD patients, odours can evoke traumatic memories and even olfactory flashbacks [52]. Because of these properties, olfactory cues could have the ability to enhance presence and probe traumatic memory recall during PTSD treatment. There is evidence that a pleasant ambient odour had a positive effect on relieving stress and improving mental relaxation. In aromatherapy, essential oil has long history to be used to treat people who have mental stress and psychological disorder. For example, the experiment conducted by Lehrner J. suggest that ambient odour of orange in a dental office could reduces anxiety and improves mood in female patients [30]. In their experiment, ambient odour of orange was diffused in the waiting room through an electrical dispenser in the odour group whereas in the control group no odour was in the air. And the result reported that compared to the controls, women who were exposed to orange odour had a lower level of state anxiety, a more positive mood, and a higher level of calmness. Since there has been an experiment using virtual reality to treat people with fear of dental work, it seems reasonable to provide patients with orange odour when they immersive in the virtual environment. The olfactory stimuli would enhance the effectiveness of therapy. A study on the effect of aromatherapy on pain, depression, and feelings of satisfaction in life of patients found that receiving massage with lavender, marjoram, eucalyptus, rosemary, and peppermint oils significantly decreased both the pain and the depression levels. Cooperating olfactory display in their VRT to treat pain may be a promising work in the future. Numerous odours have a historical and empirical reputation for improving concentration, memory, and learning, which is now being confirmed and clarified by clinical trials. The olfactory sense offers unique and interesting benefits for increasing memory through increased neural networking. The virtual reality also has preliminary applications in the rehabilitation of memory-related cognitive processes and functional abilities. This is supported by different studies showing that, in people with neurologically-based memory impairment, procedural memory often remains relatively intact. Virtual reality, by way of its interactive and immersive features, could be used to exploit the patient's preserved procedural abilities. Salvatore Capodieci have conducted a music-enhanced immersive VRT in the rehabilitation of a patient who experienced impairment in memory-related cognitive processes. Their result is promising. From their result we can predict the promising future of using odour-enhanced immersive virtual reality to treat patient with memory impairment. Moreover, the olfactory display may be introduced to the VRT in the rehabilitation of eating disorder or brain injury. But before using odours as cues in treatment more should be known about its effects as its strong properties may possibly also result in unwanted results, such as higher levels of dissociation. Anyway, it is pointed out that pictures, music and odours can strongly elicit autobiographical memories, and therefore have the potential to enhance therapeutic processes of imaginal exposure in PTSD.

3.9 Conclusions

It would take years for olfactory displays to fully develop in the virtual reality. For its high price, olfactory displays currently are still not at the level where the common consumer would use or purchase them. None of current olfactory display devices can fully generate and transmit the odour information to human. These reasons limit the application of olfactory display in virtual reality. Compare to the high technology of head mounted displays currently available, the first HMD appearing in 1960 was only able to produce visual images of simple shapes. Olfactory displays will follow the same path but are believed at a quicker pace with the well funded government programs and economic incentive for the private company. The potential use for olfactory display is great, especially in VRT. To arrive at the full potential of VRT, olfactory interfaces must be incorporated. This incorporation would not only enhance the realism of the virtual experience, but it would also serve as a stimuli treatment in the process of therapy.

Chapter 4

Prototype Design

After having showed what concern about the sensorial aspects, the potential of the odour stimuli in the rehabilitation and the state of the art of the current devices, in the following section the aspects regarding the Prototype objective of this thesis are illustrated. The intentions behind the design choices of the device built are illustrated. Information about the production processes will be presented for overall structure and electronic components. Manufacturing of the device will be discussed. Further analysis will be conducted on the final product in terms of included features and user interactions.

4.1 Concept

A fully immerse virtual reality experience can be achieved through head mounted displays although interacting with the virtual environment requires additional devices. Partial, but anyway, multimodal experiences can be also reached by desktop visual devices integrated with other sensory experience. VR systems are equipped with input or output devices that have various features as it is explained in the previous chapters. In this thesis, we proposed to build a custom device for a generic VR application that could be improved in the future. Main ideas and specifications behind the concept design of the product have to be defined clearly to achieve more efficient results.

- **Simplicity** Complex features or interactions might be an issue for a device that will be used in rehabilitation. Therefore, overuse of manual functions on the implementation must be avoided. Another important subject is the integration with the VR System. Also, the virtual interaction must be easy to do for everyone and the command available must be only few and clear. Input devices generally require additional drivers and software to be connected to VR applications which causes compatibility issues depending on the system if not managed properly. Applications which need only a mouse interaction or common input peripheries don't suffer this problem. Design solution for PC integration of the prototype device must be practical and straightforward.

- **Inexpensiveness** Virtual reality rehabilitation requires the use of several electronic devices which may be costly for some people. Thus, a cheap object that is produced for VR rehabilitation can be an efficient tool for treating numerous patients that cannot afford more expensive systems.

- **Comfortability** During the VR rehabilitation, patient should not be disturbed by the input device. Method of attachment to the VR must be comfortable and the device must be stable. Weight of the implementation have to be optimized.

- **Compactness** Essential parts must be arranged in terms to fit in the smallest place possible. In this manner the weight is also reduced. Size has to be minimized as much as possible to grant the versatility of use and the adaptivity

- **Customizability** Capacity for improvement is a crucial factor for a device. A device must be customizable for different user to adapt it to use at his best. A custom device can be redesigned with the same functions to serve for the same purpose. Further updates can be done in terms of both hardware and software. The design and the external look are not crucial, but it is important and make it customizable and adaptable for different components availability.

The final result is expected to present all the specifications mentioned above. Although, technical parts designed and the ones already available in the market have a significant impact on the form of the design. The prototype presented consists in a device that contains the fragrances that must be diffused and all the mechanism that allows the motion of the part. It is composed by plastic parts, ball bearings and electronic components. The scents used are stored in a square shaped Waffles with a thickness of about 4[mm] and made of aluminium or alternatively are liquid fragrances to be soaked on suitable materials or on the waffles themselves to strengthen the scents. The plastic parts are though to be 3D printed. This is the best choice because the design could be easily changed and adapted for different cases and this prototype is not intended to be mass manufactured. 3D printing means the realization of 3D objects with additive manufacturing starting from a 3D digital object. 3D printing can be performed with various technologies such as Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Stereo lithography (SLA) etc. In our case, as we are dealing with plastic, we have used FDM printing for low cost manufacturing. The digital object is realized with specific software and then elaborated to be realized with a 3D printer layer by layer [2]. FDM printers are equipped with an extruder head which controls the flow of the melted material. Extruder can move around in three-dimensions in a restricted area to depose the material and melted material solidifies after extrusion. This approach is a cheap method to manufacture objects but in terms of surface quality, speed, minimum tolerance it is worse than other implementations of 3D printing. Since we are aiming for an inexpensive solution these variables are not relevant and the obtained tolerances and dimensions are acceptable, therefore, we focus on producing our components with FDM printing. The material used for the 3D printed parts is Polylactide, also known as Polylactic Acid (PLA), a biodegrade thermoplastic. PLA maintains several desirable properties for 3D printing such as a low melting temperature and glass transition temperature. As a result, PLA offers a good level of detail and exceptional print quality [34]. In a following section the 3D printer processes are better explained. The prototype is basically a box divided into 2 main parts, the one below contains the board, the fan, the transmission system and the plates, the one above has the motor and its cables and the revolver, and it is closed by the top cover. Now the single parts which compose the prototype, are listed and considered in detail.

4.2 Plastic Parts

- External Case;
- Revolver;
- Motor Plate;
- Revolver Plate;
- Top Cover.

4.2.1 Case

The external Case (Fig. 4.1) consists in a rounded shape box with the holes and the attachment for the fan on the bottom, the room for the board and the predisposition to contain a ball bearing placed under the driving pulley. It has also the supports for the plates, on one side the plate to position and hold the motor, and on the other side the one for the Revolver. The top border is thinner than the rest of the case to insert easily into the top cover. It has also two holes, one in the front and one in the rear, for the snap fit. In the external part there is the predisposition for the screw-on coupling for a chest harness support. This is positioned on the front part so that the fixed system would be in the right position under the face and on the lower layer to make it easy to be manufactured. The initial prototype had a different shape, more regular and squarer shaped, but the difficulty to insert all the components and the attempt to reduce the empty space drove to this final design. Its dimensions are 10[mm] * 9[mm] * 4[mm] without considering the screw on coupling. In Fig. 4.2 the particular details are illustrated.

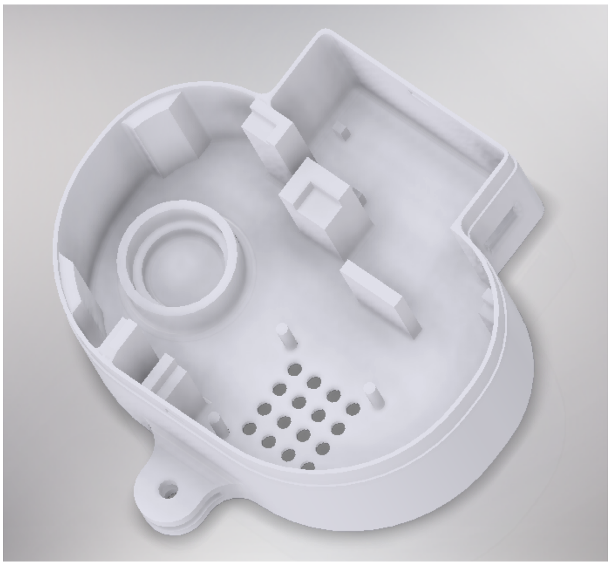


Figure 4.1: Case

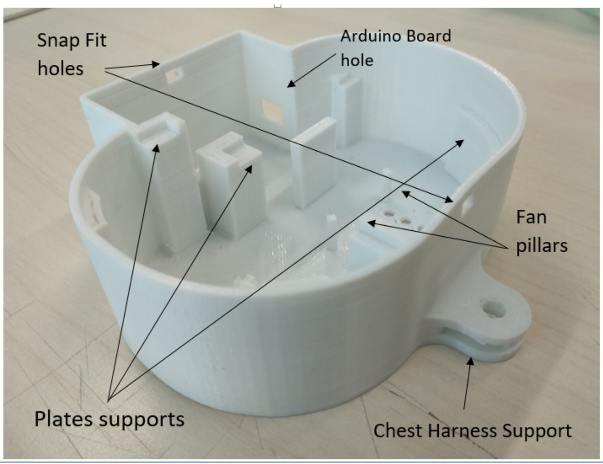


Figure 4.2: A picture of the real Case with the illustrations of the details

4.2.2 Revolver

The Revolver (Fig. 4.3) is the component designed to house the Waffles of fragrances or the perfume-soaked materials in the minimum amount of space and it has a circular shape on the external part. It has a design with 6 cloves. Each circular sector has the specific room to insert the waffles or other materials on the side, a rounded hole on the bottom while it is open on the top to let the air pass from the bottom to the top. The dimensions of the waffles drove the design and the shape of the Revolver itself. To increase the number of the waffles would have been necessary to increase the global dimensions of a great amount and so 6 was a good compromise between quantity of waffles that could be hosted and global dimensions. In the middle there is a full circular part that has the function to sustain and links the 6 sectors. It has a square hole on the bottom where the revolver pulley is coupled with interference. Its dimensions are 57[mm] diameter * 25[mm] in height.

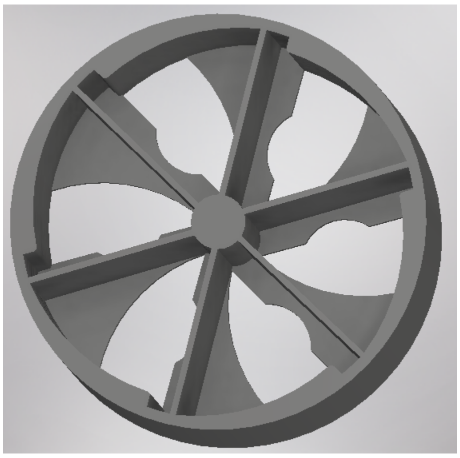


Figure 4.3: Revolver

4.2.3 Motor Plate

On one side there is the plate for the driving motor (Fig. 4.4): it consists in a holed plate with a squared hole and walls that fits around the motor and keeps it in position. It is 3[mm] thick: this thickness is due to keep at the right distance the motor from the driving pulley without forcing it and to have enough space to fix the motor with a little screw. The hole is bigger than the necessary, but it permits to have a bit of clearance to recover the tolerances and small problems of inclination, and to position the motor in the right place. The two sidewalls are aimed to contain it and offer it extra support and lateral force. The design is strictly dependent on the lateral walls of the case and fits in 2 pillars coming from the basement. Its dimensions are 30[mm]*60[mm]*3[mm] thick, while the two sidewalls are 11[mm] height.

4.2.4 Revolver Plate

The plate where the revolver (Fig. 4.5) is attached is placed directly above the fan and it has a hole to let the air pass and another one to house the ball bearing directly connected to the Revolver. It doesn't need to be as thick as the other one, only 2[mm], because its function is only to keep the components in the correct position. It also follows the design of the external sidewall to which it rests, and it is supported by 2 pillars and a column where the fan cable is wrapped. It has a circular sidewall and smaller circular plate to contain the ball bearing coupled with interference. The hole to let the air pass, follows the shape of the one on the revolver with the scope to

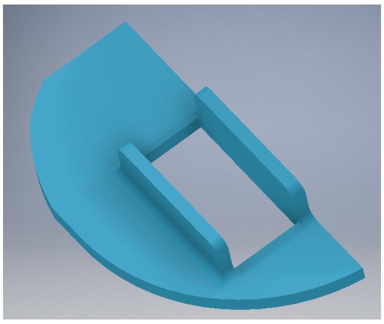


Figure 4.4: Motor Plate

convey as much air as possible. Moreover, it has sidewalls itself to avoid losses. Its dimensions follows the case shape and are 60[mm]*56[mm] with a round corner.

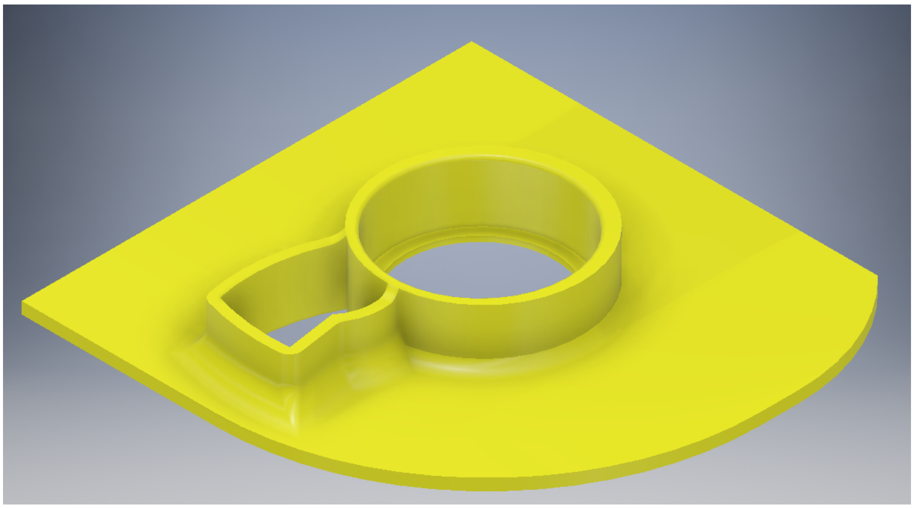


Figure 4.5: Revolver Plate

4.2.5 Top Cover

The top cover (Fig. 4.6) follows the rounded form of the case and it has a snap fit with two square extrusion to hook into the case. It has a single hole aligned with the Revolver active clove on the air flow to let the air pass under the nose as can be seen in Fig. 4.8. The hole has a grate to prevent the Waffles to go out and to avoid the finger contact with the Revolver. In the inner part of the hole, two small ribs are added to avoid the scents to come out from the other cloves not selected as seen in Fig. 4.7. The space above the Arduino board is needed to house the cable coming from the Motor and from the Fan. The sidewalls are almost vertical to simplify the 3D printing process even if a more rounded shape with fillets would be more aesthetically graceful.

Its height permits to contain the Motor and the Revolver in the vertical room. Its dimensions are 94[mm]*10,45[mm]* 2,5[mm].

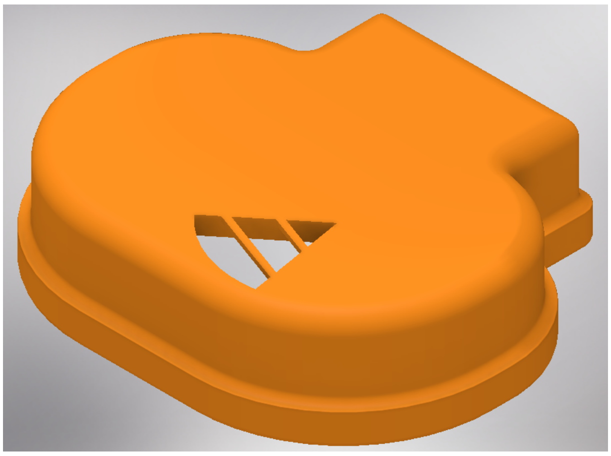


Figure 4.6: Top Cover top view

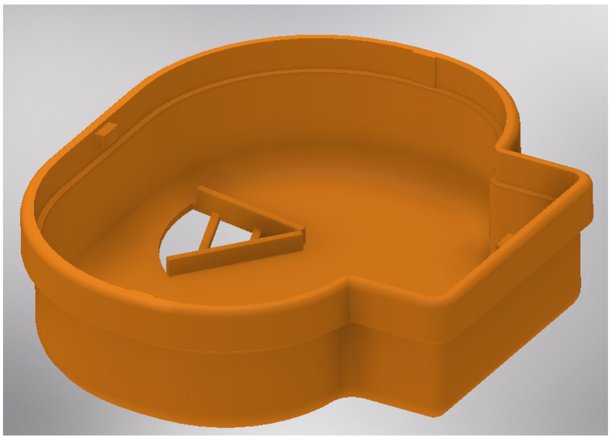


Figure 4.7: Top Cover down view

4.3 Chest Harness and Jointed Hook

The screw-on external coupling is attached to a 4 joints support ending with a universal hook, used typically for action cam. The 4 joints system, with the 3 parts composing it, permits a fine regulation in height, direction and inclination. Each regulation is made by screws with an adjustment knob that fixes them in the wanted position. The aim is to place the system in the best position for the user and directly below the face to maximise the air flow with the essences. The hook is attached to a chest harness and not directly on the VR system as usual, so that the weight of the system

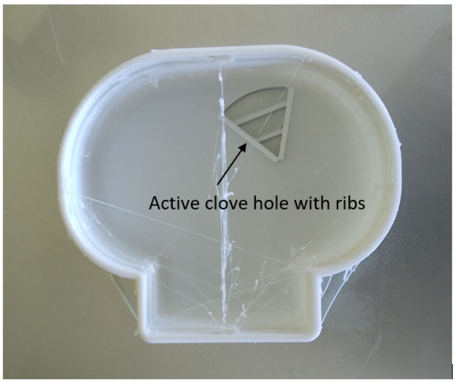


Figure 4.8: A picture of Top Cover with the clove hole

is supported by the shoulders and the chest, but it is not impacting on the neck or on the VR system itself. The disadvantage is that it doesn't follow the head direction, but it follows the chest direction; the problem arises when the head is tilted and so the nose is not placed directly above the holes where the air flow. A great advantage of this solution is that this kind of prototype and this idea, could be utilised for different kinds of VR systems from different brands because it is not designed only for a specific VR system but could be adapted to different ones. (Fig. 4.9)

Figure 4.9: The Chest Harness linked to the Jointed Hook screwed with the Case

4.4 Electronic Components

4.4.1 Fan

The Fan used is a 30*30[mm] fan, it is powered by 5V Arduino board and it is placed directly above the case holes and below the Revolver and its Plate. Its main function is to inlet external air and pushing it into the Revolver where the fragrances are housed.

The air flow permits to deliver essences to the user and get the job done. It has on its case 4 circular holes, one for each angle, where 4 little case pillars are coupled with interference. Its shape is a square of 30[mm]*10[mm] height. (Fig. 4.10)

Figure 4.10: The Fan

4.4.2 Servomotor

The servomotor is a SM-S2309S (Fig. 4.11, Fig. 4.12)and can rotate between +60° and -60° so that to cover about 180°. This issue was a problem during the design, because the angular displacement needed to deliver all the fragrances was higher, almost a round corner. It has a motor arm with a star shape end that fits into the predisposition on the top of the driving pulley where there is the same shape. The coupling is done by pressure but without fixing the components. This for recover small alignment errors and driving pulley rotations not in plane.

Figure 4.11: SM-S2309S

Technical Parameters				
4.8 V		6 V		Rotation Angle
Speed	Torque	Speed	Torque	
0.11 [s/60°]	107 [Nmm]	0.09 [s/60°]	127 [Nmm]	± 60°

Figure 4.12: The SM-S2309S spreadsheet

4.4.3 Arduino

The brain is the Arduino Nano Board (Fig. 4.13), an open source-hardware correlated with its development environment, which permits the simplified creations of prototypes for interactive projects or where the use of sensor is required. Arduino is an open source project born in Italy in 2005 by a pool of developers supported by Olivetti and Telecom Italia. Later its potential was recognised by bigger brands as Intel [15] and Microsoft [14], giving life to prestigious partnerships. Arduino is a board that correlates incoming stimuli from various inputs or sensors with outputs that generate effects following the given instructions. Everything is made possible through the Arduino programming language. Low costs, simplicity and the wide compatibility among the most common operating systems, made it one of the best platforms for prototypes, base projects or experimentations. It permits to have a clever board having all the necessary functions to do good projects in a little space. It has a USB-Mini connection to communicate with the PC and the external world. In the prototype proposed, it is placed in the rear part of the case and has a hole for the USB connection. The choice fell on this board mainly for the contained dimensions, an essential requirement for this prototype as the board was thought to be inside the system. And then it has enough memory and computational power to do the needed task: the control of the servomotor and the fan. In Fig. 4.14 is descripted the Arduino Nano spreadsheet.

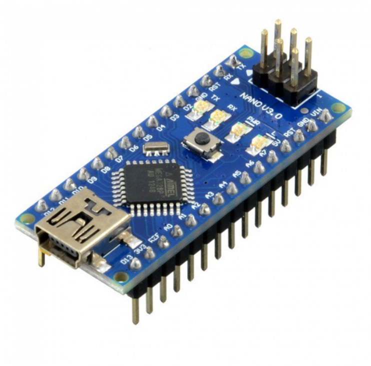


Figure 4.13: Arduino Nano Board

Microcontroller	ATmega328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
Clock Speed	16 MHz
Analog IN Pins	8
EEPROM	1 KB
DC Current per I/O Pins	40 mA (I/O Pins)
Input Voltage	7-12 V
Digital I/O Pins	22 (6 of which are PWM)
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g
Product Code	A000005

Figure 4.14: Arduino Nano spreadhseet

4.5 Transmission

The transmission consists on a belt drive with 2 pulleys, the driving one placed under the motor and the driven one linked to the Revolver containing the Waffles. The 2 Pulleys are connected into a ball bearing each, granting the correct functioning and rotation of them. The Pulleys have 2 edges, above and below the teeth, to contain the belt and to prevent the belt coming out of its seat. The driving Pulley has a particular star shape on the upper part that follows the one on the shaft. The driven one instead has a square extruding part which fits into the Revolver in the predisposed hole. The Belt is a plastic belt reinforced with glass fiber and has 2[mm] step and 6[mm] width and it is the kind typically used for 3D printers. Its dimensions are standardized and it is named MXL025. It drove the design of the two pulleys. It has been cut at the proper length and glued at the extremity with a piece of the belt itself on the back of the junction. (Fig. 4.15).

Figure 4.15: A picture of the Belt with the glue used to close it at the proper length

The belt lenght was calculated with this formula:

$$L = 2C + \frac{\pi}{2} * (D + d) + \frac{(D - d)^2}{4C}$$

where C is the wheelbase, D is the driving pulley diameter and d is the driven one diameter.

With the data C = 47,3[mm], D = 31[mm] and d = 15,5[mm], the resulting L is 168,9[mm].

The transmission has not only the aim to deliver the motion from the driving pulley to the driven one but also to duplicate the angular displacement. In fact, the servomotor covers an angle of 180° degrees while the needed angular displacement for the Revolver to cover all the section is 300° degrees. The driving pulley has 48 teeth and a diameter of 31[mm] while the driven one has 24 teeth and a diameter of 15,5[mm]. Their design was made via software basing on the used standard belt.

4.6 Ball Bearings

In this Project, 2 Ball Bearings are used, one under the driving pulley and one for the Revolver. They are simple Ball Bearings used mainly for kids toys but that can fit well for this application for their good functioning and reduced cost and weight. Its dimensions are 22[mm]*7[mm] in height (Fig. 4.16).

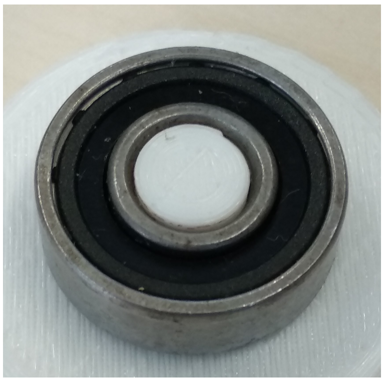


Figure 4.16: The Ball Bearing

4.7 Waffles

In this prototype the essences are stored in aluminium waffles of 23,5[mm]*20[mm]*3[mm]. Moreover to emphasize the essences, the waffles are soaked with liquid perfume of the same essence (Fig. 4.17).

4.8 Data Transmission

Arduino Nano has a Mini-B USB port located on it which can be used to power the device through USB connection or interface it with a PC through serial communication. Mini USB (Mini-A and Mini-B) connectors are middle dimension connector

Figure 4.17: The waffles correlated with the liquid perfume.

required by USB standard. They were designed for medium-size devices as satellite navigators, external drives, tablets, cameras and others. They have dimensions about 3[mm]*7[mm] [56]. Programming the Arduino is also achieved through USB connection, used to load the code from the PC to it. In Fig. 4.18 is showed the layout of this serial door.

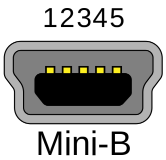


Figure 4.18: USB Mini

4.9 Baud Rate

Rate of data transmission is referred as baud rate for communication protocols. Baud rate defines how many bits are transferred per second (bps) [41]. Devices that are interfaced through serial communication must operate at the same baud rate. Data transmitting/receiving speed is determined by baud rate, but communication speed is not limitless. Microcontrollers cannot operate properly at very high rates (more than 115200bps) and occurrence of data errors might increase due to high baud rate. The serial communication in our case is performed at 9600bps without any issues.

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Chapter 5

3D Printer Process and Parameters

The passages that goes from the 3D virtual cad components to the physical object are different. In the following are illustrated. The cad 3D software used for the design was Autodesk Inventor [4] (Fig. 5.1). This software permits via a sketch-based design, to built 3D virtual components. In order to make these components real, two more passages are required. The first one is to generate a *.STL* file readable by programs that can generate a .gcode file containing the instruction for the 3D printer.

5.1 STL Generation

After that the object has been designed on Inventor, the object must be saved in a specific format extension called *.stl*. STL is a format STL (STereo Lithography interface format o acronym of "Standard Triangulation Language") is a file extension, binary or ASCII, born for stereolithography CAD. It is used for rapid prototyping through CAD software. An STL file *.stl* represents a solid with its surface discretized in triangles. It consists in X, Y e Z repeated for each of the three vertices for each triangle, with a vector to describe the surface normal (Fig. 5.2 . STL format presents advantages as simplicity: it is very easy to be generated and to be processed by the PC. On the contrary it has an approximate geometry and its data structure, even if it

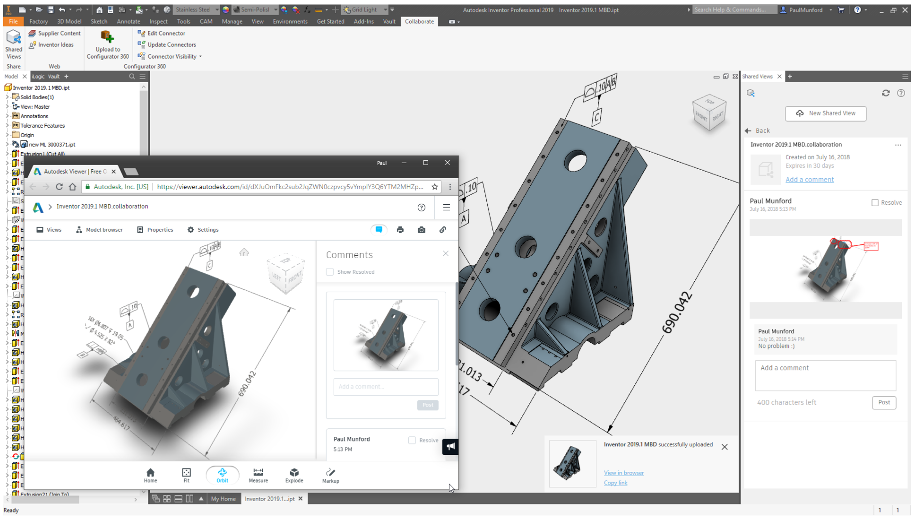

Figure 5.1: Autodesk Inventor work environment

is simple, can present the repetition of a same vertex more time. STL file can be open with open source software, in our case Ultimaker Cura [11] has been used. Cura is a 3D printing slicer application that works by slicing the user's model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacturing the physical object.

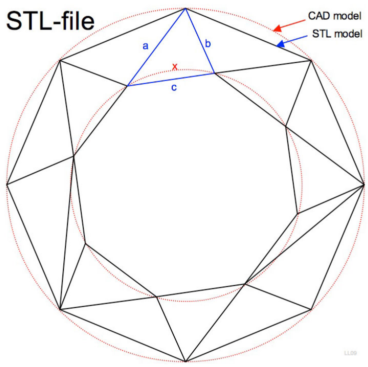

Figure 5.2: STL and CAD differences: in particular the triangular mesh is highlighted

5.2 G code Generation

The *.stl* file open in Cura (Fig. 5.3) permits the control of all the possible variables and parameters. After having decided the process velocity, extrusion temperature, infill % and supports management and other minor options, a *.g-code* file can be exported. G-code (also RS-274), which has many variants, is the common name for the most widely used numerical control (NC) programming language. It is used mainly in computer-aided manufacturing to control automated machine tools. G-code is a language in which people tell computerized machine tools how to make something. The "how" is defined by g-code instructions provided to a machine controller (industrial computer) that tells the motors where to move, how fast to move, and what path to follow (Fig. 5.4). The same concept extends from cutting tools to noncutting ones such as forming or burnishing tools, photo plotting, additive methods such as 3D printing, and measuring instruments. The g-code generated it is saved on memory card and open directly in the 3D printer that is working the piece.

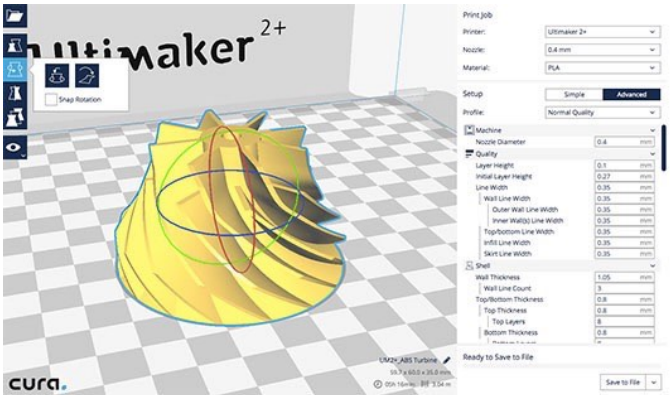

Figure 5.3: Cura software interface

```
G02 X33.171944 Y70.454862 Z-0.050000 I3.146309 J-33.690888
G02 X36.600000 Y69.507031 Z-0.050000 I-1.004582 J-10.306423
G02 X38.104729 Y68.492243 Z-0.050000 I-2.584564 J-5.455393
G02 X39.011809 Y67.286112 Z-0.050000 I-2.828059 J-3.071018
G02 X39.331246 Y66.514942 Z-0.050000 I-5.323865 J-2.657010
G02 X39.807199 Y64.905525 Z-0.050000 I-22.763254 J-7.606872
G02 X40.177928 Y63.253731 Z-0.050000 I-25.737692 J-6.644065
G02 X40.767720 Y59.882203 Z-0.050000 I-106.718161 J-20.405906
G03 X41.575635 Y54.882646 Z-0.050000 I900.292941 J142.919939
G03 X41.596655 Y54.841610 Z-0.050000 I0.074477 J0.012248
G01 X41.616504 Y54.840865 Z-0.050000
G03 X43.832193 Y56.902860 Z-0.050000 I-237.748889 J257.691322
G01 X46.048541 Y58.983077 Z-0.050000
G01 X46.413663 Y58.586171 Z-0.050000
G02 X46.762135 Y58.185736 Z-0.050000 I-7.064100 J-6.499264
G01 X46.767705 Y58.155859 Z-0.050000
G02 X46.748493 Y58.124940 Z-0.050000 I-0.068315 J0.021020
G02 X44.293003 Y55.813775 Z-0.050000 I-522.960908 J553.158477
G03 X41.880186 Y53.489265 Z-0.050000 I82.663840 J-88.218658
G03 X41.852150 Y53.396102 Z-0.050000 I0.071683 J-0.072371
G02 X41.874633 Y53.286906 Z-0.050000 I-23.517215 J-4.898958
G02 X42.036314 Y52.491032 Z-0.050000 I-1269.134869 J-258.238797
G01 X42.197709 Y51.694954 Z-0.050000
G01 X43.390572 Y51.694954 Z-0.050000
G02 X53.746174 Y50.143945 Z-0.050000 I-0.014687 J-35.444133
G02 X63.838961 Y45.438448 Z-0.050000 I-11.729341 J-38.334901
G02 X71.346855 Y38.826978 Z-0.050000 I-18.670215 J-28.770305
G02 X75.133285 Y32.095385 Z-0.050000 I-15.602289 J-13.206781
G02 X75.630257 Y30.300412 Z-0.050000 I-16.928676 J-5.653304
G02 X75.868172 Y28.776325 Z-0.050000 I-11.951813 J-2.646331
G03 X75.951985 Y28.284115 Z-0.050000 I3.239037 J0.298300
G03 X76.001090 Y28.245795 Z-0.050000 I0.049105 J0.012303
G03 X76.050678 Y28.254190 Z-0.050000 I0.000000 J0.150648
G03 X76.726523 Y28.498604 Z-0.050000 I-10.207675 J29.282525
G01 X76.726571 Y28.498313 Z-0.050000
```

Figure 5.4: Example of a .gcode file

5.3 3D Print Parameters

Since most of the part are aimed to be 3D printed, in this section is presented the parameters, time taken for each print and the components weight. The 3D printer used to build this Prototype is an Anet A8 (Fig. 5.5), a very basic 3D printer, cheap and buildable at home. It can be built following accurately the instruction but some minimum technical knowledge on the component are required by the builder. The material

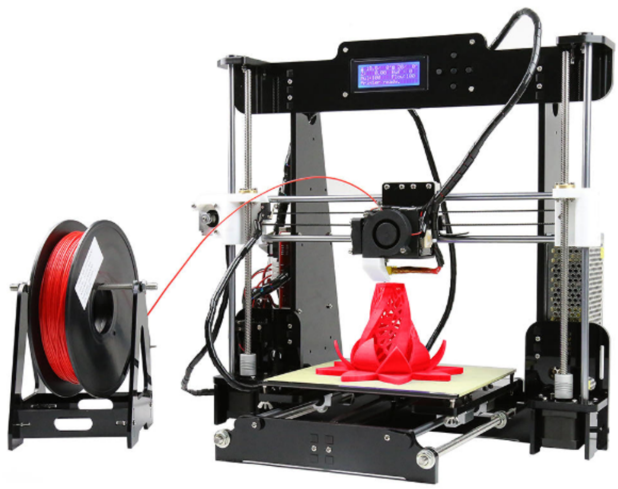

Figure 5.5: Anet A8 3D printer

used is Polylactide, also known as Polylactic Acid (PLA), a biodegrade thermoplastic. Synthesized from organic sugars, PLA has become the most common material for 3D filaments due to its eco-friendliness and ease of use (Fig. 5.6). PLA maintains several desirable properties for 3D printing such as a low melting temperature and glass transition temperature. As a result, PLA offers a high level of detail and good print quality, a perfect combination for our case.

Figure 5.6: An example of a PLA filament coil

In the 3D printing process, among other conditions, two of the most important ones are the printing velocity and extrusion temperature of the filament. These parameters have a certain influence on the process:

- The velocity influences the quality of the print and the time needed for the printing. When the velocity increases, the time needed decreases, but with the increase of velocity the quality obtained is decreased. This because the filament has not enough time to fix well on the plate or on the previous layer and, if the velocity is too high, changes in the directions or sharp edges are hard to be obtained because the filament cuts the curves and doesn't follow the extrusion path. A typical and useful common trick is to reduce the printing speed a lot for the first layers in order to make precise borders and surface detail and then increase the speed to reduce the time needed. The critical aspects concerning the speed regards mainly the layer adherent with the plate, when the plastic is above other plastic, these aspects are less critical. (Fig. 5.7).

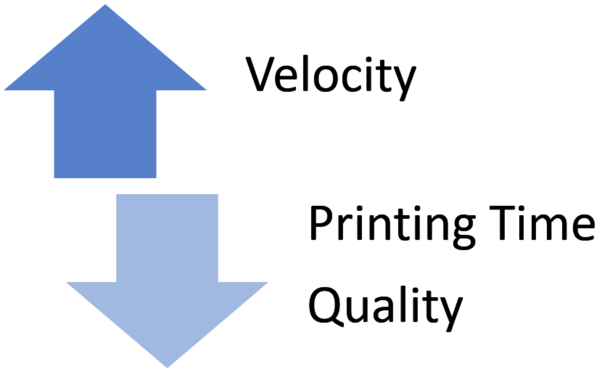

Figure 5.7: The velocity influence in 3D printing

- The 3D printing temperature represents the extrusion temperature and so the temperature at which the filament is melt. The typical temperature range for the PLA is between 190°[C] and 205°[C]. Below 190°[C] the filament is not sufficiently melted while above 205°[C] is too much liquid. Decreasing the extrusion temperature at about 190°[C] it permits to obtain better details because the extrusion is more precise but there is the risk that the filling of the layers is not complete. On the contrary, as far as the maximum possible temperature is reached, the extrusion is more liquid causing a better filling of the surfaces but decreasing the sharp details quality. A right tread off must be found focusing on what component is being made. (Fig. 5.8).

Another important condition is what concerns the % of internal filling. In fact, increasing the % of filling, the mechanical resistance of the component is increased but also increases the time taken to print, the global weight and the material used. At the same time on the contrary the elasticity and the possibility to deform and change its shape when the part is cold, is reduced. Since the components in our case are not massive but they are thin, on except of the small pulleys, this parameter was not important during the printing settings. In Fig. 5.9 the influence of the % infill is explained.

5.3.1 Upper and Lower Case Printing Parameters

The two components considered have similar shape: they have a flat surface, an emptying internal part and thin external walls. The process parameters chosen for

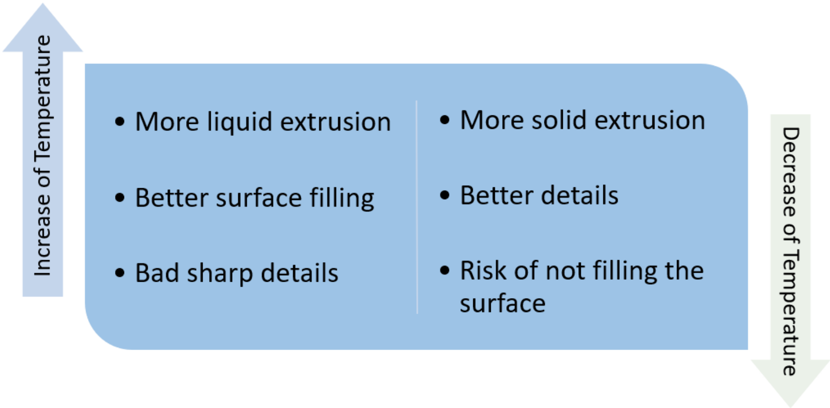

Figure 5.8: The temperature effect in 3D printing

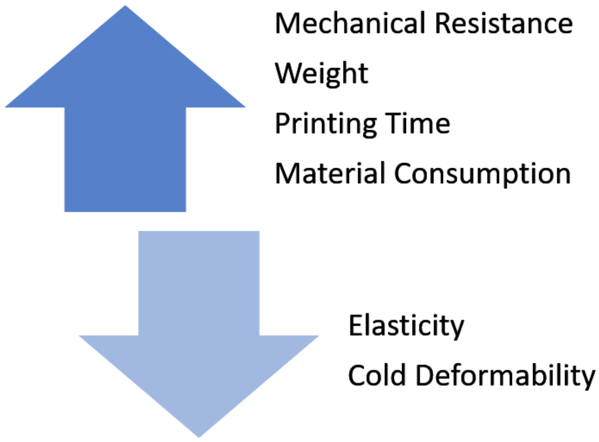

Figure 5.9: The increase infill influence in 3D printing

both are similar. A quite medium extruding temperature for both was chosen, to grant that the first layer in contact with the plate were done with sufficient precision and with a good filling of the melted material. The speed chosen is higher in respect to other components because otherwise the process would have taken too much time. To make better details and a good start, the first layers were done at a very low speed, about 10 [mm/s], increased to 50 [mm/s] in the successive layers to save time. The precise paramers are depicted in Fig. 5.10.

5.3.2 Plates Printing Parameters

In the case of the Revolver plate and the Motor plate different considerations were done. The components are less complicated in shape and the most important part were the surfaces. The components develop mainly in the plane dimensions while the thickness is reduced. The temperature chosen was higher to highly melt the filament,

Extruder Temperature	200° [C]
Printing Velocity	50 [mm/s]
Printing Time	5.30[h] upper case 7[h] lower case

Figure 5.10: Cases 3D printing parameters

fill the empty spaces and have a better surface finishing. The speed instead was reduced so to recover the edge precision lost in the increase of temperature. This was not a problem for these cases because the reduced thickness of the components didn't lead to a big increase in the time duration of the printing process, and both components could be done in an acceptable time of about half an hour, as shown in the related table (Fig. 5.11).

Extruder Temperature	205° [C]
Printing Velocity	40 [mm/s]
Printing Time	40 [min]

Figure 5.11: Plates 3D printing parameters

5.3.3 Revolver Printing Parameters

The Revolver needed a good precision having very thin sidewalls. Moreover, the squared hole on its lower part must be well printed for a good coupling with the Driven Pulley. The parameters chosen moved in this direction with low speed and medium low extrusion temperature. The price paid was a quite long printing time and a quite bad roughness on the lateral surface (Fig. 5.12).

5.3.4 Pulleys Printing Parameters

The two Pulleys needed to be printed very precisely because they have the teeth to be coupled with the Belt. The decided process parameters so were a very low printing speed and the minimum possible printing temperature. In this case, since

Extruder Temperature	195° [C]
Printing Velocity	35 [mm/s]
Printing Time	3 [h]

Figure 5.12: Revolver 3D printing parameters

the components are massive pieces, albeit small, also the infill percentage had to be decided. The time taken to the print was quite long on respect on the dimensions of the components, but anyway acceptable. The corresponding table shows the parameter (Fig. 5.13).

Extruder Temperature	190° [C]
Printing Velocity	25 [mm/s]
Printing Time	30 [min]

Figure 5.13: Pulleys 3D printing parameters

Chapter 6

Assembly Operations and Cost Evaluation

In the two sections of this chapter the assembly procedure for the prototype mounting are illustrated and a global cost evaluation is presented.

6.1 Assembly Operations

Due to the small dimensions of the pieces and the few room available, the assembly step is not so easy as it seems. So, this is the suggested order to follow.

First of all, the attention must be given to parts that once positioned could be not touched anymore. The first operation to do is to insert the Driving Pulley into the Ball Bearing, forcing it till it is completely inserted but paying attention there would not be friction between the Pulley and the Bearing. A spray of lubricating oil in the bearing is done to reduce the friction. (Fig. 6.1)

Then insert the Ball Bearing with the Driving Pulley, into the predisposition on the lower part of the case. The coupling is with interference, so a force must be applied from the top. The two components must be forced till the Ball Bearing is completely inserted into the dedicated extruding part on the lower part of the Case, but paying attention also in this case, that there is no friction between the Pulley and

Figure 6.1: The Driving Pulley insertion in the ball bearing

the extruding part of the Case that contains the Ball Bearing. (Fig. 6.2)

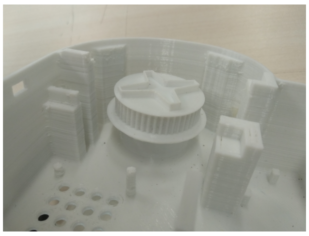

Figure 6.2: The insertion of the Driving Pulley with the Ball Bearing in the Case

Then the attention is focused on the Revolver system, that must be prepared separately before mounting in the prototype. At first the Driven Pulley is inserted into the second Ball Bearing with interference, till the upper edge of the Pulley is in contact with the Bearing. Again a lubricant spray in the Ball Bearing is done to prevent frictions. After that the Bearing and the Pulley are inserted with interference into the hole on the Revolver Plate, till the Bearing is in contact with the designed circular surface of the Plate. When everything is mounted, the Revolver is placed onto the Driven Pulley, via its squared extrusion that fits into the prepared hole in the central lower part of the Revolver. (Fig. 6.3,6.4,6.5).

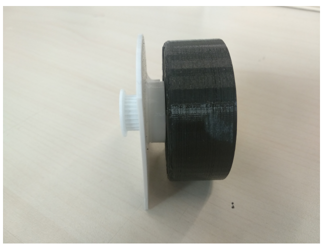

Figure 6.3: The Revolver system preparation

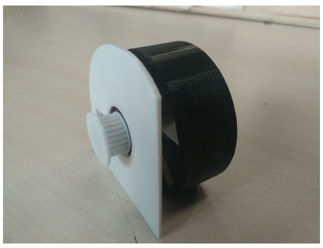

Figure 6.4:

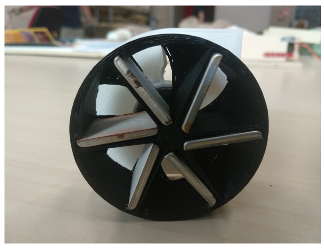

Figure 6.5:

Afterwards the Fan is positioned being careful that the arrow engraved on it, points upwards, so that the air flow, goes in that direction. The Fan structure has 4 holes at its angles, where the Case pillars are inserted with interference. The Fan is pushed until it is in contact with the upper surface of the lower part of the Case. The fan cables are wrapped around an extruding part of the Case. This part has the function of being wrapped by the cables and to sustain the Revolver Plate. The final parts of the cables will be inserted into the Arduino pins, the Red terminal goes into Pin 11 and the Black one into the Ground Pin. (Fig. 6.6)

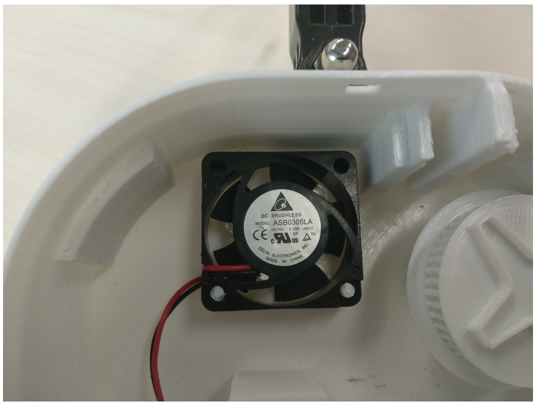

Figure 6.6: The insertion of the Fan in the Case

Once the Fan is in position, let's focus on the Belt. The Belt is designed to be slightly in tension so that it can move the system without slipping. At first the Belt is positioned around the Driving Pulley (Fig. 6.7), then even the Driven one is inserted. The Revolver Plate slides pulling the Belt with it (Fig. 6.8), and it is put in position into the predisposed pillars and it is fixed (Fig. 6.9).

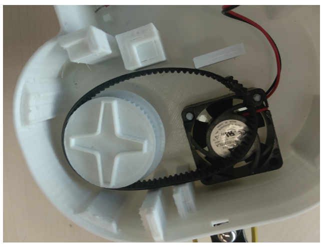

Figure 6.7: Driving Pulley insertion

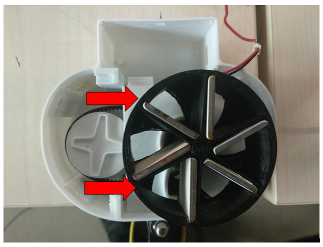

Figure 6.8: Positioning and sliding into the pillars

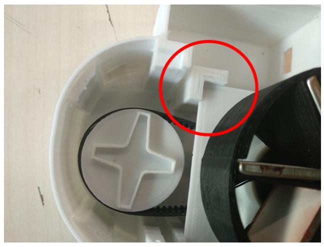

Figure 6.9: Fixing

Then the star shaped motor arm, is placed into the Driving Pulley in the designed layout (Fig. 6.10). Subsequently the Motor Plate is put in position on the pillars and the Motor is inserted in it, paying attention to fit the motor arm into the Star shape component (Fig. 6.11). Then the cables are wrapped to save space and are inserted into the Arduino Board in the chosen pins.

The Arduino connected properly with the cables is housed in the Case in the designed position. The USB Mini port is placed in its hole and ready to be connected with the USB PC cable. Now the Waffles wet with a drop of the corresponding essence (Fig. 6.12), are located into the Revolver in their predisposed space (Fig. 6.13).

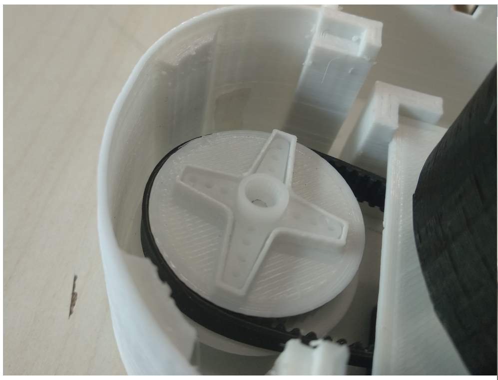

Figure 6.10: The motor arm inserted into the Driving Pulley upper surface

Figure 6.11: The Motor mounting

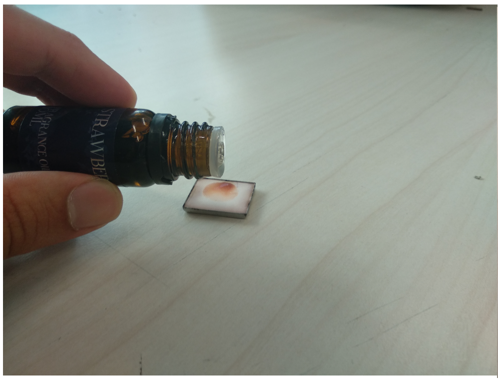

Figure 6.12: The Waffles preparations with drops of the scpecific perfume

Figure 6.13: The Waffles are located into the Revolver in the selected order

The Waffle clove order decided is:

1. Cut grass
2. Pineapple
3. Rose
4. Lemon
5. Strawberry
6. Smoke

The Revolver turns clockwise and the clove order follow the Revolver rotation. At this point with also the waffles correctly housed and with no more jobs to do on the inside components, the prototype can be closed by the Top Cover. The final steps consist in screw the Hook system into the Case, put the mounting into the snap fit on the Chest Harness and regulate directions and inclinations of the joints basing on the user preferences. After the PC connection, the prototype is now ready to be used.

Figure 6.14: The Olfactory Display mounted and ready to be used

6.2 Cost Evaluation

In this section a cost estimation to make the prototype is presented. The cost analysis when we talk about prototypes is crucial, because in this phase the budget constrain is very strict. Moreover one of the wanted characteristics of this prototype is to be cheap to consent a wide diffusion.

The components that constitute the prototype now will be divided in two categories: the bought ones and the made ones.

6.2.1 Bought Components

Component	Cost
Chest Harness	10 [€]
Arduino Nano board	5 [€]
3x3 Fan	5 [€]
Ball Bearings	2 [€]
SM-S2309S Servo Motor	6 [€]
Belt 169 [mm]	0.30 [€]
Waffles and Essences	5 [€]
Total Bought Component Cost	**33,30 [€]**

To calculate the cost of the belt, the total length of the bought belt was 5 [m] and cost 9[€] but the belt used was 16,895[mm] long. The proportional cost calculated of the portion of the belt used is therefore reduced.

6.2.2 Made Components

To calculate the total cost of the components the calculations were made with these considerations: the estimated hour consumption in [W] of the 3D printer used is 90[W], the energy cost is 0,20[€/kW] and the PLA cost is 18[€/kg]. The cost for each component were calculated adding the energy contribute with the cost of the material used. The energy cost was calculating basing on the printing time while the material cost depends on the weight of the object calculated on a balance (Fig. 6.15).

Figure 6.15: The weighing operations to calculate the material consumption

Lower Case	
Printing Time	7 [h]
Weight	46.82 [g]
Energy Cost	0,13 [€]
Material Cost	0,84 [€]
Total Cost	0,97 [€]

Upper Case	
Printing Time	5.30 [h]
Weight	27,72 [g]
Energy Cost	0,10 [€]
Material Cost	0,50 [€]
Total Cost	0,60 [€]

Motor Plate	
Printing Time	40 [min]
Weight	2,66 [g]
Energy Cost	0,01 [€]
Material Cost	0,05 [€]
Total Cost	0,06 [€]

What can be deducted from this data is that the energy cost impact is almost irrelevant and also the material cost, that is the main cost in the made components, is very low.

Revolver Plate	
Printing Time	40 [min]
Weight	5,36 [g]
Energy Cost	0,01 [€]
Material Cost	0,10 [€]
Total Cost	0,11 [€]

Revolver	
Printing Time	3 [h]
Weight	22,33
Energy Cost	0,06 [€]
Material Cost	0,40 [€]
Total Cost	0,46 [€]

Driving Pulley	
Printing Time	30 [m]
Weight	5,14 [g]
Energy Cost	0,01 [€]
Material Cost	0,09 [€]
Total Cost	0,10 [€]

Driven Pulley	
Printing Time	30 [m]
Weight	1,7 [g]
Energy Cost	0,01 [€]
Material Cost	0,03 [€]
Total Cost	0,04 [€]

6.3 Final Considerations

The total cost to make this prototype is around 40[€] (Fig. 6.2.2), that is considered acceptable for the item designed. The most impacting costs are related to the bought components. The only way to reduce them is to buy these items in large quantity and take the advantage of the economy of scale.

The total weight of the prototype considering also the jointed hook is of 226,91[g], considered very low and tolerable by the chest without particular discomfort. (Fig. 6.16)

Component	**Cost**
Lower Case	0,97 [€]
Upper Case	0,60 [€]
Motor Plate	0,06 [€]
Revolver Plate	0,11 [€]
Revolver	0,46 [€]
Driving Pulley	0,10 [€]
Driven Pulley	0,04 [€]
Total Made Component Cost	**2,34 [€]**

Total Bought Component Cost	33,30 [€]
Total Made Component Cost	2,34 [€]
Total Cost	**35,64 [€]**

Figure 6.16: The total weight of the prototype measured with a scale

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Chapter 7

Virtual Interface Design

In this chapter, we present a software application for a virtual reality use and interaction. Design choices and method of implementation will be presented. Detailed analysis of the software application will be conducted. Virtual reality choices and configurations will be discussed.

7.1 Design Approach

A virtual reality system requires a certain software that can present the virtual environment to the user. Three-dimensional visuals, integration with the hardware (head mounted displays or input devices) and interactions with simulations are provided by the software. Therefore, it is essential to have a viable software application for the virtual reality interaction that is proposed in this thesis. Definition of the specifications that will be involved in the software application have to be clear for a proper implementation of immersive VR experience.

- **Interactive** User-defined settings and choices can be extremely beneficial for a VR rehabilitation. Depending on the requirements of the patient, most effective options can be selected from a variety of choices. Therefore, presentation of choices in terms of rehabilitation methods, VE objects/models and hardware integration have to be included in our design.

- **Communicative** User must understand how to interact with the software through visual and informative guidance that is presented by the application. Each function and interaction must be clearly mentioned for anyone who does not have enough experience with the designed software.

- **Versatile** Functions included for VR rehabilitation has to be sufficient or capable of further improvements. The options to choose have to be represented properly in virtual environment.

- **Robust** Software must operate without any technical problems which may disturb the rehabilitation process. Integration with the hardware has to be as simple and practical as possible.

Development of the intended software based on our definitive specifications was a needed task for the VR interaction we aimed for. An adaptable output for the device proposed with the VR environment is necessary and its integration had to be implemented in the software. Potential future VR headset integration can also be inserted. Accomplishing these tasked required a VR supported application that can produce 3D graphics. Therefore, we chose to develop our VR software with the help of a game engine called Unity (Fig. 7.1).

unity

Figure 7.1: Unity

7.2 Unity Game Engine

Unity was developed for a game called "GooBall" (Fig. 7.2) by Unity Technologies in 2004 and officially announced as a game engine in Apple's Worldwide Developers Conference a year later [19].

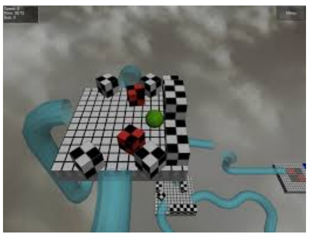

Figure 7.2: GooBall, the first game developed in Unity

The intention behind this engine was to provide a free tool for 3D content developers and diffuse the development of 2D and 3D contents among people [23]. Unity provides various tools for the developers such as the Unity Editor which is a built-in menu system that allows many tasks to be performed from a visual interface, script behaviour system which utilizes on JavaScript, C#, Boo and multi-platform release including mobile and consoles. Today Unity supports 21 platforms including Oculus Rift, PlayStation 4 and Linux [50]. Community support is a tremendous factor about the success of this game engine by allowing developers to present their tools for others to use. This permitted developers to save 1 Billion Dollars in 2015 [8]. Unity software is open source and free to download and use. A more detailed version of Unity can also be acquired through Unity Pro License which provides additional features for professional use [51]. The fact that is open source and the potential VR support of this engine is the main reason that we chose to build our software on it. The possibility of use various input devices, from the simple mouse to Haptic, Leap Motion, and plugins for HMDs are very beneficial to properly design a VR application with addition to 3D capabilities of the engine for building a virtual environment.

7.3 Interface Description

Since the graphical feature was not the main part of this project, a very basic virtual environment is proposed. The virtual ambient consist in a neutral background on where 6 objects are placed as can be seen in Fig. 7.3 . These objects are cubes placed in 2 rows and 3 columns. These represent the virtual object linked each to a different Revolver position and a different clove where the fragrances are housed. The cubes are of different colours and are prettified with different graphical rotational effects based on their position. These rotations are done by rotation functions associated to the objects.

The input device used for this application is the simple PC mouse, but the integration with other input peripheries is possible. The mouse choice permits the initial use this application in every PC available, since no drivers for others input peripheries are necessary to be installed. The very simple application is useful for different reasons:

- the praticity, and the fact that is intuitive allows its utilization even for users not keen on technology;
- the very simple architecture with which is done permits to understand immediately if the prototype is working or not and it is so a valid method to test the system functioning and if there are operating anomalies;
- the application made in this way can be easily implemented in almost every of the current PCs as it is not performance demanding.

7.4 Unity Functions

Unity supports the C# programming language natively, most the functions used on Unity in our case are C# scripts made in Microsoft Visual Studio, a multilingual

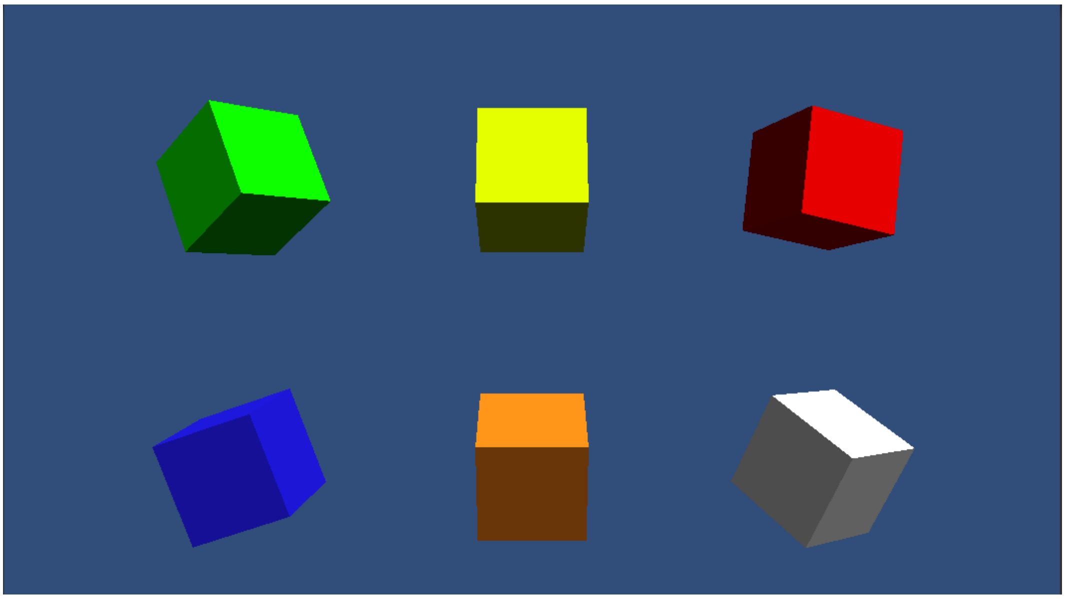

Figure 7.3: The application graphical User Interface

Integrated Development Environment (IDE), developed by Microsoft [57]. C# (pronounced C-sharp) is an industry-standard language like Java or C++ [49]. The functions in the applications are:

- the 3 different *Spinning* functions associated to items, they have only graphical impact. These functions make the cubes rotate in the 3D space. One drives the rotation around the X axis, one around the Y axis and the other one around the Z axis. Different combinations of them allow to have several solutions and graphical movements;

- the *Colour* functions, associated one different for each of the six cubes. This for differentiate the various objects and to allow a better association of the essences available. Moreover, in addiction to colours, the objects have shadows and different light reflections based on their inclinations. This enhances the depth sensation and the better identification of the objects in the 3D space;

- the different *Sending* functions associated one for each of the six cubes. They have the task to detect every time a cube is clicked by the mouse;

- the *Send to Arduino* function that is not associated singularly but collects the command of every Sending function and is in charge of tell the Arduino what choice has been made.

7.5 Unity Arduino Interaction

The Unity – Arduino interaction is the mechanism that allows the control of the Prototype using the Virtual Environment. In addition to the graphical function and colours that characterize each of the six virtual objects, a C# calling function is also associated to them. This function, as well as print on screen the confirmation, forwards the command containing the choice made, to the Sending function when the mouse is left clicked on the specific object. The Sending function contains different cases for the six objects. This function, after having identified and opened the Serial Port chosen at the proper Baud Rate, as it receives the command to send the colour, writes on the Serial Port the command. The Serial Port and the Baud Rate must be the same written on the Arduino code. In the Arduino code loaded on the board, if the Serial Port is available, it is pre-set that the command sent by the Sending function and read on the Serial Port, is recorded in a variable. Then a Switch command, based on what it is written in the variable, makes the different choose between the available case. At this point, Arduino turns on the Fan at its maximum speed and makes the Servo Motors rotate to the chosen angle value. In this way the Servo Motor, thanks to the transmission, drives the Revolver in the wanted angular position to make the essence smell. In Fig. 7.4the interaction procedure is illustrated.

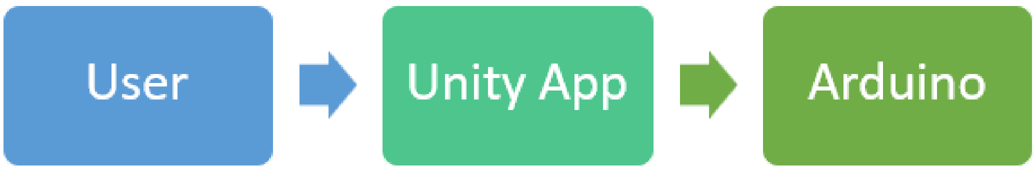

Figure 7.4: The scheme of interaction between the User and Arduino

7.6 Olfactory Display Application

In the following section are illustrated the mechanisms of the app generation and the way the users can utilize it.

7.6.1 Generation

Once the code part has been prepared, it has been generated a usable application. Unity allows the generation of an executable application *.exe* working on the PCs. Unity provides the tool to generate the app, adding all the needed parts and functions for its working (Fig. 7.5). The app generated is called *Olfactory Display App* and it is correlated with a folder containing the compulsory information for the correct and possible app use. The app and the folder must be in the same place, otherwise the app can not be executed.

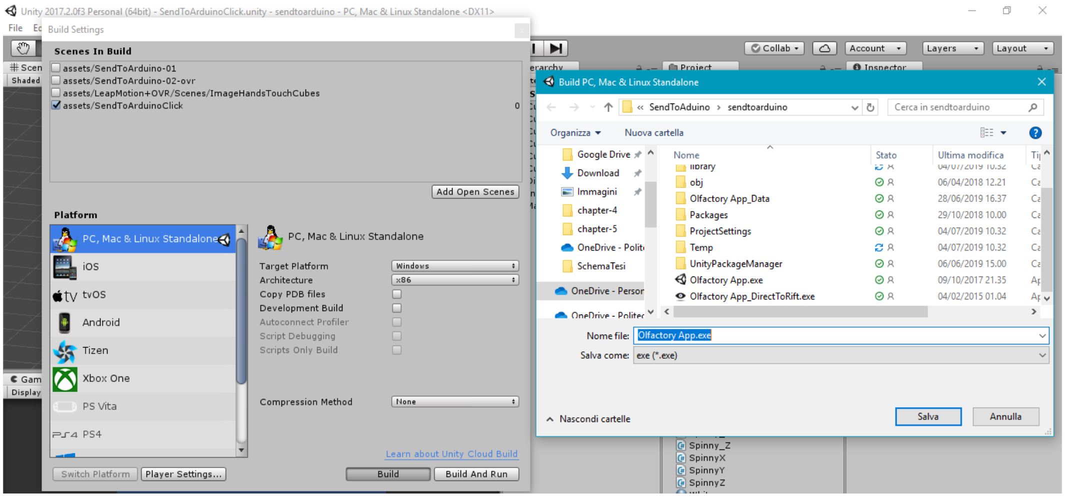

Figure 7.5: The passages to generate the executable application

7.6.2 App Utilisation

To utilise the app, the potential user has first to connect the Arduino to PC via the USB – USB Mini cable. Then he has to open the *.exe* file. The process is very simple, and no other activities are required. Instantaneously the user finds the working interface made up by the six rotating cubes. The application is ready to be utilised and when the user clicks a cube, the Revolver turns in the selected position. The six waffles predefined are collocated in the predisposed positions associated one for each cube, here listed:

- Green cube = cut grass;
- Yellow cube = pineapple;
- Red cube = rose;
- Blue cube = lemon;
- Orange cube = strawberry;
- White cube = smoke.

At the end of the usage, the user must click on the classic exit button on the right up corner and must detach the Arduino board from the PC. This very simple and minimal User Interface is addressed to reach different kind of people, even the ones not keen on technology. In fact, only few common notions of PCs and App Usage are required so that almost everyone from kids to elder people could work with this application. Another positive aspect of this choice is that the graphical computational effort required for the PC is very low because a neutral colourful background is used, no HD images are applied, and the movements of picture is reduced and confined in the same space. This can be tolerated by most of the working PCs. In Fig. 7.6 can be seen a person using the prototype in a home environment with a common personal computer.

Figure 7.6: An example of the utilization of the prototype in a home environment

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Chapter 8

Other Possible Design Solutions

During the design of this component various alternative solutions were hypothesized before coming to the final solution which is thought to be the best. In this section the other design hypothesis are reviewed and it is given an explanation for the different choices.

8.1 Transmission

Before coming to the Belt solution, the first idea was to use gears to transfer the motion from the motor to the Revolver. The bigger issue was that the Servo Motor could only rotate by 180° degrees while 300° were necessary. So, the angular speed of the driven wheel must be double on respect of the driving wheel one, so that in the meaning that the motor crankshaft does a 180° spin, the driven wheel could do a turn angle. The transmission ratio is defined as the ratio between the angular velocity of the driving speed divided by the angular velocity of the driven one as refers the equation below. In this case, as it is less then 1, the transmission is defined multiplying because the driven wheel spins faster than the driving one even if it has less driving torque.

$$\frac{z2}{z1} = \frac{d2}{d1} = \frac{r2}{r1} = \frac{w1}{w2} \tag{8.1}$$

To obtain the desired gear ratio, the diameter dimension of the driving wheel must be doubled on respect of the driven one. Here there could be 2 possible solutions, each with some drawbacks:

1. Directly set the teeth on the external part of the Revolver but its relative huge dimensions would have made too big the driving wheel, about 110[mm], that was not acceptable for a device like this; in fact the sum of the driving wheel diameter and the Revolver diameter would have been more than 160[mm] itself and it would be definetly too high. Other hypothesis as multiple wheels, dividing by 2 and multiplying by 4, so to obtain a duplication of angular rotation were thought, but the complexity of this said system, the precision needed and the stiffness required drove out from this solution.

2. Put the gear system under the Revolver with the driven wheel directly connected with it. But the two wheels in contact, even more if they have no holes, would have occlude the hole where the air passes preventing the scient diffusion. Moreover, the Motor position would have been fixed directly above the driving wheel with the problem that would be very close to the Revolver itself with the risk of contact. To increase the mutual distance would have been necessary to increase the gear dimensions with increasing the global dimensions. So, the belt solution was preferred because it takes up less space and gives the possibility to place the motor in the wanted position.

It was thought to use also an elastic, but the friction was not enough and the mutual slip between the elastic and the pulley didn't grant the movement. Fig. 8.1 represents the pulley designed to house the elastic.

Figure 8.1: The pulley concept with the elastic

8.2 Case Shape

The initial case shape was a square, easier to manufacture and more regular. The insertion of the 30*30[mm] fan instead of the bigger one and the availability of empty space at the corners drove to this final solution that is also more beautiful to see. The space in the current design is optimized, so in the case of a future insertion of a Bluetooth module and of a removable battery, the case design will have to be changed. At the beginning it was thought a mono block solution with a flat cover, but this would have made the assembly much more complex and critical in case of parts substitution. So, a two parts case was preferred because it gives the possibility to better arrange the part in case of necessity.

8.3 Cover Shape

The cover was subjected to different changes during the design phase. From the first holed flat solution at the beginning, become an integral part of the case itself to contain the components. The final changes regard the air duct. In particular, after some tests, it was noticed that the holes over the flat surface made confusion with the different essences smelt housed in the Revolver. So, a different solution was applied: a single air duct that follows the Revolver clove housing the essences placed directly above it, instead of the pattern of holes placed also on essences we didn't want to smell at this moment. Two stripes were added to avoid the finger contact with the Revolver and two small ribs were also added in the internal part to convoy the air into the hole. The back slope above the Arduino space was removed and substituted by more regular flat shape, easier to be 3D printed that also increased the room available for the cables.

Fig. 8.2 illustrates the evolution of the case shape during the design phase from a more regular shape to the final solution adopted.

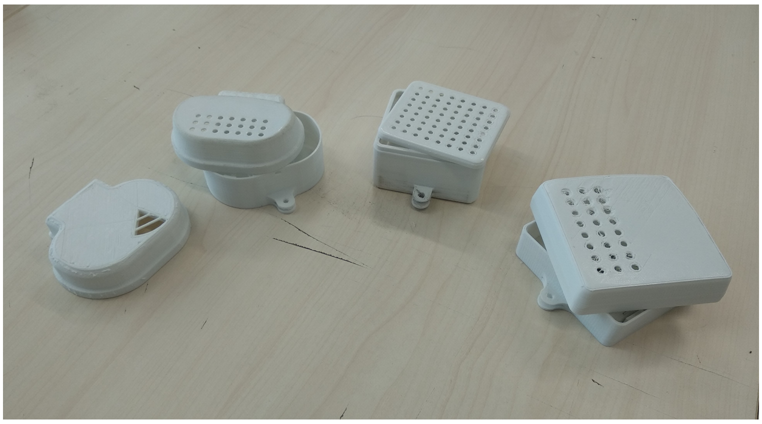

Figure 8.2: The evolution of the case shape from right to left

8.4 Ball Bearings Implementation

The Ball Bearings insertion was necessary under the Driving Wheel in the final design because the Motor crankshaft could not have sustained a radial load and would have blocked the system. Moreover, a ball bearing was also inserted between the Driven Pulley and the Revolver Plate because without it there would be too much friction between the Pulley and the plate and the perpendicularity between the Revolver and the Plate could not be granted.

8.5 Additional Belt Guard and Pulleys Design

An additional Belt Guard for the driving pulley mounting on its top was thought. This would have prevented the belt to go out from its track and it would also have blocked the motor crankshaft in it. In the final concept, instead of this extra Belt Guard, a design issue consisting in a thick border was added to the top and the bottom layer of the pulley to make the belt impossible to go out from its track (Fig. 8.3). Moreover, the star shape termination fitting into the top layer was enough to keep the crankshaft in position without going out.

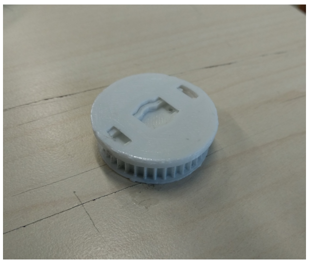

Figure 8.3: The Belt Guard solution, later abandoned in favour of the star shape design

8.6 Revolver Plate

Also, the Revolver Plate design has undergone changes because the edge surrounding the hole was extended for all the Bearing thickness to convey as much as possible the air into the revolver and to minimize the load losses. The evolution of the Revolver Plate is illustrated in Fig. 8.4.

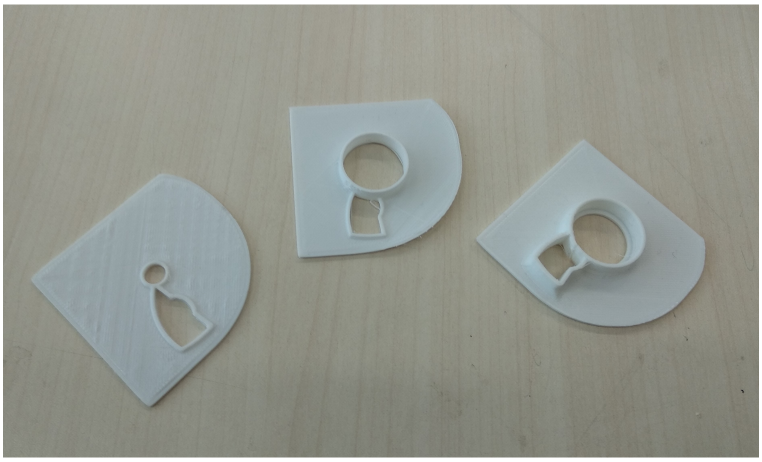

Figure 8.4: The evolution of the Revolver Plate shape from left to right

Chapter 9

SUS Protocol - the System Usability Scale

The System Usability Scale (SUS) is a simple, ten-item scale giving a global view of subjective assessments of usability. SUS is a Likert scale. It is often assumed that a Likert scale is simply one based on forced-choice questions, where a statement is made, and the respondent then indicates the degree of agreement or disagreement with the statement on a 5 (or 7) point scale. However, the construction of a Likert scale is somewhat subtler than this. Whilst Likert scales are presented in this form, the statements with which the respondent indicates agreement and disagreement must be selected carefully. The technique used for selecting items for a Likert scale is to identify examples of things which lead to extreme expressions of the attitude being captured. For instance, if one was interested in attitudes to crimes and misdemeanours, one might use serial murder and parking offences as examples of the extreme ends of the spectrum. When these examples have been selected, then a sample of respondents is asked to give ratings to these examples across a wide pool of potential questionnaire items. For instance, respondents might be asked to respond to statements such as "hanging's too good for them", or "I can imagine myself doing something like this". Given a large pool of such statements, there will generally be some where there is a lot of agreement between respondents. In addition, some of these will be ones where the statements provoke extreme statements of agreement or disagreement among all respondents. It is these latter statements which one tries to identify for inclusion in a Likert scale, since, we would hope that, if we have selected suitable examples, there would be general agreement of extreme attitudes to them. Items where there is ambiguity are not good discriminators of attitudes. For instance, while one hopes that there would be a general, extreme disagreement that “hanging’s too good” for those who perpetrate parking offences, there may well be less agreement about applying this statement to serial killers, since opinions differ widely about the ethics and efficacy of capital punishment. The items leading to the most extreme responses from the original pool were then selected. There were very close intercorrelations between all the selected items ($\pm$ 0.7 to $\pm$ 0.9). In addition, items were selected so that the common response to half of them was strong agreement, and to the other half, strong disagreement. This was done to prevent response biases caused by respondents not having to think about each statement; by alternating positive and negative items, the respondent must read each statement and make an effort to think whether they agree or disagree with it. The System Usability Scale is shown next (Fig. 9.1). It can be seen that the selected statements actually cover a variety of aspects of system usability, such as the need for support, training, and complexity, and thus have a high level of face validity for measuring usability of a system.

9.1 Using SUS

The SU scale is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time. All items should be checked. If a respondent feels that they cannot respond to a particular item, they should mark the centre point of the scale.

9.2 Scoring SUS

SUS yields a single number representing a composite measure of the overall usability of the system being studied. Note that scores for individual items are not meaningful on their own. To calculate the SUS score, first sum the score contributions from each item. Each item’s score contribution will range from 0 to 4. For items 1, 3, 5, 7 and 9 the score contribution is the scale position minus 1. For items 2, 4, 6, 8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU. SUS scores have a range of 0 to 100.

9.3 Conclusions

SUS has proved to be a valuable evaluation tool, being robust and reliable. SUS has been made freely available for use in usability assessment and has been used for a variety of research projects and industrial evaluations; the only prerequisite for its use is that any published report should acknowledge the source of the measure.

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently					
2. I found the system unnecessarily complex					
3. I thought the system was easy to use					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated					
6. I thought there was too much inconsistency in this system					
7. I would imagine that most people would learn to use this system very quickly					
8. I found the system very cumbersome to use					
9. I felt very confident using the system					
10. I needed to learn a lot of things before I could get going with this system					

Figure 9.1: The System Usability Scale test the user have been submitted

9.4 Acknowledgements

SUS was developed as part of the usability engineering programme in integrated office systems development at Digital Equipment Co Ltd., Reading, United Kingdom.

9.5 References

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9.6 Results Analysis and Comments

Several SUS protocol tests were made, with an average score of about 70 points (Fig. 9.2). The people who underwent the test didn't suffer any disease so for them it didn't have a therapeutic purpose. Most of them said that for the first time an operator was necessary. Not too much instructions were necessary to be given but the presence of an operator was better even to restore the system in case of problems. The application was found very easy to be used with a very basic functioning and everyone could do it. A lot of patients said that, having no need for it for therapeutic use, would not often use it, but anyway they found pleasure to smell the essences giving them a relaxing effect. The most important issue still to be overcome is the problem of the weakness of the fan not spreading the airflow too much. Moreover, even if they could distinguish the changing in fragrances, the smells incorporated in the waffles didn't represent very much the real scent and biggest improvement could be done in that way.

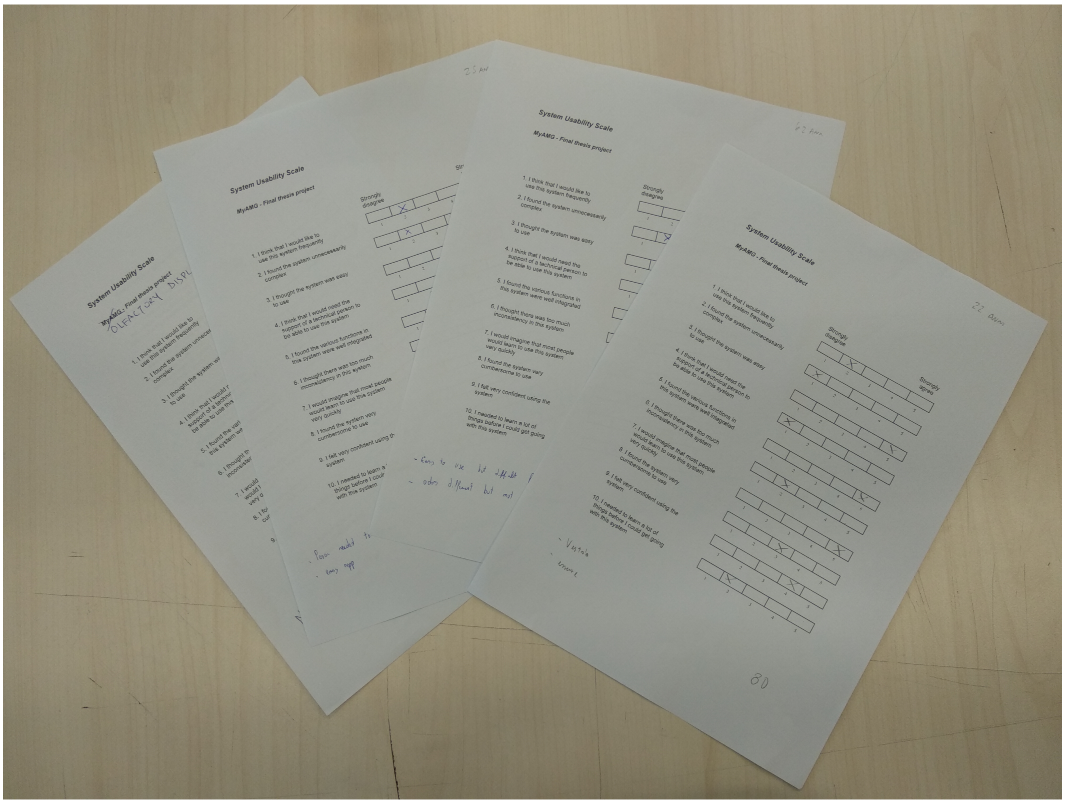

Figure 9.2: The SUS test answersheets with the results

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Chapter 10

Future Improvements

Some future improvements could be done to make the prototype better. These improvements could impact both on the software section and both on the physical object. A first important change could be the Fan. In fact, the Fan powered by the Arduino is not as powerful as it should be for a right usage. A bigger or more powerful one will grant a major air flow to deliver the essences. Other alternatives as to power the Fan not by the Arduino or to insert a mofset could be evaluated. Another big improvement could be the implementation of a Bluetooth Module and a rechargeable Battery so to allow the usage of this Prototype without being connected to a PC. These modifications unfortunately would increase a lot the global dimensions and weight. In our stage, for the simplicity of the product and the related software part, were not taken into consideration. In fact, the Prototype presented is thought to be used near a PC and without walking around, so having a cable is not a great problem. Since the components once positioned are fixed, a method to move and tend the belt could be implemented because in the actual conditions, the belt length must be decided before mounting the components. The biggest improvements can be done on what concerns the software part. This application is very simple, and it is run on a desktop PC. The same application could be implemented into more complex VR system as Head Mounted Displays or on augmented reality devices. This would greatly increase the sense of presence and immersion in this contest. Even the application, in this project, still very simple and intuitive, can be improved for example by replacing the six rotating cubes with the object representing the essences being smelt in the moment. Other efforts could be done on the improvement of the essences taste, housed in the Waffles or in the liquid form. This is a topic not strictly connected to the prototype design but improvements in the chemical production and composition of this objects would increase a lot the likelihood of the odours smelt.

Chapter 11

Conclusions

As described in previous chapters, I have developed an Olfactory Display prototype correlated with a software environment part. Thanks to a fan, the device proposed can diffuse scents housed in waffles in the air for therapeutic purposes.

In addition, the system also is linked to a software part that permits the interaction with the user and the control of the prototype.

In Chapter 2 the key concepts of Virtual Reality were introduced. In particular the focus was concentrated on the applications in the medical fields. In particular first on the training possibilities and then on the possible uses of Virtual Reality in Rehabilitation, Psychotherapy, and Surgery, to conclude with possible future improvements.

Then in Chapter 3 the attention was focused on the sensory aspects of sight and hearing, the the two human senses involved in the functioning of the deviced produced. After having highlighted the aspect regarding the eye and the olfactory and gustatory aspects, the technologies are listed. The main suddivision is based on stationary and portable device and a description of positive and negative aspects is done. The potential applications of the said devices is illustrated.

In the following Chapter 4 the prototype design is illustrated, from the key concepts that drove the design to a complete description in all of the single parts, including the design choices made.

In Chapter 5 the 3D printing process is illustrated and are listed the parameters and the different choices based on every piece. In the successive Chapter 6 the assembly sequence procedure is illustrated.

The visual virtual interface aspects are illustrated in Chapter 7 at first looking at the requirements and the wanted characteristics and then by considering the app development and creation.

Possible alternatives design are analized in Chapter 8 by looking at the different choices made and thinking if there could be possible alternative solutions.

Chapter 9 contains the survey and represents the practical part did during the thesis work.

Possible future works and improvement are show in Chapter 10 and represent the starting point for the next steps to be done on this project.

The prototype made resulted at the end lightweight, easy to be done and cheap. Its use is mainly addressed to people in need of this device and the fields of actions are mainly in the medical field, but it could be used by almost everyone. This devices have a great potential and represent the future of the Virtual Reality. Anyway, there are problems in this device that are difficult to be overcome as in the other similar produced and representing the state of the art.

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Appendix A

Drawings

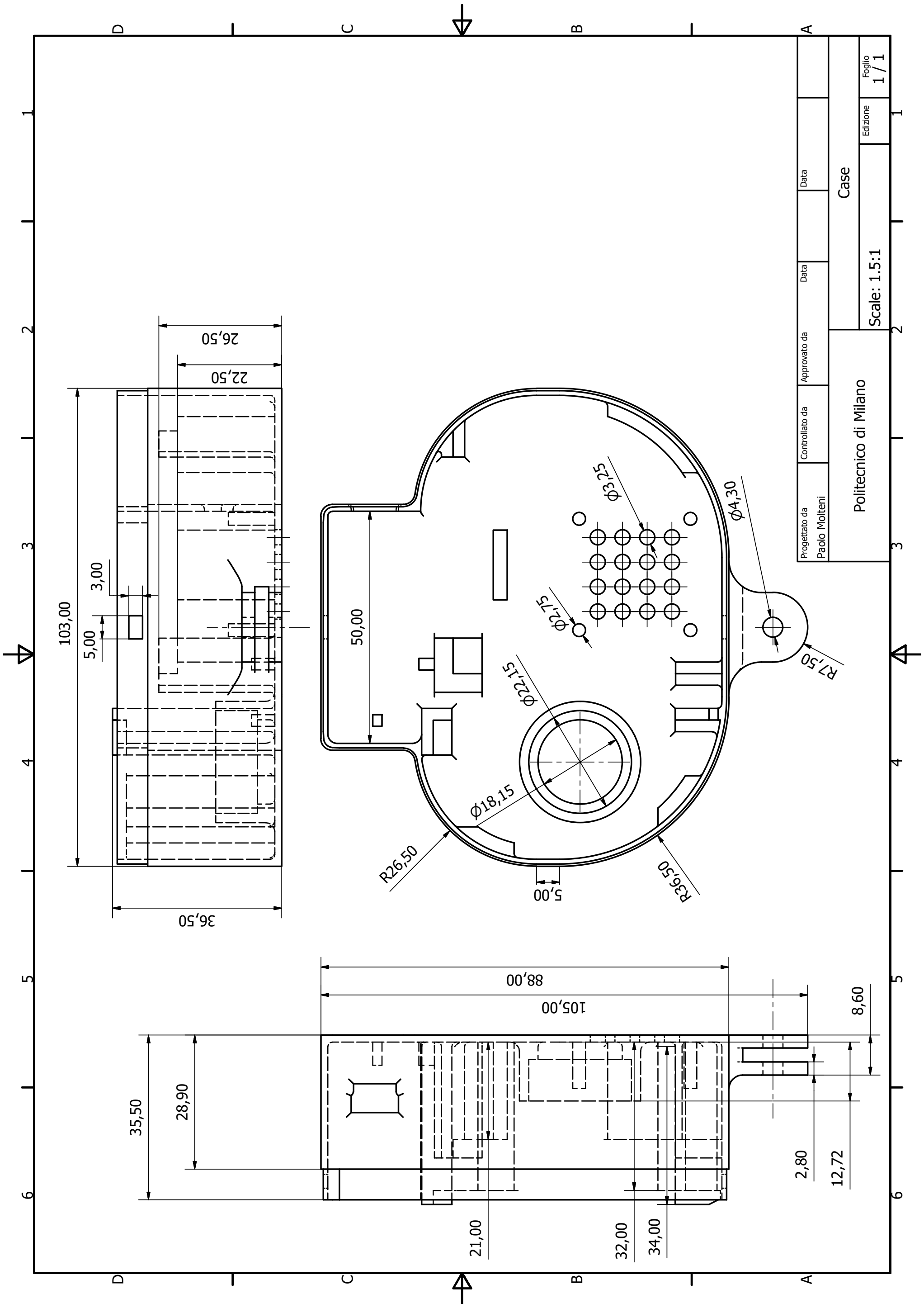


Figure A.1: Case

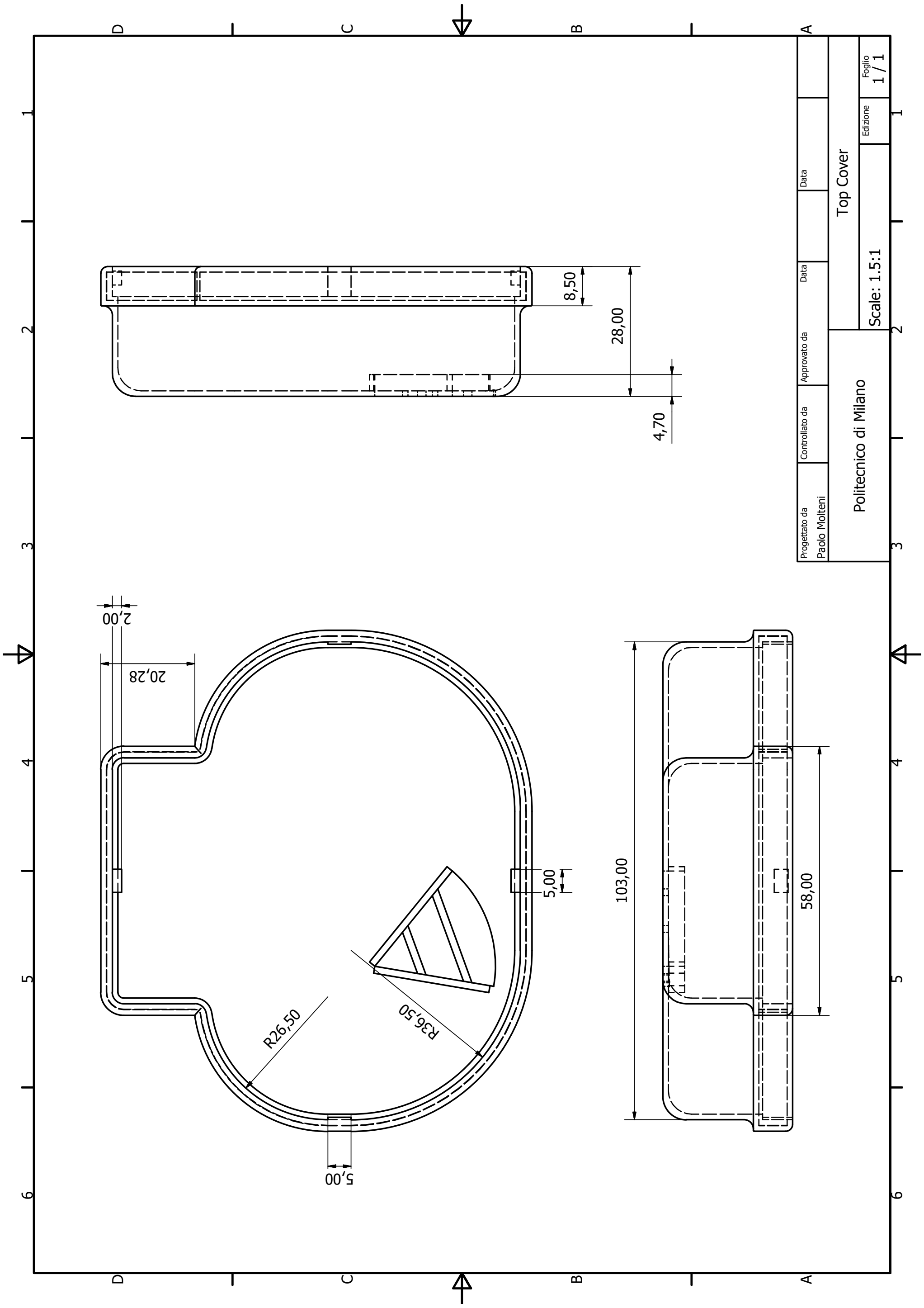


Figure A.2: Top Cover

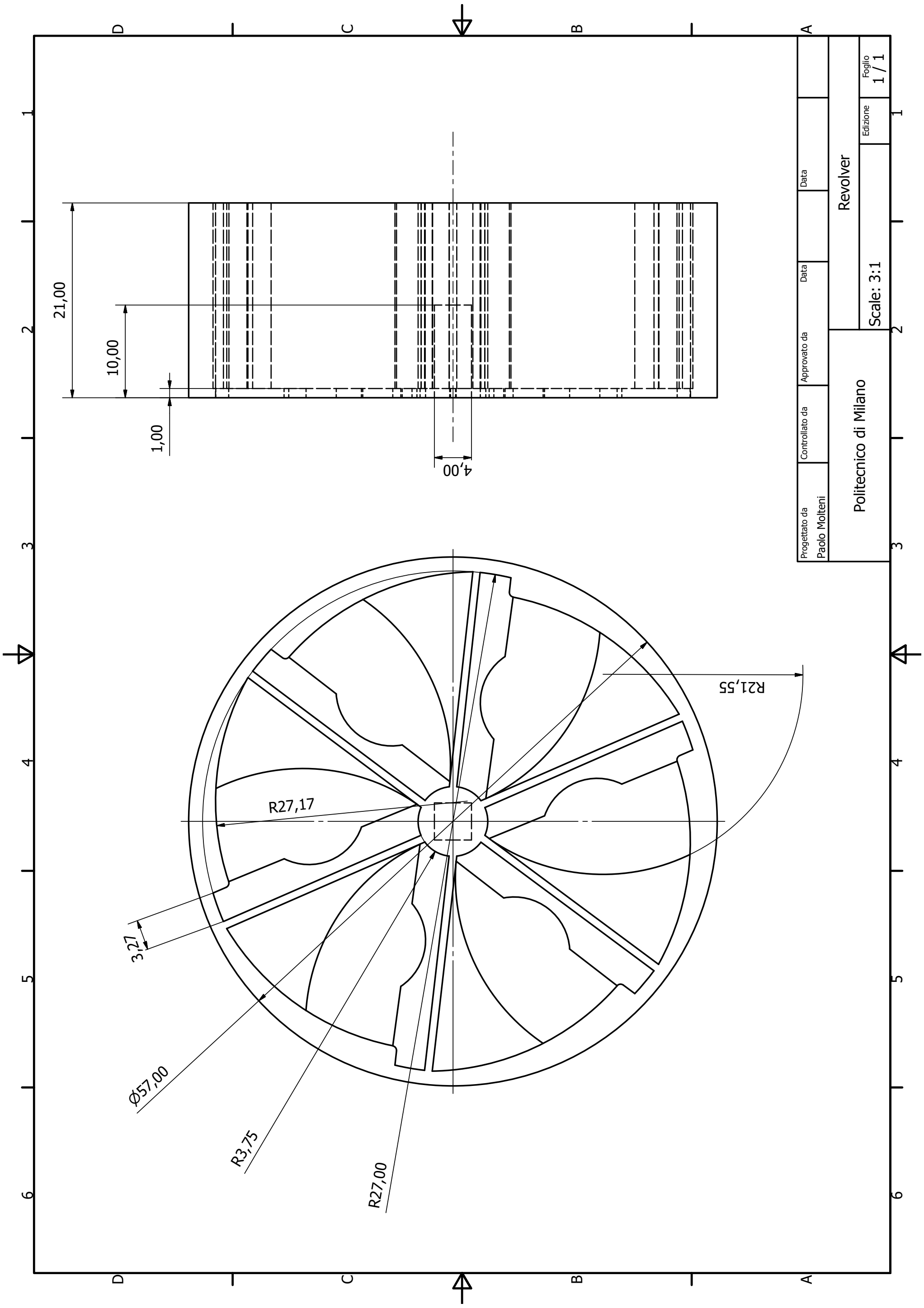


Figure A.3: Revolver

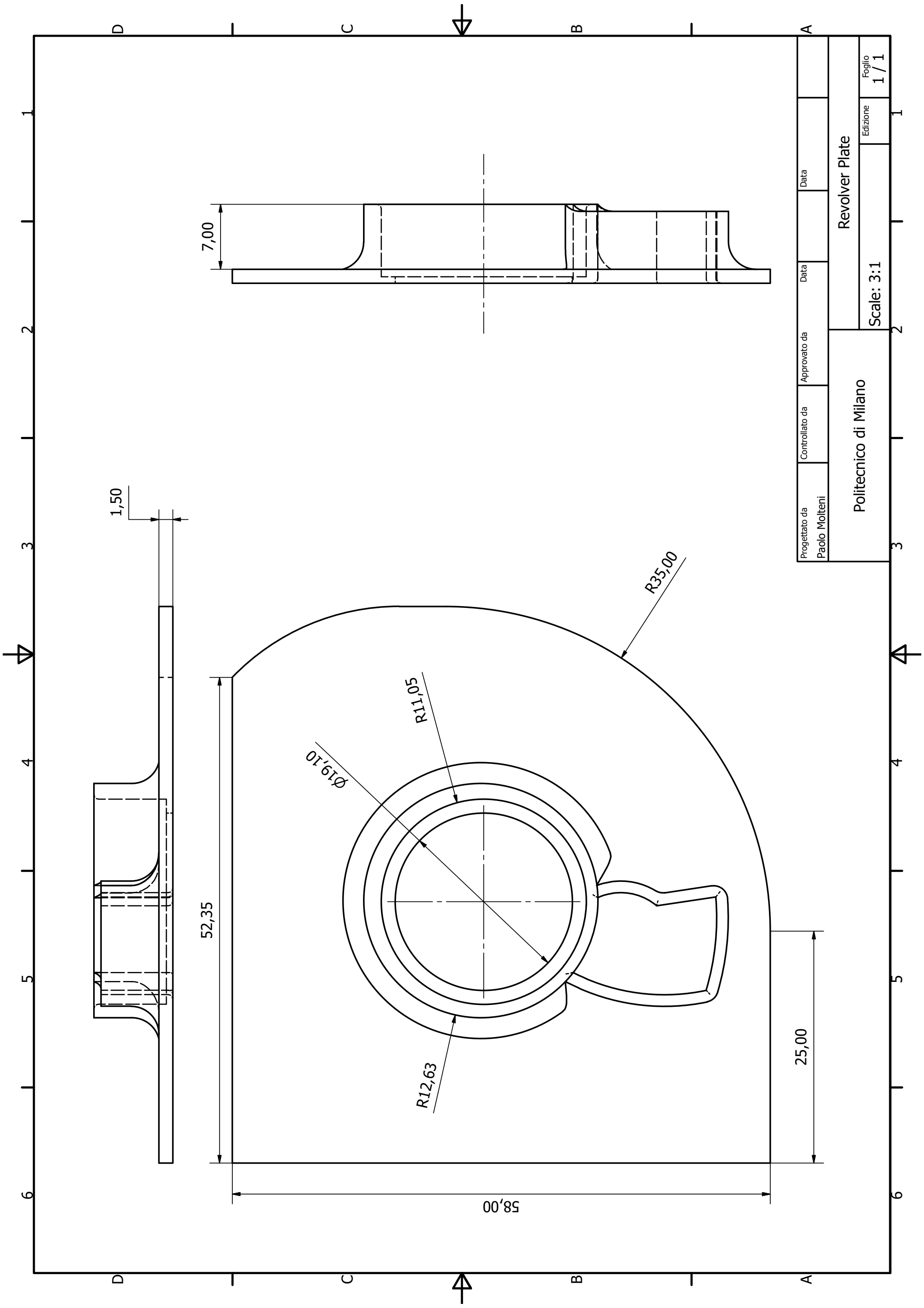


Figure A.4: Revolver Plate

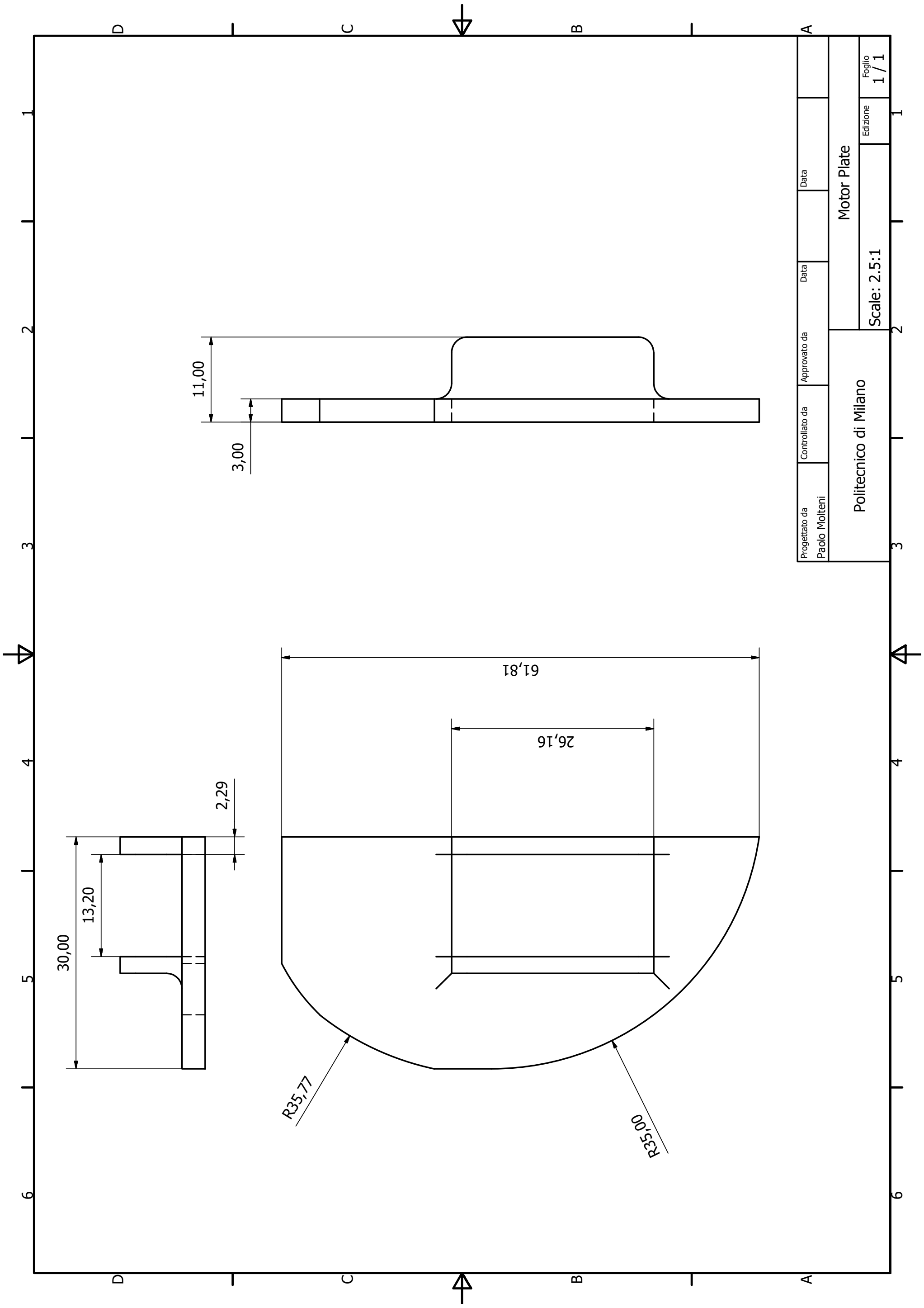


Figure A.5: Motor Plate

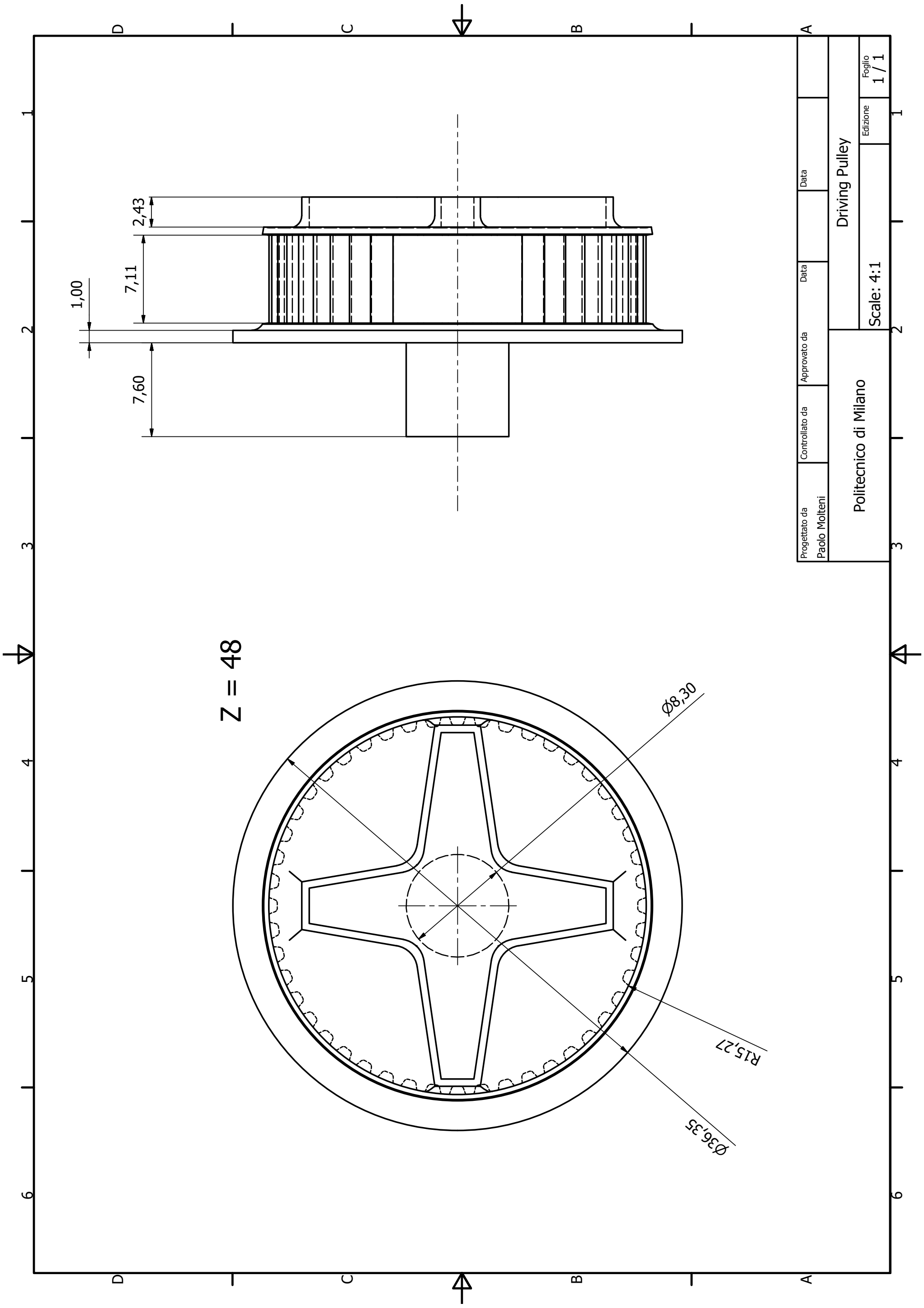


Figure A.6: Driving Pulley

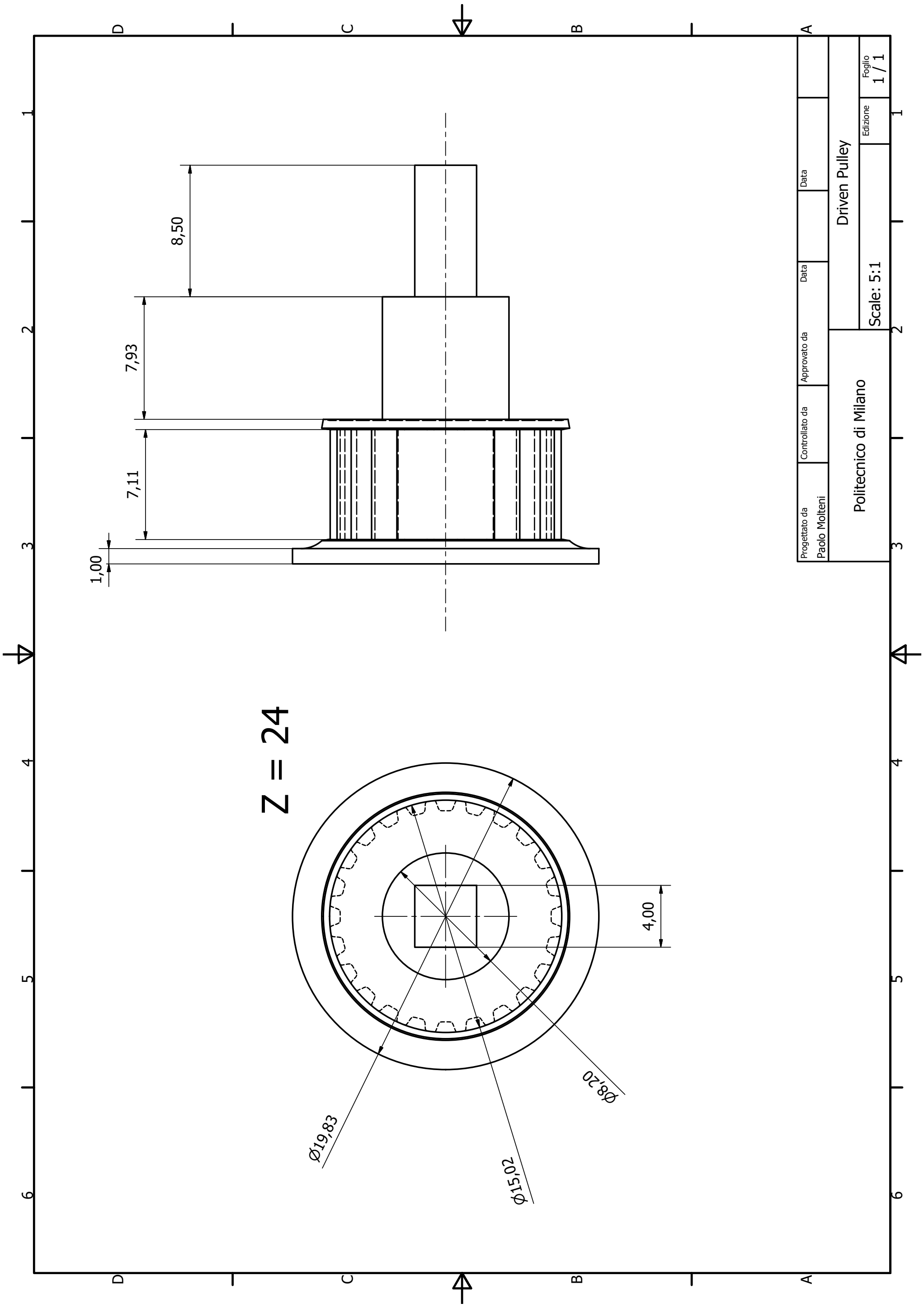
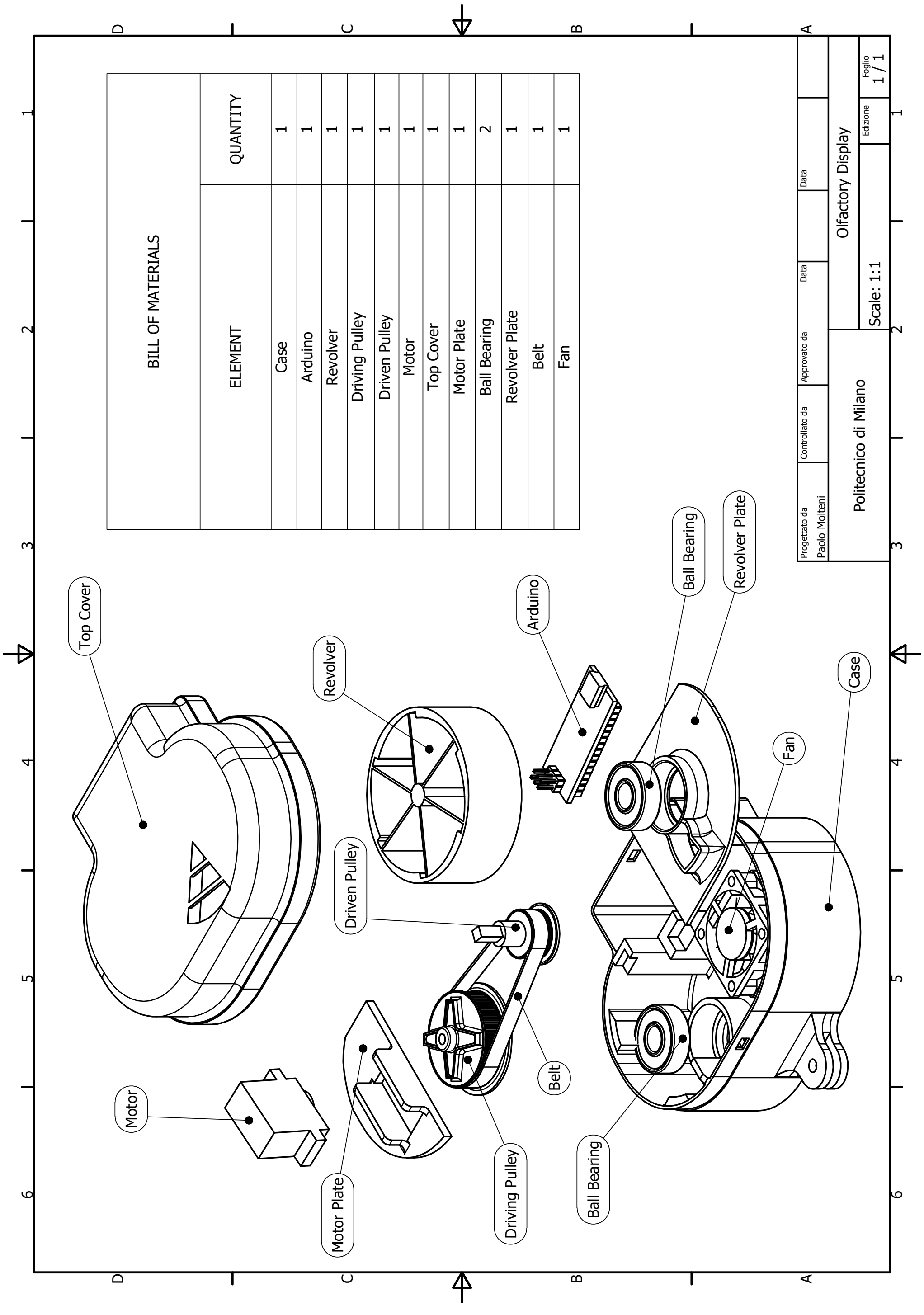


Figure A.7: Driven Pulley



ELEMENT	QUANTITY
Case	1
Arduino	1
Revolver	1
Driving Pulley	1
Driven Pulley	1
Motor	1
Top Cover	1
Motor Plate	1
Ball Bearing	2
Revolver Plate	1
Belt	1
Fan	1

Figure A.8: The Olfactory Display

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Appendix B

Arduino Code

```
#include <Servo.h> //Inserire la libreria Servo
Servo Servo1; //Il nome del servo è Servo1
//collegamenti: - Rosso = 5V
//              - Nero = GND
//              - Giallo = PIN 9

#define fanpin 11 //La ventola è collegata al PIN 11
//collegamenti: - Rosso = PIN 11
//              - Nero = GND
int fanspeed;


void setup() {
  Servo1.attach (9); //Il Servo1 è collegato al pin digitale
//Serial.begin(19200); // apro la seriale
  Serial.begin(9600);
  delay(1000); //attendo che l'utente faccia altrettanto
  Serial.println(F("Pronto")); //sono pronto

  pinMode(fanpin, OUTPUT);
}

void loop() {



//controllo se c'è qualcosa in arrivo sulla seriale
   if (Serial.available()) {
   byte command = Serial.read(); //leggo il primo byte
   switch (command) { //controllo che sia un comando valido


  case 'n':
         //invio la lettura dell'ingresso
         fanspeed = 0;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: NULL"));
         Servo1.write (15);
  break;

  case 'g':
         //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: GREEN"));
         Servo1.write (10);
  break;
```

```
        //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: YELLOW"));
         Servo1.write (42);
  break;

  case 'r':
        //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: RED"));
         Servo1.write (77);
  break;

  case 'b':
        //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: BLUE"));
         Servo1.write (108);
  break;

  case 'o':
        //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: ORANGE"));
         Servo1.write (139);
  break;

  case 'w':
        //invio la lettura dell'ingresso
         fanspeed = 255;
        analogWrite(fanpin, fanspeed);
        Serial.println(F("Lettura ingresso: WHITE"));
         Servo1.write (172);
  break;

   }
   }
}
```

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Appendix C

Unity Codes

...-arduino\SendToAduino\sendtoarduino\assets\CallGreen.cs 1

```
using UnityEngine;
using System.Collections;

public class CallGreen : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {

    }

     void OnMouseDown() {
        print("Clicked Green - Mouse Down");
        Sending.sendGreen();
     }



}
```

...arduino\SendToAduino\sendtoarduino\assets\CallYellow.cs

```
using UnityEngine;
using System.Collections;

public class CallYellow : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {

    }

    void OnMouseDown() {
        print("Clicked Yellow - Mouse Down");
        Sending.sendYellow();
     }


}
```

...ty-arduino\SendToAduino\sendtoarduino\assets\CallRed.cs 1

```
using UnityEngine;
using System.Collections;

public class CallRed : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {

    }

    void OnMouseDown() {
        print("Clicked Red - Mouse Down");
        Sending.sendRed();
     }


}

```

...y-arduino\SendToAduino\sendtoarduino\assets\CallBlue.cs

```
using UnityEngine;
using System.Collections;

public class CallBlue : MonoBehaviour
{

    // Use this for initialization
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {

    }

    void OnMouseDown()
    {
        print("Clicked Blue - Mouse Down");
        Sending.sendBlue();
    }



}

```

...arduino\SendToAduino\sendtoarduino\assets\CallOrange.cs 1

```
using UnityEngine;
using System.Collections;

public class CallOrange : MonoBehaviour
{

    // Use this for initialization
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {

    }

    void OnMouseDown()
    {
        print("Clicked Orange - Mouse Down");
        Sending.sendOrange();
    }



}
```

...-arduino\SendToAduino\sendtoarduino\assets\CallWhite.cs

```
using UnityEngine;
using System.Collections;

public class CallWhite : MonoBehaviour
{

    // Use this for initialization
    void Start()
    {

    }

    // Update is called once per frame
    void Update()
    {

    }

    void OnMouseDown()
    {
        print("Clicked White - Mouse Down");
        Sending.sendWhite();
    }


}

```

...ty-arduino\SendToAduino\sendtoarduino\assets\SpinnyZ.cs 1

```
using UnityEngine;
using System.Collections;

public class SpinnyX : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {
        transform.Rotate(90*Time.deltaTime,0,0);
    }
}

```

...ty-arduino\SendToAduino\sendtoarduino\assets\SpinnyX.cs

```
using UnityEngine;
using System.Collections;

public class SpinnyY : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {
    transform.Rotate(0,90*Time.deltaTime,0);
    }
}
```

...ty-arduino\SendToAduino\sendtoarduino\assets\SpinnyY.cs 1

```
using UnityEngine;
using System.Collections;

public class SpinnyZ : MonoBehaviour {

    // Use this for initialization
    void Start () {

    }

    // Update is called once per frame
    void Update () {
        transform.Rotate(0,0,90*Time.deltaTime);
    }
}
```

...ty-arduino\SendToAduino\sendtoarduino\assets\Sending.cs

```
using UnityEngine;
using System.Collections;
using System.IO.Ports;
using System.Threading;

public class Sending : MonoBehaviour {

    //public static SerialPort sp = new SerialPort("COM14", 9600, Parity.None, 8, StopBits.One);
    public static SerialPort sp = new SerialPort("COM8", 9600);
    public string message2;
    float timePassed = 0.0f;
    // Use this for initialization
    void Start () {
        OpenConnection();
    }

    // Update is called once per frame


    public void OpenConnection()
    {
        if (sp != null)
        {
            if (sp.IsOpen)
            {
                sp.Close();
                print("Closing port, because it was already open!");
            }
            else
            {
                sp.Open();  // opens the connection
                sp.ReadTimeout = 16;  // sets the timeout value before reporting error
                print("Port Opened!");
                //      message = "Port Opened!";
            }
        }
        else
        {
            if (sp.IsOpen)
            {
                print("Port is already open");
            }
            else
            {
                print("Port == null");
            }
        }
    }

    void OnApplicationQuit()
    {
       sp.Close();
    }

```

...ty-arduino\SendToAduino\sendtoarduino\assets\Sending.cs 2

```
    public static void sendYellow(){
        sp.Write("y");
    }

    public static void sendGreen(){
        sp.Write("g");
        //sp.Write("\n");
    }

    public static void sendRed(){
        sp.Write("r");
    }

    public static void sendBlue()
    {
        sp.Write("b");
    }

    public static void sendOrange()
    {
        sp.Write("o");
    }

    public static void sendWhite()
    {
        sp.Write("w");
    }

}
```