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Computer-Aided Design and Applications

Simulating a Virtual Journey on Italian Alps through a Multisensory Mixed Reality Environment

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ABSTRACT

Virtual, Augmented and Mixed Reality technologies are more and more getting attention from tourism researchers and professionals, because of their recognized potential to support marketing activities. The paper describes the development of a multisensory environment thought for a travel agency, which combines visual, auditory, tactile and olfactory stimuli. The idea is to develop an experience able to provide a virtual preview of the desired holiday destination, resulting in both an attractive experience for the customer and an effective way to increase sales. A case study about the multisensory experience of a walk on Italian Alps has been developed. The multisensory experience is based on a video streaming, recorded in the real environment, synchronously matched with a haptic interface. The haptic interface is made up of a pair of slippers provided with actuators, and also an actuator positioned on the customer trunk, used to reproduce the feeling of a snowball hit. Moreover, an olfactory display is also used to provide pine smell during the walk. During the experience, the user is sitting on a yoga ball, whose inclination allows him/her to start and stop the multisensory virtual experience.

Keywords: Virtual Prototyping, Multisensory simulation, User experience, Virtual Tourism
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1 INTRODUCTION

This research proposes a multisensory Virtual Reality (VR) application to be used in the tourism sector, which uses visual, audio, tactile and olfactory stimuli, in order to provide the user with the possibility to experience and enjoy a walk on Italian Alps. The simulation environment is specifically designed for being used in travel agencies: here the customers might have the possibility of virtually experiencing different holiday destinations before booking one of them.

VR already offers tourism a number of useful applications that deserve a considerable attention from tourism researchers and professionals [7]. Planning and management, marketing, entertainment, education, accessibility, and heritage preservation are six areas of tourism in which VR may be particularly valuable [7].

Creating a realistic full virtual simulation might be time-consuming. Thus, in this research, we used a different approach compared to traditional VR. We captured real movies and integrated them into an interactive Mixed Reality (MR) simulation.

The overall multisensory experience is based on a video streaming, recorded in the real environment, synchronized with a tactile interface. The haptic interface is made up of a pair of slippers provided with actuators, and an actuator applied on the user body, which reproduces a snowball hit. Moreover, a fan combined with a scent delivery system is used as an olfactory display and provides pine smell. Furthermore, the user sits on a yoga ball, whose inclination allows him/her to start and stop the multisensory experience. Finally, the simulation includes sounds.

The goal of this research is thus the use of the senses of smell and touch, combined with vision and hearing, to improve the user experience of VR applications that are used to support the sale of journeys in travel agencies (as suggested in [5]). The result is an experience able to provide a virtual preview of the desired holiday destination, which is attractive for the customer but especially useful in increasing sales for the tourism provider.

2 RELATED WORKS

Several Virtual and Augmented Reality application for the tourism sector have been already developed and are described in the literature [7].

An example is the "Sala degli Abissi VR" at the Acquario di Genova (Italy). The application provides the user with an immersive experience into the deep abysses by means of a Head Mounted Display (HMD) [6]. Similarly, the Everest VR application [13] allows users to virtually undertake the climb through the Khumbu Icefalls, Lhotse Face, Hillary Step, and eventually, the final stretch to the top of the world's highest peak. The Digital Domain Company [10] has developed several VR applications for the tourism sector, concerning several countries (Iceland, Hawaii, Italy etc.) and sports experiences. Among them, the Teleport Tahiti is an experience that allows the user to fly over the mountains, waters, coral reefs, beaches, and jungles of this Polynesian island, and then immerses him/her in a diving expedition. In the Grand Canyon VR Experience [12] the user is placed on a motorized kayak or stand-up paddleboard and can explore in either 'day' or 'night' mode rock formations, cliffs, waterfalls, and animal life. Finally, the Google Earth VR [14] is the improved version of the Google Earth application, which allows the user exploring destinations to plan a trip, or just appreciate places from a brand-new view.

Virtual tours are also becoming popular for marketing purpose. For this reason, in the last years, the number of advertising agencies specialized in virtual tour creation has grown. For instance, "PearlEye HD Virtual Tour" company realized for the winery "Zaccagnini" a 360° virtual interactive tour that could also be visualized by means of a Google Cardboard [18]. However, all these applications are affected by a lack of haptic and olfactory stimuli, which can be found in other areas, such video games or the medical one [7].

Tactile stimuli are generally provided through the hands, but several research have been also conducted on developing tactile devices also for other area of the human body. As an example, concerning tactile sensations related to feet, some studies were done in haptic communication via floor surfaces [22]. In literature, there are various applications, like a floor tile able to provide the pedestrian with the illusion of walking on different materials, through vibrotactile signals delivered to the feet [21]. Another example is a floor-space design that provides the user with the impression of walking on various terrains by synchronously rendering graphical, audio and haptic stimuli [17]. One of the problems in simulating locomotion in VR is the device which captures human movements and returns a realistic bodily walking experience. Some devices have been developed for entertainment field, especially in video game applications or simulators, like treadmills [23] or motion chairs [24]. Most of these devices allow the user to move into the VR environment, but not to receive any haptic feedback at his/her feet. In fact, vibrotactile devices able to provide stimuli to the soles of the feet have been little explored to date [22]. Until now one of the few commercial devices able to match these two requirements is the "Taclim" by Cerevo, a set of shoes and gloves for VR with built-in tactile devices that give haptic feedback to the users and generate the sense of stepping on the ground in virtual spaces [9]. A similar shoe-shaped interface was used to induce a specific walking cycle, useful for walking navigation system [25].

Concerning olfactory simulation in VR, despite its importance and potential benefits, it is often neglected when creating immersive experiences, mostly due to the fact that olfactory displays are not readily available [8]. In fact, there are few olfactory displays already available on the market, and they all mainly work exploiting the airflow generated through a fan, able to diffuse the odorant contained in small cartridge, like the "Olorama" by Olorama Technology [15] or the "Vortex Activ" by Dale Air [11]. In literature, similar devices are used to add smell to an advertising movie [19], and there are also other solutions based on a micro-porous piezoelectric film combined with a displayed video on a PC with auditory and 3D visual effects [1]. The authors have explored the use of olfactory displays in a multisensory VR environment for products evaluation [2], for improving the drivers' attention level [3], for heritage studies [20] and for improving the reading experience [4].

3 METHOD

The idea of the scenario relies on two factors: the "sense of embodiment" [25] and sense of presence, both related to the virtual experience. A video and the audio, recorded in the real scenario, are presented to the user and the same tactile and olfactory sensations perceived during the recording phase, by the operator, are synchronously reproduced by using a tactile and an olfactory display. In order to make the overall experience interactive and not a simple passive video/audio streaming enhanced by other sensory stimuli, the user has the possibility to control (activate and stop) the simulation with his/her own movement.

Because the application has been designed for the promotion and selling of travel solutions in the tourism sector, in order to prove the effectiveness of the solution a case study has been selected, and in particular, we decided to focus on mountain tourism related to nature exploration. We selected the Italian Alps environment and, specifically, the little town of Foppolo, which is a known skiing destination. In order to develop the application, the following main activities have been performed:

- video and audio recording, data acquisition, analysis;
- design and development of the tactile and olfactory interfaces;
- integration of the interfaces with the video/audio environment.

3.1 Video recording, data acquisition and analysis

To create the walking experience, we recorded a video of a walk in the snow along a mountain path surrounded by nature and, at the same time, collected data related to tactile sensations perceived at the feet level by the user while walking. Furthermore, we integrated into the experience the smell of pines that are typical of the selected location. Finally, in order to improve the "journey experience" we decided to include an event which was unexpected by the user, i.e. the tactile feedback of a snowball hitting his/her body.

For the video creation, we selected an area close to a creek and characterized by the presence of a small path coming out from a wood and completely covered with high fresh snow. From that site is possible to have an overview of the city.

As previously said, we designed the experience for a travel agency who wants to give to its customers the chance to have a virtual preview of a journey before booking it [7]. In this case, a simulator is effective if a customer can make better-informed decisions and have more realistic expectations compared to traditional media content used to present the travel solution, which at the end might lead to a more satisfactory vacation [5]. To this end, an "active experience", in which the user can freely move in a limited environment and obtain stimuli by sensory activation, has been considered not suitable for this application. That is because it could happen that he/she focuses his/her attention only on some aspects of the simulation, not considering all the attractions of the destination. Also, the user could feel as inside a playful application instead of a marketing one and use it as a video game, with the result of a potential loss of time and money for the travel agency. These are the reasons that brought us to design a "quasi-passive experience", namely an experience in which the user feels like being inside the body of who physically recorded the video and undergoes the sensations related to the actions shown in the video. This type of approach allows creating a guided tour of all the principal beauties of the location, in a short time and in an effective way.

To obtain an immersive and personal experience from the visual viewpoint, we recorded the video with a smartphone, an Asus Zenfone 3, positioned on the top of a helmet worn by the user during the recording.

Moreover, we used some tricks for improving the "sense of embodiment" of the user during the interactive experience [16]. Firstly, both men and women should be able to embody into the user, who physically lived the experience. To this aim, during the recording, the operator was asked to wear neutral clothes, namely boots, jeans, ski jacket and gloves. In this way, when the video starts with the observation of the hands and the feet, it is not possible to understand the gender of the operator who recorded the video. The embodiment effect is moreover strengthened by the integration of haptic and olfactory stimuli related to actions performed during the video.

We decided to organize the video in the following way:

1) at the beginning the user is still in front of the wood and looks down to see his/her hands and feet (to improve the sense of embodiment);

2) later on, the user turns around in the opposite direction, to observe the landscape and perceive the smell of pines coming from the front-left direction;

3) at this point, he/she starts walking;

4) at a certain point he/she is hit by a snowball on the right side of the chest and stops walking;

5) he/she starts walking again and, after a while, stops walking at the end of the path and turns his/her head to observe the landscape and the city.

During the video acquisition, we also synchronously acquired data useful to reconstruct the walking cycle, namely the temporal history of the steps and the feet position during motion. The walking cycle can be schematized in 3 parts:

- stance (60% of the total cycle), corresponding to the time period in which the foot is in contact with the ground;
- swing (30% of the total cycle), corresponding to the time period in which the foot is lifted from the ground;
- double support (10% of the total cycle), corresponding to the time period in which both feet are in contact with the ground.

We decided to use a 3-axis accelerometer and gyroscope to acquire data related to the position of one foot during the walking.

In order to be able to study the motion on a plane (assuming the oscillation in the z-direction as negligible), we placed the device on an ankle (the left one), and oriented it in the following way (see Figure 1):

- x-axis parallel to the line that connects the ankle with the knee;
- y-axis corresponding with the walking direction (perpendicular to the previous one);

- rotation around z-axis corresponding to the rotation of the ankle during the motion [27].

Regarding the tactile interface, most of the effort was the modelling of the tactile sensations perceived by the user during the walk. Considering that the person walking in the snow is wearing a pair of boots (thus the movement of the foot is constrained), the authors schematized the stresses on the feet as concentrated in 3 main areas (see Figure 1):

- under the heel (rear support area of the foot, A);
- under the forefoot (frontal support area of the foot, B);
- above the forefoot, just before the toes (where the boot bends during walking, C).

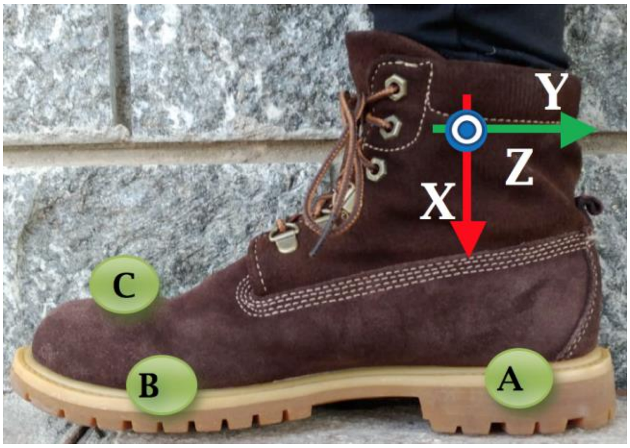

Figure 1: The green circles represent the 3 main areas in which the stresses are concentrated according to our assumption. The reference system refers to MPU-6050 IMU sensor orientation respect to the ankle.

Because in the simulated experience we reproduced the stresses in a simplified way by using an actuator in the centre of each area, we acquired data from the three different points of the foot. We used an MPU-6050 IMU sensor to acquire the walking cycle. Also, we acquired the data regarding the snowball hit placing the sensor under the jacket, at ribs level on the right side of the trunk and placing a layer of sponge between the accelerometer and the jacket to avoid damaging it with the hit of the snowball.

The data acquisition has been carried out by using a Micro SD storage interface, which allowed us to obtain a 10-bit acquisition and a sampling frequency of 20 Hz. This allowed us to obtain a good reconstruction of the signals since the walk was quite slow, and the acquisition can be considered as continuous.

The analysis of the collected data started with the reconstruction of the walking cycle by using the Matlab software (www.mathworks.com) for data elaboration. In a typical plot of a walk in normal conditions, namely on a stiff and planar surface, it is possible to observe some marked peaks of short duration. In our case, we took into account different boundary conditions such as the height of the person that physically walked in the snow, the snow level and its softness. Since the person who recorded the walk was 1.65 m tall and the snow was very soft, with about 30 cm of snow, the walk was deeply influenced, and the data concerning the y-axis were too noisy for being analyzed. For this reason, we decided to use the heel contact as the driving parameter for the identification of the different steps. Also, we based the analysis on the data from the accelerometer for the x-axis and on the data from the gyroscope for the z-axis. We plotted the walk on a graph. Considering the schematization of the walking cycle, each peak corresponds to the starting impact of the heel with the fresh snow, which is simultaneous the contact of the forefoot with the ground of the opposite foot (double support).

3.2 Design and development of the tactile and olfactory interfaces

Concerning the simulation of the tactile sensations, we used three actuators for each foot, and another one for the snowball hit simulation (seven in total). In the choice of the actuators we had to meet a set requirements, such as the possibility to integrate them in a pair of slippers, low-energy consumption (because of the presence of seven actuators on the same board) and the ability to start and stop in a short time.
We used Linear Resonating Actuators (LRAs) and a SparkFun Haptic Motor Driver DRV2605L to control the actuators easily. It is compatible with an Arduino Uno board. We used this driver for the four motors related to the ground contact zones of the feet, so the areas A and B, because they were the ones in which the vibrating pattern was more complicated to render.
In the other three cases, each motor was connected to a circuit made by a diode, a PN2222 transistor, a resistor of 1 kΩ and a ceramic capacitor of 0.1 μF.
Due to the fact that the LRA motor delivers cues in only one direction, we considered for each zone only the acceleration related to the vertical direction.
The program to drive the whole system was written by using the Arduino Software (IDE).

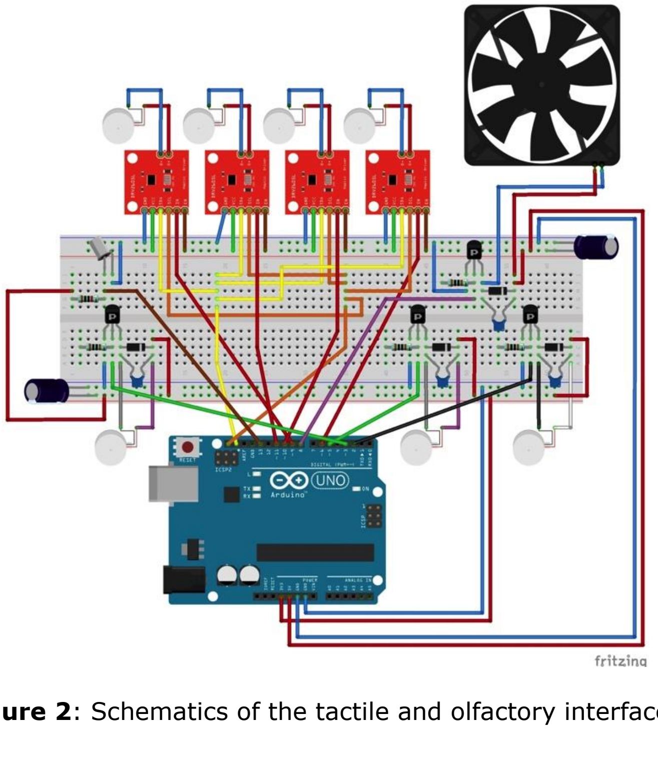

Figure 2: Schematics of the tactile and olfactory interfaces.

Concerning the olfactory simulation, we decided to simulate the pines scent carried by the breeze passing through the tree branches. Therefore, we used a 5 V fan, and we covered it with a piece of fine fabric soaked with a mix of drops of pine essential oil and water, achieving the desired effect [8]. Since the fan is a simple rotating motor, it was connected to Arduino board, without the Haptic Motor Drivers (Figure 2).

The DRV2650L with LRA actuators and the fan are fed with 5V. Instead, the other components are fed with 3.3V. A capacitor of 100 µF was added in correspondence of each feeding line on the breadboard in order to protect Arduino from voltage spikes (Figure 2).

3.3 Integration of the tactile and olfactory interfaces with the video/audio environment.

The interface with which the user will interact consists in a pair of slippers in which the vibrating motors are embedded, an olfactory display, a pair of professional headphones and a yoga ball used as a chair.
We used a pair of slippers made of plastic, cut and shaped in a way to make them adjustable. In correspondence of the two interactive areas on the sole, the slippers were carved, and the actuators embedded and covered with a layer of protective sponge. The third actuator was placed between two layers of sponge and fabric and fixed to a belt that allows fitting different feet dimensions (Figure 3). In the same way, the "snowball hit" motor was embedded between fabric layers, in this case without a sponge in order to maximize the tactile effect, and fixed to an adjustable belt (Figure 4).

Figure 3: On the left: slipper with vibrating motors embedded. On the right: slippers used during the simulation.

Figure 4: On the left: user using the simulator. On top-right: a wearable device for reproducing the snowball hitting. On bottom-right the fan for simulating the pine smell.

Concerning the olfactory display, the fan has been attached to a piece of cardboard, with an inclination of 45 degrees, and placed on a table at the level of the user's nose (20-25 cm in our case, see Figure 4).

Knowing the time history of the walking cycle, we reconstructed the sequence of signal that has to be sent to the slippers in order to simulate the same tactile sensations felt by the person in the video (Figure 5).

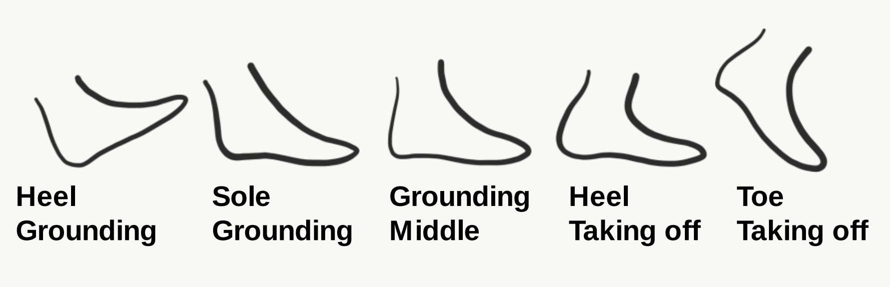

Figure 5: State of walking and related area activation.

For instance, considering the heel contact of the right foot as starting position, the sequence of areas activation (Figure 5) could be schematized as in Table 1.

Walking cycle subdivision	Left foot	Right foot
1	B - C	A
2	/	A - B
3	/	B
4	A	B - C
5	A - B	/
6	B	/

Table 1: Sequence of areas activation for the feet where: A= heel, B= lower forefoot, C= upper forefoot.

For the video playback, we used the software Processing (https://processing.org), that allows creating a data exchange interface with Arduino software by means of the serial connection. We used the tilt sensor state as the control parameter to start and stop both the video and the tactile simulation, namely stopping the experience in case of "OFF" state and let it run in case of "ON" state. We reproduced the original recorded audio of the video using a pair of professional headphones "AKG K 240 MK II".

In order to make the simulation being experienced interactively, we added the possibility to start and stop the video according to the will of the user. To this aim, we used a tilt sensor that can pass from "OFF" to "ON" state and vice versa, according to the inclination of the ball. By using a yoga ball as a chair, the user can spin the ball to activate and deactivate the tilt sensor. At the beginning of the simulation, the user is sitting like on a rigid chair. In order to run the simulation, the person is asked to slightly tilt forward, moving the weight partially on the legs, reaching thus the equilibrium state of the ball. In addition, the ball is elastic, so in the activation position, the user feels like "going to stand up and start walking" (Figure 4). A graphical representation of the whole system is shown in Figure 6.

The overall experience the user can perceive is of a walk into the specific location, combining information of four sensory modalities.

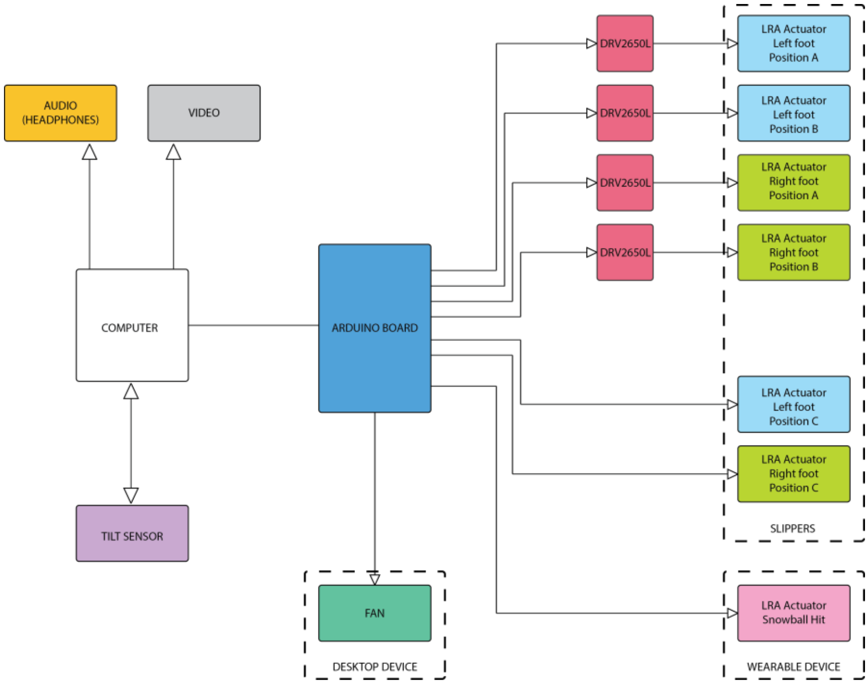

Figure 6: Graphical representation of the system architecture.

4 CONCLUSIONS

In this paper, we described the design and the implementation of an interactive, multisensory virtual journey, specifically designed to help travel agencies to improve their selling activity. By means of this simulation, the potential customer can select and buy a journey by experiencing part of the journey itself and can make a choice. The simulation involves four senses and is a combination of real and virtual information.

We selected as case study an experience for mountain tourism, but the same system could be fitted and modified to simulate also other tourism destinations. Moreover, the same application could be used in fields different from the tourism marketing, such as for people interested in visiting locations which cannot be easily reached or as an entertainment application. In both cases the system could be improved from a "passive" to a more "active" interaction, to further improve the user experience.

The next step of the research will be an improvement of the visual part of the simulation, by recording a 360° video and using a Head Mounted Display for obtaining a fully-immersive VR multisensory experience. Also, testing sessions with users will be set-up in order to evaluate the system performances, the pleasantness and effectiveness of the multisensory experience as a whole and of the tactile and olfactory interfaces independently.

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