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Smart Cultural Site: an Interactive 3d Model Accessible to People with Visual Impairment

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Abstract. In our study, we proposed a prototype of “Piazza dei Miracoli” (Pisa, Italy) as an intelligent 3D interface system aimed at improving the accessibility and usability of cultural sites for all, including people with vision impairment. We combine tactile information with audio tracks in order to enable potential users to explore the artifact autonomously. Low-cost and partially open-source technologies are two important features leading our approach, creating a system easily replicable. First, we designed some 3D source-based models to be printed with an additive manufacturing technology. Next, the 3D prototype has been linked to a Raspberry for handling a set of detailed audio tracks to enrich the tactile exploration with an interactive audio guide. A preliminary evaluation was conducted to test the proposed system in order to better refine its design.

1. Introduction

In cultural heritage, technology is more and more exploited in order to grant everyone a concrete access to culture. The increasing development of modern technologies of rapid prototyping (RP), which allows reproducing an object from a 3D model, can offer new opportunities to experience for several purposes. Compared to traditional techniques, such as gypsum casts, thermoformed boards, etc., tactile patterns obtained with RP and 3D printing technologies speed up and improve the model reproduction process. Having 3D models of statues, buildings or plans is more suitable for users with special needs, such as blind people (BP), who rely on the sense of touch to perceive objects. In particular, tactile models allow a blind user to get information on fundamental details, such as 3D shapes and surface textures. However, as demonstrated by Hayhoe [6], tactile 3D models may be not enough to fully enjoy the content exploration and perception, especially for multifaceted objects. The correct understanding of a 3D reproduction is affected by many factors, such as personal skills, size (compared to the original), reproduction details and the overall quality of the tactile model. Details of some particulars are often missed by BP due to the limitation of model reproduction. Thus, a 3D reproduction of specific details of an artwork could be a valuable contribution for educational and an inclusive perception. In addition, some type of information cannot be reproduced in a tactile way. Thus, combining a tactile model with audio contents can help BP to build a better mental picture of the whole work.

In this paper, we propose a novel interface model which can provide a multimodal interaction to explore 3D objects. To exemplify our idea, we present a working prototype built up by of some 3D models developed using source-based modeling [4] and RP. The models are equipped with tangible buttons (placed aside). These are modelled in 3D format and allow the activation of descriptive audio tracks, in such a way that each shape means a different type of information. Tracks can also be interrupted and reactivated in a simple way. The prototype is built using low cost components and uses a Raspberry to connect each button to a Python script managing and playing the tracks. Some studies investigated interactive tactile prototypes to allow art works exploration by visually-impaired users. However, these solutions do not consider a 3D interactive modelling. For instance, [9] investigates a combination of vibration and speech feedback which can be used in order to make a digital map on a touch screen device more accessible. In [13], the authors created a prototype of a tactile-audio map based on a combination of tactile hardcopy and a SVG file used together to provide an interactive access to a map image through a touchpad. The result is a tactile-audio representation of the original input image.

These projects, along with other ones like the study presented in [1] and [12], propose interactive tactile approaches that are not based on truly 3D models, since they adopt a 2D touchable format in which the representation is basically 2D with some parts in relief. In our study, instead, we combined a 3D modelling approach with audio descriptions in order to enrich the BP's interaction. The contribution of this paper is about proposing and experimenting a working methodology to develop interactive interfaces of artistic objects or cultural sites, which is easily replicable, and can improve the cultural experience of BP while increasing their autonomy. In short, we aim to propose an enriched and interactive tactile model for BP with particular attention to details, which can be useful for touristic and educational purposes. The idea intends to face some issues often encountered when exploring tactile models available on the market, such as those reported in several projects [3], [15], [16]. The main issues observed can be summarized in: lack of details (granularity of some important particulars), replicability by specialized centers (more expensive), lack of choice in selecting information types, and free exploration by using both hands. Specifically, our approach is characterized by:

(1) Cost and replicability: develop a model which is easy to reproduce for other sites and objects at low cost.
(2) Avoiding unintentional selections: many BP appreciate the opportunity of exploring the model with both hands and no restrictions, that could not be feasible when sensors are embedded in the model itself.
(3) Semantic information and on-demand selection: buttons with different shapes are proposed for activating different types of information (historical, architectural and practical). An artefact is usually associated with a single audio track that describes all information and requires to be listened entirely. In our model, only desired information can be selected and listened.

The paper is organized as follows. Section 2 discusses some related work. Section 3 gives an outline of our approach. Section 4 details the methodology and technology used. Section 5 describes the interactive prototype and Section 6 reports a short description of the preliminary evaluation with BP. Conclusions (Section 7) end the work.

2. Related work

Several studies and projects investigated the opportunity to provide to BP a multimodal interaction to increase access to cultural contents. Tooteko [3] is based on a smart ring that allows the user to navigate a 3D surface with finger tips and get in return an audio content that is relevant to the part of the surface he/she is touching in that moment. The system is made out of three elements: a high-tech ring, a tactile surface tagged with NFC sensors, and an app for tablet or smartphone. When the ring reaches a NFC sensor it communicates with the app for activating the audio track. The 3D models are built using standard 3D printing. The hotspots are inserted inside the model, which needs to be reasonably large to accommodate them. Hotspots need also to be at a reasonable distance to be clearly detected by the reader. Hi-Storia [15] proposes a similar approach. In both these projects, sensors activating the audio tracks are integrated in the model itself. This has some important drawbacks. First, while listening to an audio track, the user can easily jam into another hotspot causing the stop of the old track and the activation of the new one. This is rather annoying since BP often use both hands when exploring a 3D object and listen to audio tracks [8]. Moreover, integrating sensors into the model is very costly, which can refrain single small museums from adopting such an approach. Finally, these approaches assume an external person explaining the user how to move and what to do before starting to browse the model.

A different approach is proposed in 3D Photoworks [14]. Here, colour images are printed directly on the relief surfaces and infrared sensors are integrated into reliefs. Their interactive tactile prototypes accompanied by audio guides are based on motion capture [2], [10]. Depth cameras, placed above the tactile template detect the movement of the user's hands. The main disadvantage of hand tracking systems is their cost and complexity. Even though the technologies are continuously improving and becoming cheaper, the current low-cost trackers generally exhibit poor accuracy of tracking. In particular, while slow movements and limited rotations of the hand are usually traced in an effective manner, when speed increases the position of the hand is easily lost causing the user a deep feeling of frustration.

All these systems, although with the limitations outlined, represent an important first step towards a real access to cultural sites, using tactile interactive models. Our approach, explained in the rest of the paper, tries to overcome these problems by designing a low cost solution and moving the audio track activation outside the 3D model, still relying on sensors for their activation.

3. Approach

In this study our approach consists in reproducing an interactive 3D model by combining tactile perception with audio contents to explore the floor plans of monuments, rather than the main structure of the buildings. The reason of this decision is the lack of plans and indoor reproduction perceivable by touch. Likewise, the lack of particulars and details in a tactile reproduction led our study to investigate also these aspects. These types of reproduction (floor plans and particulars) can be, in fact, very useful for learning and perceiving details which are usually neglected for BP. However, this approach can be also exploited for reproducing the outside of the buildings.

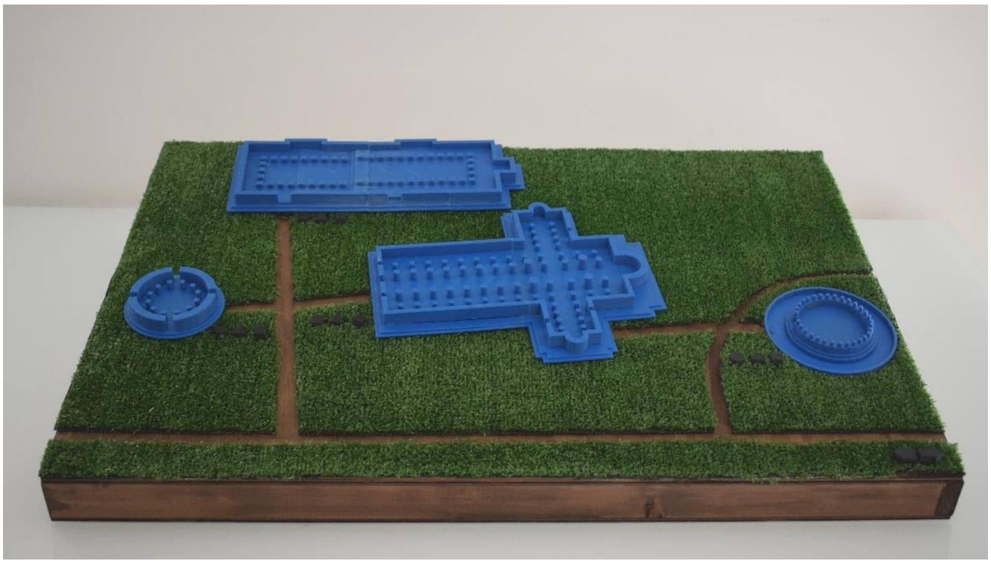

Figure 1. The 3D model of Piazza dei Miracoli

We applied our approach to a tangible 3D model of the four monuments placed in "Piazza dei Miracoli" in Pisa, Italy. We choose this case study because this site includes four cultural monuments with different floor plans: (1) the central plan of the Leaning Tower and the set of columns stacked outside; (2) the Latin cross plan of the Cathedral of Santa Maria Assunta; (3) the rectangular plan of the Monumental Graveyard; and (4) the central plan of the Baptistery. When visiting Piazza dei Miracoli, the plan of the square and of the pavements linking the four monuments is clearly visible for a sighted person. Our goal is to deliver a similar perception of the global structure available also for BP. To achieve this, we reproduced a 3D model of Piazza dei Miracoli, including the four monuments. The reproduction of each monument is built considering a two-dimensional plane which cuts the monument at height of approximately 1 m (3.28 feet) from the floor. In this way, we are able to show the section of the perimeter walls and of the columns which are important to understand the overall architectural setting (see Fig. 1). This tactile reproduction allows BP to perceive primary information, such as the thickness and position of the columns, the fact that the central nave is higher than the side naves, the position of different sets of arches, and the like.

4. Methodology

In building our prototype we followed guidelines and standards for tactile graphics [5]. However, these guidelines refer to the constructions of 2D and1D models, thus we have added some rules especially related to 3D. For instance, during participative design with a blind person we noticed that there is a minimal distance between two 3D objects (e.g. columns) which needs to be maintained in order to allow BP to perceive them correctly with the touch. Our system is built according to a modeling methodology for work of cultural sites based on the real reproduction [4]. The 3D model can be obtained using two different approaches to get the artwork (monument, statue, etc.) structure: (I) *reality-based*, such as via laser scanning or reflex camera; (II) *source-based*, via a digital representation of a work. Through this second approach, we can also model a work not existing anymore, or that has survived just partially, and whose reconstruction is based on historical sources. The approach actually used depends on the characteristics of the work and on the project goal. When using 3D modelling for huge monuments, as occurred in our case study, the work is simplified for a small scale reproduction (suppressing some uninfluential details). For this reason, we preferred to use a source-based approach, which is faithful to its original plan and to the historical facts, and we decided not to reproduce child elements that might not be easily perceptible by touch.

Starting from the digital source, the tactile models have been obtained through modern digital fabrication techniques. To model a source to be printed we: (1) got the plant in 2D; (2) model a 3D version based on the scale and the official sources (e.g. a circle on the plant is a cylinder in the 3D model); (3) select a simplified style plant, i.e. without architectural details; and (4) reproduce some architectural style details. The appropriate scale resolution was decided in a participative way involving BP during the whole design-development cycle (see Section 5).

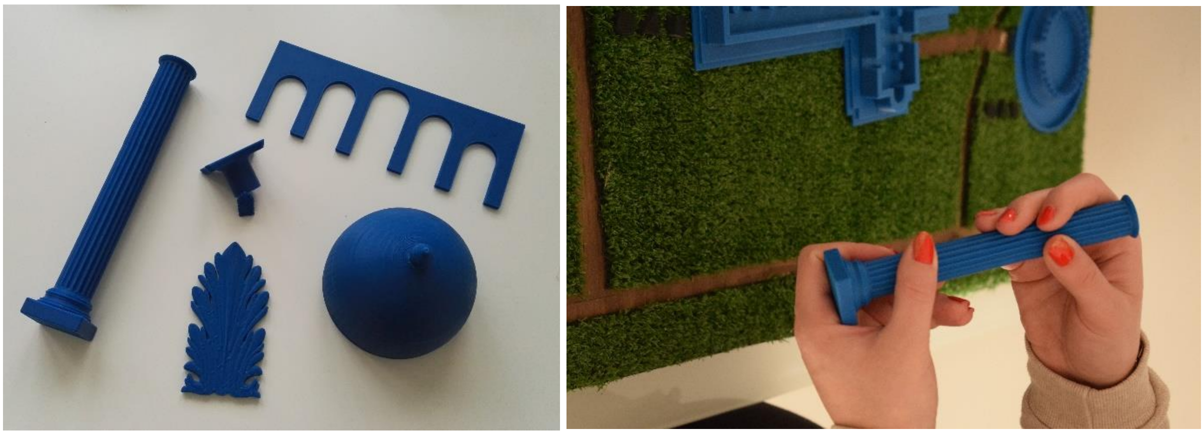

Figure 2. The architectural elements (left) and their size compared with the main model (right)

For the 3D printing step, an additive technical process has been adopted for our purposes: the object is produced by progressive accumulation of material [11]. The 3D prints were made with a Fused Filament Fabrication printer (FFF) that melts and extrudes a thermoplastic filament, in our case the Acrylonitrile-Butadiene-Styrene (ABS), an oil-based plastic. The models' size are appropriate to ensure a good exploration of the relevant details. We used Blender for developing the models and a proprietary software for slicing on the printer, a Zortrax M200 (available at the laboratory, cheaper printers can be used instead). Because of technological limitations of the printer used, for some of the models, such as the Monumental Graveyard or the Cathedral, we had to print individual items in separate pieces glued together in postproduction. We also created 3D models for parts of the monuments that are relevant to understand the global structure, such as the dome and the nave profile of the Cathedral, a Corinthian column representing the main style of the Cathedral, the Baptistery and the Leaning Tower of Pisa (see Fig. 2). Reproducing these details is very important since they usually cannot be perceived by a BP.

Decorations were not reproduced on the 3D model of an element (e.g., acanthus leaves of column capitals) due to a scale limitation. However, some decorations are fundamental for the overall perception, such as the acanthus leaf in the Corinthian style representation. In this case, we preferred to produce a detailed model of the decoration, in a different scale, and print it. For instance, an acanthus leaf was printed on a larger scale separately from the capital. The architectural elements are located in a panel placed near to the main square model (Fig. 3). Each of these is introduced and described in the architectural audio description, whose reproduction is triggered by the button of circular shape.

5. The interactive 3D prototype

The interaction model proposed is conform to our aim of making the user entirely autonomous in the exploration of an artwork. To meet this aim, any piece of information should be provided using both the tactile and the audio channel. BP should be able to explore the model by touch and to activate an audio description related to a specific monument/detail. Spoken descriptions are organized into several audio tracks, which can be recorded by a person or via voice synthesizer through a specific audio content generation application, such as DSpeech**[11]** or Balabolka**[11]**. This allows to prepare various contents even into different languages. In addition, for each description more than one file can be available so that we can have different depth levels.

Figure 3. Panel with the architectural elements

The device used to manage the interaction user-3d model is Raspberry PI 3, a device single-board computer a few centimeters long, with general purpose input/output capabilities. The Raspberry is fixed below the prototype. Aural descriptions are activated by buttons placed aside each model (e.g. near the main entrance of each monument in Fig. 4). Buttons are connected to the Raspberry with cables. In our prototype each model has three buttons next to, and these are easily detectable via their geometric shapes: circular, triangular and squared. Each shape represents a specific type of information: (1) the circle is used for practical information, (2) the triangle for the historical overview and (3) the square for the architectural description.

When the user approaches to the model of the Piazza dei Miracoli, two proximity sensors activate a welcome audio track explaining how to interact with the model itself. The sensors, placed in front of the prototype, compute the distance between them and an obstacle in front of them. When a new obstacle (BP) appears in a distance between 0 and 50 cm, the sensors send to the Raspberry the information and the welcome audio track is activated.

The user is autonomous in deciding the times and the ways of interacting with the other audio tracks. A press on the button activates the correspondent track. Then the user can navigate the tracks pressing again the same button. The current track can also be suspended by pressing a pause button placed at the bottom right of the prototype.

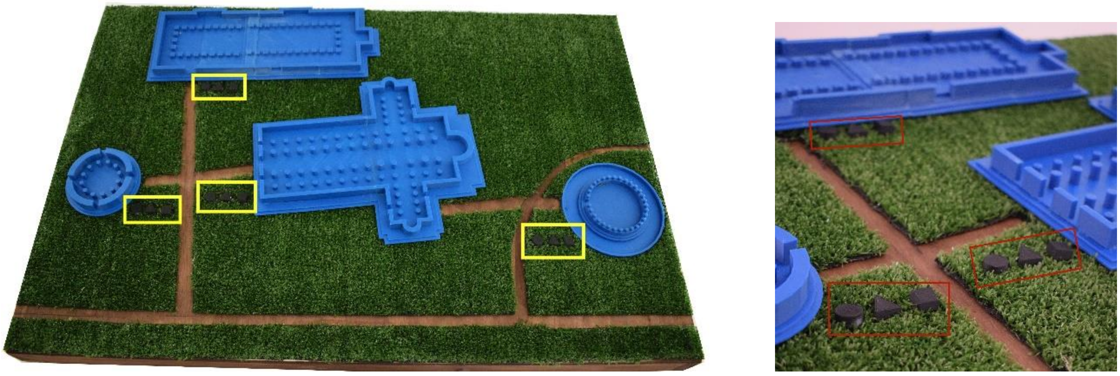

Figure 4. The position of buttons near main building entrances (left) and particular of Cathedral and Baptistery (right)

6. Evaluation

The aim of our approach is to support the user in an interactive autonomous exploration of a cultural site and/or an artwork through a 3D reproduction. The prototype has been thought as an interactive system usable by all, but useful especially for blind people who are able to 'see' a monument or a detail only via the sense of touch. In this perspective, we firstly evaluated our prototype with a group of blind and low vision users in order to evaluate if the approach of combining tactile interaction with structured audio descriptions is suitable and intuitive for a visually-impaired person. Thus, through the BP participation we aimed at evaluating:

(1) the appropriateness of the 3D models in terms of size, shape, texture and scale perceivable by touch;
(2) The suitability of the audio descriptions, i.e. the levels of the tracks, their activation, their structure, and so on;
(3) The difficulties encountered while exploring the models and using the audio tracks.

We tested the 3D models with the BP group during the design-development cycle in order to tune up the details of the prototype**.** Thus, we involved a group of three visually-impaired users who firstly familiarized with the model and expressed freely their impressions and perplexities. For our purpose we asked them:

- Are the monuments clearly perceivable by touch? This in order to understand if size and shape had been well designed and appropriately reproduced by the 3D printer.

- Are the audio tracks useful for the exploration, clear and easy to be listened to? These questions aimed at collecting impressions on how the tracks had been organized and proposed to the user.

- What about the interaction with the model? This type of question has been proposed to get opinions and feedback by the user with regards the interaction modality used to explore the prototype. Impressions and comments on audio descriptions activation, buttons styles, details reproduced in 3D, and so on were included in our investigation.

Two members of our research team observed the users while interacting with the prototype; this allowed us to collect information on those interaction aspects that were not mentioned by the people.

About the first goal, the BP were involved to set up the scale to use for reproducing elements and details. One user observed that some dimensions and spaces left between the columns were not easily perceptible by touch. Therefore, we consequently remodelled such part of the prototype. The users also suggested to reproduce some details of a piece (e.g. the arches) in a larger scale in order to improve their perception. So we modelled also that particular. One user observed that the base of the tower of Pisa had not a right gradient according to the leaning of tower. All the users suggested to reproduce more particulars into 3D format, since it is not easy to get information and 'see' a three-dimensional version of small objects, especially for perceiving the little architectural details. They declared that usually the 3D models reproduce monuments and artworks on the whole, but the particulars and the details are neglected.

With regard to the audio contents, the users expressed the preference for multiple tracks so that a blind person has the opportunity to listen to the amount and type of information according to the time and interests. Accordingly, we prepared three different types of information (architectural, historical and practical). Furthermore, each type of information has been recorded into different tracks in order to provide various levels of details which can be chosen by the user according to his/her preference.

With reference to the interaction modality, we observed that BP use to search for the buttons in specific positions; for example, we noticed that the users tried to find the buttons for activating the audio tracks in the same place for each artwork. The users clarified that if a certain consistency is preserved, for a blind person it is easier to localize the objects (e.g. all them are placed on the right of each monument). So we finally decided to place the three buttons near the entrance of each artwork. It was not possible to place them at the right of each artwork due to space limitation on the model.

Concerning the shapes of the buttons, the users declared to perceive them well, and to find very useful to listen to the audio tracks. Specifically, we discussed with them about the opportunity to have different levels of information to be listened to. This idea was immediately appreciated, in order to enable the user to better adapt the exploration according to his/her preferences and available time. Then the discussion moved on how to manage those types of levels. The proposed solutions were basically two: (1) two additional buttons to be placed in a fix position to perform 'previous' / 'next' of the current track (any it is); (2) the navigation among the tracks by pressing more than one times the same button which activated the current information. For example, the circle button when pressed actives the practical information (the first level), by pressing again it the second level, and so on. After a short discussion about this, all the blind users opted for the second proposal. So in the final version of our prototype the levels are handled through the same button activating the audio track.

Based on the comments and data observed by the users, we refined our prototype we will use for a more structured evaluation. As a result, we are currently working on a more extensive user testing with blind and non-blind people.

7. Conclusions

In this paper, we presented a novel approach to guide a blind user in an interactive exploration of a cultural artwork. The approach has been exemplified building a working prototype of Piazza dei Miracoli, the square in which is located the Leaning Tower of Pisa. Our approach considered indoor elements rather than the entire external monuments as well as particulars of the artworks in order to overcome the gap in this field. We worked to allow free model exploration with two hands and introduced a simple interaction model based on buttons with different shapes. At the moment, the prototype is thought for a single user exploration, a limit of most of technological devices used for the cultural fruition (e.g. Leap Motion or viewer like Oculus Rift, HTC Vive, etc.). For the future we would like develop a multi-user system. Moreover, our intention is to design an interactive system that is at the same time an emotional one.

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