# INTERACTIVE PAINTING SONIFICATION USING A SENSOR-EQUIPPED RUNWAY

**Edoardo Micheloni, Marcella Mandanici, Antonio Rodà, Sergio Canazza**
Dept. of Information Engineering
University of Padova (Italy)
{micheloni, mandanici, roda, canazza}@dei.unipd.it

## ABSTRACT

In the present study we will show the realization of a multimedia installation for the interactive sonification of a painting of Hartwig Thaler. The sonification is achieved by means of sound synthesis models, capable of reproducing continuous auditory feedback, eventually generated from the feature analysis of three color layers extracted from the painting (red, blue, yellow). Furthermore, a wooden sensors equipped runway, divided in three sections, each of which represent a different layer, will activate the corresponding soundscape according to the visitor position. This system enables to discover a 2D painting in a new 3D approach, moving along the runway toward the projection of the painting. The paper describes in details the developing of all the elements of the system: starting from the analysis of the image and the algorithm to realize the acoustic elements, than the sensorized runway and finally the testing results.

## 1. INTRODUCTION

The conjunction of real-time computer graphics, sensors and synthesized music is creating a new medium where people are physically immersed in an environment by a world of images, sounds, and objects that react to their actions. In the late '60s and '70s, installations became a favorite form for the artists working against the notion of the permanent, and therefore collectable, art object. It is from the union of interactive spaces and multimedia installation that the idea of the present work took shape. Interactive installations are a sub-category of art installations and, for instance, can be electronic-based, mobile-based, web-based, etc [1]. They frequently involve the audience acting on the work of art, increase their involvement [2, 3]. Several experiments have been carried out on the augmentation art museums with interactive technology. They may include, for instance, the project [4] that introduce the notion of 3D sound in headphones for an art museum, providing the user with a contextual and spatial audio guide. In [5], the idea is to use computer graphics and augmented reality techniques in order to provide projected overlays on backgrounds with



(a) The original image (b) The yellow matrix

Figure 1: Example of image processing from the original painting to a single color mask.

arbitrary color and reflectance. Another project may refer to is [6, 7] where an ancient musical instrument can be virtually played thanks to sensors and a touch interfaces. One of the most representative exponent of virtual reality is surely Myron Krueger. He is considered to be one of the first-generation virtual reality and augmented reality researchers. He conceived art of interactivity as opposed to the interactive art: there was more interest in interactivity design than in the art itself. [8] is one of his most representative works. The current paper will present an interactive installation where the body of visitors becomes the Interaction Device. Some examples are documented in literature, like [9] and [10]. Moreover, works on interactive floors with which the body is the only interaction device [11, 12] are documented too. The goal of the installation is to provide the user with the immersive experience of a soundwalk simulating an imaginary navigation inside the painting. The environment is formed by a rich sound background. Such outcome is realized by the painting sonification and the rendering of the users' footsteps over a bed of dry leaves, like the one represented in the painting of Figure 1a. Both the sonic background and the steps sound change according to the user's distance from the painting, which results in a sort of three-dimensional spatial development from the original two-dimensional artifact.

### 1.1 The Interactive Painting Sonification Project

This work proposal comes directly from the South Tyroler artist Hartwig Thaler [1] who has commissioned the Sound

[1] Further information about painter Hartwig Thaler can be found at his website https://www.hartwigthaler.de/

and Music Computing Group of the University of Padova [2] to produce a sonification of one of his works. The artist invited us to choose one painting among a series of 9, where various leaves textures are depicted. Although the textures would vary for density, leaf dimension and color, the paintings are united by the presence of a single subject (a carpet of dry leaves) occupying uniformly their entire surface. This suggests that also the sound rendering should be made regular and constant although with some degree of variability inside. Moreover, the paintings seem to be the result of the superimposition of different layers representing leaves of similar color, as confirmed by the creative process declared by the artist himself. This suggests the possibility of decomposing the image in different color matrices and to consider the painting as a sort of three-dimensional object of various superimposed layers. This idea envisions that various layers should not simply be seen as one above the other on the surface of the painting but that they can be disposed in the space in front of it. Thus, the painting is stretched from the wall into the space, allowing a user to walk through its various layers. The resulting interaction space is depicted in Figure 2 where the user walks

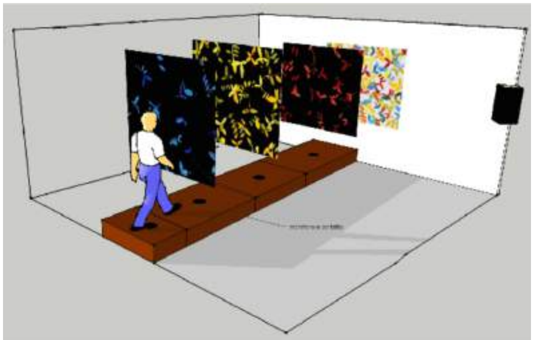


Figure 2: The painting sonification setup with the imaginary projection of three color matrices in the space in front of the painting.

on a wooden runway positioned in front of the painting. The runway is subdivided into three sections, each corresponding to the imaginary projection of the color matrices which can act as triggering points of some changes in the audio output. Thus, the installation does not only qualify as a mere image sonification project, but becomes a truly interactive environment based on the spatial projection of the painting. The paper is structured as follows: Section 2 focuses on the sonification of the painting; Section 3 describes the general architecture of the installation; Section 4 describes in details the localization system used in the installation; Section 5 presents the results of data analysis collected from the elements of previous section. Finally, section 6 summarize the results of the work and outline any possible further steps.

## 2. SYSTEM ARCHITECTURE

The installation is characterized by two main elements: a wooden runway that leads the visitor toward the projection of the painting, and an audio reproduction system, fed by a sound background derived by the painting and users' step sonification. Fig.3 shows the schema of the installation, outlining the components of these two main elements. The soundscape of the installation changes according to the distance of the visitors from the image of the painting. In order to detect the position on the wooden runway, a system of eight piezoelectric sensors is used (Sensing). The signals acquired is then processed by means of an algorithm developed ad hoc based on the TDOA approach (Localization). Other localization approaches were considered. One of them exploit computer vision algorithm. This was not considered because of issue in case of unmanaged environment with multiple people interacting in the installation. Furthermore, it was necessary to detect either the user position or his steps to sonorize them. In addition, the installation has been developed with the collaboration of company specialized in diagnosis of wooden board and analysis of propagation time of waves. This led to the development of this specific system.

The information acquired are used to control the soundscape. It is produced by a bank of oscillator, fed by pink noise. Its outputs (Soundscape reproduction) are differently weighted according to an algorithm of image processing that extracts the needed features (Image feature extraction) from the three color layers of the painting (color matrix extraction). Furthermore, the runway is provided with a led "stream" that changes its color according to the color matrix of the painting. This provide a visual feedback so as to outline different portions of the runway each of which corresponds a different color layer. Further details on the elements illustrated in Fig.3 will be described in the following sections.

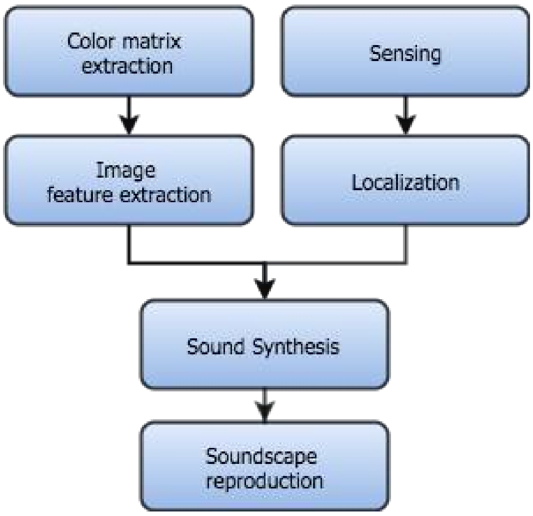



Figure 3: Schema of the system architecture: painting analysis, position detection and sonification

## 3. FROM THE PAINTING TO THE SOUND

The basic idea of this image sonification project is to consider the leaves as the elements of a mask, in which the colored spots represent open holes on a solid background.

[2] The website of the SMC group of the University of Padova is at http://smc.dei.unipd.it/

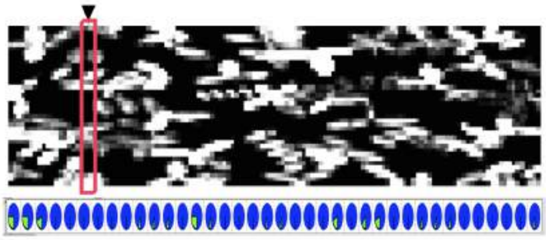


Figure 4: The 38x127 lightness matrix with the mixer controls of the separated filters output

| | | STEPS | | | |
|---|---|---|---|---|---|
| | SPECTRA | H | B | hB | lB |
| BACKGD. | H | | | | |
| | B | | | | |
| | hB | | | | |
| | lB | | | | |

Table 1: Combination possibilities of background and step sonification employing 4 different spectra: H (harmonic components), B (bell components), hB (highest range of bell components) lB (lowest range of bell components)

Transposing this interpretation in musical terms, the background comes to be a complex wide range spectrum of frequencies and the holes are the points where the single frequencies can be heard. In this perspective, the function of the image is similar to that of an orchestral score, where each line corresponds to a musical instrument or orchestral section. The black holes (signle note or group of notes) activate the section, while the white lines (rests) mute them. Hence, the spectrum plays the role of the whole orchestra and the image the role of the musical score. To realize this idea, we selected the painting with the lowest degree of leaves density among the 9 proposed (see Figure 1a). Following the idea of the various superimposed layers, we needed also to extract different colors matrices from the original painting. To do so we analyzed the image using the hue-saturation-value color model, where hue refers to the pure color, saturation to the quantity of white and value to the lightness [13]. Choosing an appropriate hue range, it is possible to obtain matrices that represent only the leaves of the selected color range. According to the suggestion of the artist, we extracted three matrices corresponding approximately to the primary colors (red, green and blue), shifting a little bit the green matrix towards the yellow which is the predominant color of the painting. The result of this process is depicted in Figure 1b, where a mask of yellow and green leaves extracted from the original image is shown. [3] To provide a rich background texture for the image sonification, we employed a bank of 38 band pass resonant filters [4] fed with pink noise and with separate controlled outputs. To superimpose the mask to the background texture, we scaled the yellow matrix in a 38 rows and 127 column matrix, where only the lightness values are reported (see Figure 4). This matrix can be considered as the real sonification score because it provides columns of lightness values which are scanned at a regular speed from the left to the right and vice versa. This timing mechanism allows the necessary link between the visual representation and the sequential nature of music. The time-controlled columns of lightness values are converted in numeric controls for a mixer matrix, thus making it possible to weight the filter's output according to the lightness of the every single pixel. This process results in different harmonies coming from the various weights and assigned to the spectral components. For instance, in the case represented in Figure 4, the marked column has higher values in the lower part of the painting and very small values in the higher part. This opens the lowest frequencies of the spectrum much more than the highest, allowing a major weight of the lowest components. The situations is very similar to a 38 voices chorale [5] where the dynamics of the various voices depend on the pixel lightness values.

### 3.1 The Installation Soundscape

The characteristic of the sonification engine described above is to be very close to the image features and to be easily adaptable to produce a painting-related soundscape. For this project we focused our attention on subtractive synthesis due to its flexibility and richness of expressive possibilities. The bank of filters can be fed with different input sounds and can be easily tuned according to various spectral models, which can be changed in relationship to the color of the matrix employed as musical score. Moreover, the resonant filters output allows a kind of smearing effect which smooths the harmonic transitions which characterize our image sonification approach, giving to the audio rendering a great variety in a seamless way. Another possibility offered by our sonification system is to implement a second bank of filters with the same characteristics of the first, being fed by a file reproducing the sound of a step on a carpet of leaves which can be triggered by impulses coming from a user's real step on the wooden runway. Thus, not only this would produce step sounds completely different from real ones, but these steps could be tuned according to a spectrum complementary to that used for the background. In the actual project we experimented four spectra: H (a harmonic spectrum of 38 frequencies starting from 100Hz), B (38 frequencies extracted from the full spectrum of a bell sound), hB (38 frequencies extracted from the highest band of the same bell spectrum) and lB (the same as above in the lowest band). Table 1 shows the full range of the possibilities in order to combine a background spectrum with its complementaries with a wide number

[3] Of course many other options are available to extract color matrices from an image, starting with the number of matrices to be extracted and with their color range. In our case the choice of extracting three matrices depends not only on the artist's suggestion but also on the actual available space for the interactive sonification on the sensor-equipped runaway (see Section **??**.

[4] The sonification is implemented in a Max/MSP patch employing the fffb object. See `https://docs.cycling74.com/max5/refpages/msp-ref/fffb~.html` for reference.

[5] The chorale is a vocal polyphonic composition, usually a religious hymn, typical of the sacred literature of the German Protestant Church under Martin Luther (1523). The chorale is characterized by a regular homo-rhythmic proceeding of the voices, exactly in the same way of the scanned columns of the image matrix.

of soundscape generation possibilities, which can be chosen according to the user's position on the sensor-equipped runway [6].

## 4. THE SENSOR-EQUIPPED RUNWAY

The installation is composed of a wooden runway, with the dimension of 350x100x7cm, which guides the visitors towards the painting projection. The wooden board used for the runway has been individually chosen, in order to guarantee the most uniform possible speed of propagation of vibrations (see Tab.2). This feature is necessary in order to avoid difference in arrival time to the sensors, as far as possible. The measure of the speed of propagation in the boards was possible thanks to the tool Viscan [7]

| # board | length (cm) | width (cm) | speed (m/s) |
|---|---|---|---|
| 41 | 495 | 14,5 | 544,5 |
| 4 | 550 | 14,5 | 544,5 |
| 999 | 490 | 31 | 529,2 |
| 41 | 494 | 30 | 513,8 |
| 111 | 550 | 7,5 | 511,5 |
| 118 | 523 | 7,5 | 493,7 |

Table 2: Wooden boards description: the identifier number of the board, its length, its width and the speed of propagation of sound for each of them

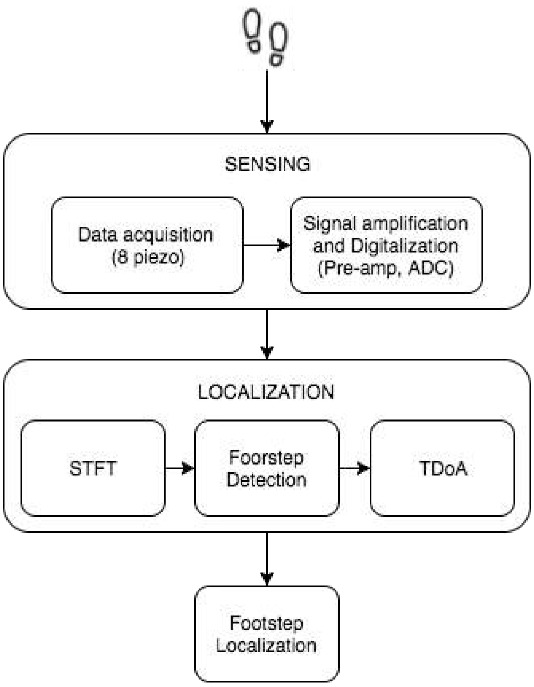



Figure 5: Schema of the position detection system: Sensing is responsible of acquire the signals from the runway, Localization detect the steps and the position

The objective of sensing section is to acquire the footstep-induced structural vibration through sensors mounted on the runway. The sensing module consists of data acquisition, using eight piezoelectric sensors, signal amplification and digitization by means of a digital audio interface. The localization section is mainly divided in: STFT, footstep detection and TDOA estimation (see Fig. 5).

### 4.1 Footsteps characteristic

Human steps generates vibrations that propagate away from the source as seismic waves. For a single impact on an elastic half space, Miller and Purssey (1955) have shown that 70% of the energy of the impact is distributed in the Rayleigh wave. The remaining 30% of the energy is transmitted into the earth via body waves (transverse and longitudinal), while diminishing in amplitude as $r^{-2}$ [14, 15]. The signal has also frequency dependent attenuation characteristics [16]. Furthermore, thanks to clinical gait analysis, like in [17–20], is possible to outline the GRF [8] of a footstep. Fig.6 describes the main behavior on amplitude/time graph, where the first peak is attributable to the heel strike and the second to the toe push-off as the body is propelled forward. In the light of these analysis, a "delay" time after the first peak, before next detection, was necessary in order to identify the position of the whole step at the heel position and to avoid continuous changes in short period of time. With this approach, the vibrations made by the step can be considered as produced by an impulsive hit.

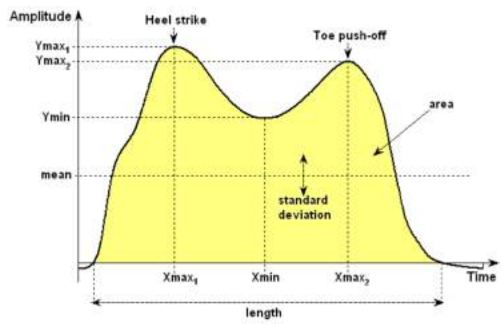



Figure 6: Representation of a usual Ground Reaction Force of footsteps on an Amplitude/Time graph

### 4.2 Sensing

Usual applications of floor vibrations detection use sophisticated sensors like the geophone sm-24. It can detect very small vibrations with high precision going to the detriment of very high price. In this application, due to the small size of the runway and the resonance of steps, a good SNR can be ensured with piezoelectric sensors of 2cm diameter. They are equally distributed on the runway in order to divide it in twelve areas, each of which is identified by the four nearest sensors that the localization system will use. As described in Section 3, the painting is divided in three color layers and each of which is assigned to the section of

[6] Some sound examples of these possibilities can be found at https://youtu.be/wzE17agkZ7I

[7] Description of this tool can be found at http://microtec.eu/en/catalogue/products/viscan/

[8] GRF (Ground Reaction Force) is, according to Newton's Law of Reaction, the force equal in magnitude but opposite in direction produced by the ground as reaction to the force the body exerts on the ground. The ground reaction force is used as propulsion to initiate and control the movement, and it is normally measured by force sensor plates.

the runway. This last is composed of four areas as outlined by the sensors described in Fig 7. Afterwards, in order to acquire the signal, the TASCAM US-2000 (8 Microphonic input) Digital converter was used. For this application, the audio interface works at 44.100kHz with a resolution of 24bit. The cable and connectors used to attach the sensors to the audio interface are respectively Klots and Neutrik so as to minimize possible filtering caused by unwanted parasitic capacitance.

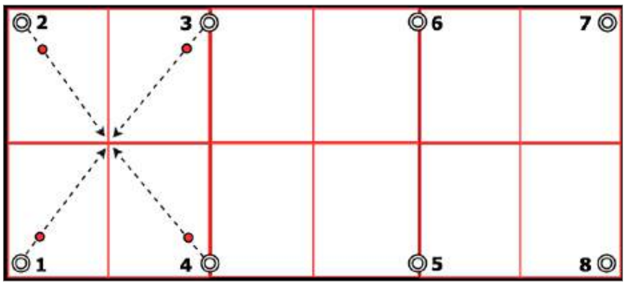



Figure 7: Disposition of the sensors and consequent division in twelve areas of the runway

### 4.3 Localization

Usually, the localization of sound events is based on the amplitude of time signals and the cross-correlation is used to find the lag between them [21, 22]. After several tests, this approach turned out to be unable to extract the necessary information because of the nature of the runway: wood is flexible and inhomogeneous, this lead to echoes and creaks that alter either the sound signal or speed. On the contrary, by means of STFT it is possible to clearly detect the onset of the footstep and so to highlight the TDOA. For the footstep detection, a moving average method is used: with two windows of size $N$ and $M$, with $N >> M$ and N multiple of M, the average energy of the signal in the long period and in the short period are computed respectively. Every N samples the long period average is set, than every M samples a value of energy is computed and compared with the previous average energy (see Fig. 8). The algorithm was first simulated and evaluated using MATLAB with data sets of measured taken from the prototype runway equipped with four sensors. In formula:

$$\frac{1}{M}\sum_{m=0}^{M}|X(jN+kM+m)| > \alpha\frac{1}{N}\sum_{n=0}^{N}|X((j-1)N+n)|$$

with $X(f)$ is the Fourier transform of input signal $x(t)$, $j$ number of the N-samples windows, $k$ number of the M-sample windows and $\alpha$ a tuning factor. The tuning factor is necessary in order to make the system more robust against environmental noises. Additionally, in view of increasing the SNR of the signal, a cubic factor is applied to signal values.

Multilateration is a common approach for source localization that uses the time difference of arrival. Mathematically, the localization procedure can be described as

$$||x - p_2||_2 = v(t_2 - t_1) + ||x - p_1|| \qquad (1)$$

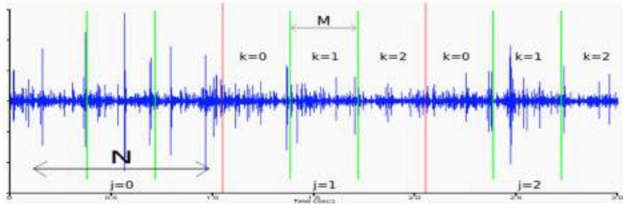



Figure 8: Graphical representation of the moving average algorithm implemented for the localization algorithm.

where $p_1$ is the location of the first sensor and $p_2$ is the location of the second sensor, x is the location of the excitation (i.e. footstep) and $v$ is the propagation speed. This approach, view that non homogeneous material does not ensure constant speed of propagation of waves [23], can not be used. This is the reason why the runway is divided in twelve regions, so as that the maximum localization precision is proportional to the dimensions of each area. The information about TDOA of each sensor is finally processed, using a decision algorithm, to identify the region in which the event occurred. This algorithm is described in the next sections in the light of the results obtained from the evaluation test on the runway.

### 4.4 Real-time implementation

The localization system works in real-time thanks to the implementation of a software dedicated to the acquisition from Tascam buffer and the processing of the data received. The framework is implemented in C++ in order to maximize portability on different systems. A well-known and widely used library for managing Audio Interface buffers is used: Port-Audio. It provides a very simple API real-time streaming audio using a simple callback function or a blocking read/write interface. Finally, a visual interface using Qt simply allow to interact with the sensing and localization system. Qt is used for development multi-platform applications and graphical user interfaces (GUIs). This interface, during test phase, allows to visualize in real-time the position of the user on the runway and simply change algorithm parameters so as to test its correctness.

## 5. EVALUATION

At the beginning, in order to test the algorithm of step detection and to evaluate the results, a prototype of the runway was deemed necessary. A wooden pallet 120x80x15cm with a 2 cm thick wooden board whose base measures the same as height was used. The results obtained by the step detection algorithm on the prototype, shown in Fig.9, are: after 10 campaigns of data collection each of which composed of 16 footsteps, the accuracy measured is 91%. After this preliminary part, the next test was performed on the wooden runway. First of all, to analyze its response, the sensors have been positioned in the first four position of Fig.7 like for the test on the prototype. Afterwards, an experimental set-up was designed to make the analysis easily repeatable. In order to realize an homogeneous excitation from which extract the TDOA data, the experimental set-

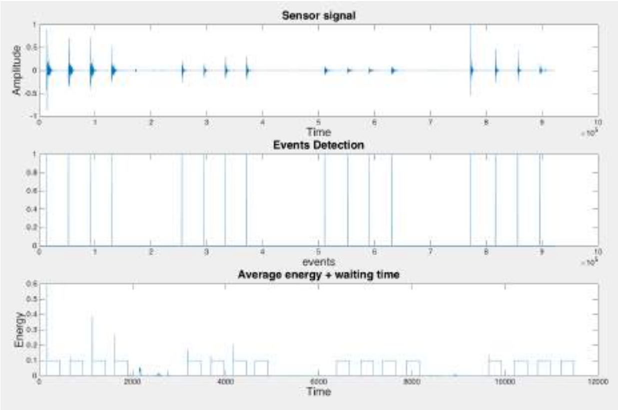



Figure 9: Event detection: First image shows the signal of sixteen steps, the second the detection of the steps and the third the average energy variation (straight line describes the waiting time after an event detection)

up was mainly composed of a 1 meter height reference and a mass of 50g. Along the diagonal, at 20 cm from each sensor toward the center of the relative area (red dots in Fig.7), 10 campaigns of series of 10 impulse excitations have been carried out using the mass dropped from the height reference. These two elements of the experimental set-up are respectively an adjustable stand for speakers, with a transverse metal bar, and a tennis ball. The choice of using a bouncing mass is dictate by the necessity to generate an impulsive excitation, therefore to avoid further bounces. This was possible taking the mass, while it was going, before the second bounce (see 10). The data collected from

Figure 10: Experimental set-up: an adjustable stand for speakers, with a transverse metal bar, and a tennis ball

the sensors were then processed and the TDOA (measured in number of windows of size M) evaluated. Focusing on the impulses generated in the areas of sensor 1 and 2:

- The first sensor able to detect the hit is the nearest;
- The second sensor is the nearest to the first (i.e. sensor 2 if impulse is generated near sensor 1 and vice versa);
- The third and the fourth are respectively the one on the longitudinal direction and the one on the diagonal one.

An example of data is represented in Fig.11a where is shown a graph of the trend of TDOA between different hits in the same campaign. Therefore, these results are in contrast with those collected from sensor 3 and 4:

- The first sensor able to detect the hit is the nearest, as previous test;
- The second sensor is no more the nearest to the first but the one on the longitudinal direction.

These results are shown in Fig.11b and can be explained by the construction design of the runway: as explained in [23] the propagation of waves along the wood grain is faster than the transversal one. In the case of position 1, the two sensors are near the board of the runway, realized with a single peace of wood, which grain are horizontal with respect to long edge of the runway. Therefore, in this board the waves travel faster than the usual transversal propagation and reach the sensor in position 2 before the one in the position 3. On the contrary, sensor 3 and 4 are separated by wooden boards whose grain are transversal w.r.t. the abstracted joining line of the two sensor and this contrast the fast direct propagation of the waves.

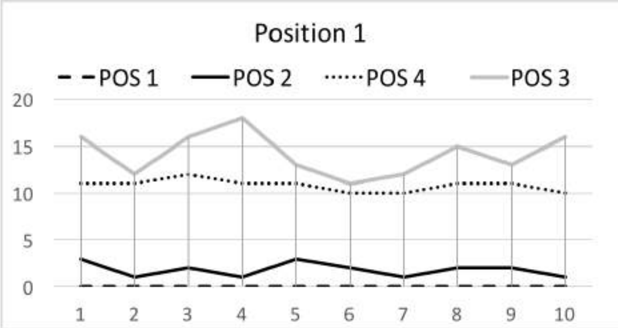
The mean and the standard error of the data collected for all the four sensors of the example campaign just described are summarized in Tab.3. They dictate the implementation of the decision algorithm that process the TDOA information according to which sensor is the first to detect an event:

- if the first is on the smaller side of the runway, the area where the event occurred is the same of the sensor position;
- if the first is on the longer side of the runway, the area is determined by the second sensor reached (i.e. if it is the number 6, than the area will be the one on the right of sensor 3 and vice versa with sensor 2).

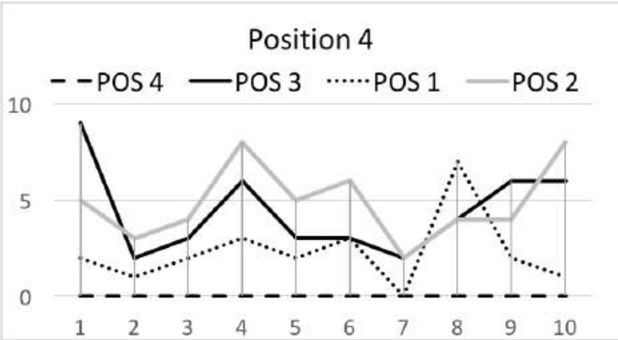
Finally, in the light of these results, was possible to implement the decision algorithm and complete the Localization system for the wooden runway described in this article. Now, the installation can localize the position of the people on the wooden runway, change the parameters of the sonification algorithm and allow to discover a 2D painting in a new 3D approach.

## 6. CONCLUSIONS

The result of the project is the realization of an interactive installation which reproduce an auditory feedback according to the analysis either of the color features of the painting or the steps of the visitors on the wooden runway. The latter are detected thanks to a Localization system based on




(a) Graph of TDOA trend for hits in position 1




(b) Graph of TDOA trend for hits in position 4

Figure 11: Graphs of the TDOA trend (measured in windows of size N as in Fig.8) between signal sensors for excitations respectively in position 1 and 4: POS# describe the area of the sensor, the POS order in the legend is the expected order of arrival of waves at the sensors (geometric considerations); y axis describe the TDOA in number of windows and finally x axis describe the number of hit of a single campaign

the the TDOA measured by piezoelectric sensors, focusing on the first able to detects the steps.

One possible further step could be the use of machine learning techniques in order to map the position on the runway by means of a single sensor and studying the different features that can describe it. Some of these techniques have already been used for indoor localization and space mapping using microphones. With this application, this type of study could allow to overcome the non uniform speed of propagation of the wood. Furthermore this new approach could avoid interferences from outside the runway and from wood crackles and echoes, due to users' steps. A second likely further step could be the use of different sensors. One example could be microphones arrays, positioned just under the runway board. This system could recognize the direction of incoming sound waves and discriminate between the directions of interest and the one outside our range of interest. In the near future, in order to save the installation at the end of the exhibition, a preservation strategy has to be implemented, creating a digital copy and transposing the concepts of active preservation used for audio documents in the field of interactive installations [24–26].

| Mean±S.E. | Sensor1 | Sensor2 | Sensor3 | Sensor4 |
|---|---|---|---|---|
| POS1 | 0 | 1.8±0.2 | 10.8±0.1 | 14.2±0.4 |
| POS2 | 2.2±0.3 | 0 | 7.1±0.1 | 18.5±0.3 |
| POS3 | 6.5±0.1 | 4.2±0.3 | 0 | 6.8±0.1 |
| POS4 | 2.3±0.1 | 4.9±0.1 | 4.4±1.0 | 0 |

Table 3: Mean and standard error of the TDOA of a campaign of measure

**Acknowledgments**

This work has been partially supported by Microtec s.r.l. (Grant n. 98/2015).

## 7. REFERENCES

[1] L. Bullivant, *Responsive Environments: Architecture, Art and Design*. London: V & A Publications, 2006.

[2] M. Eisenberg, N. Elumeze, G. B. L. Buechley, S. Hendrix, and A. Eisenberg, "The homespun museum: computers, fabrication, and the design of personalized exhibits," in *In Proceedings of the 5th Conference on Creativity & Cognition*, ACM, New York, NY, 2005, pp. 13–21.

[3] E. Hornecker and M. Stifter, "Learning from interactive museum installations about interaction design for public settings," in *In Proc. of the 20th Conference of the Computer-Human interaction*, OZCHI '06, vol. 206. ACM, New York, NY, 2005, pp. 135–142.

[4] L. Terrenghi and A. Zimmermann, "Tailored audio augmented environments for museums," in *In Proceedings of the 9th international Conference on intelligent User interfaces*, IUI '04. ACM, New York, NY, 334-336., 2004, pp. 334–336.

[5] O. Bimber, F. Coriand, A. Kleppe, E. Bruns, S. Zollmann, and T. Langlotz, "Superimposing pictorial artwork with projected imagery," in *In ACM SIGGRAPH 2006 Courses*, SIGGRAPH '06. ACM, New York, NY, 2006.

[6] F. Avanzini, S. Canazza, G. D. Poli, C. Fantozzi, E. Micheloni, N. Pretto, A. Rodá, S. Gasparotto, and G. Salemmi, "Virtual reconstruction of an ancient greek pan flute," in *In Proc. Int. Conf. Sound and Music Computing (SMC 2016)*, 2016.

[7] F. Avanzini, S. Canazza, G. D. Poli, C. Fantozzi, N. Pretto, A. Rodá, I. Angelini, and C. Bettin, "Archaeology and virtual acoustics. a pan flute from ancient egypt," in *In Proc. Int. Conf. Sound and Music Computing (SMC 2015)*, 2015.

[8] M. W. Krueger, T. Gionfriddo, and K. Hinrichsen, "Videoplace — an artificial reality," in *in Proceeding of the SIGCHI Conference on Human Factors in Computing Systems*, 1985, pp. 35–40.

[9] F. Sparacino, “Scenographies of the past and museums of the future: from the wunderkammer to body-driven interactive narrative spaces,” in *In Proceedings of the 12th Annual ACM international Conference on Multimedia*, 2004, pp. 72–79.

[10] A. Webb, A. Kerne, E. Koh, P. Joshi, T. Park, and R. Graeber, “Choreographic buttons: promoting social interaction through human movement and clear affordances,” in *In Proceedings of the 14th Annual ACM international Conference on Multimedia*, 2006, pp. 451–460.

[11] K. Gronbaek, O. Iversen, K. Kortbek, K. Nielsen, and L. Aagaard, “igamefloor - a platform for co-located collaborative games,” in *In Proceedings of the International Conference on Advances in Computer Entertainment ACE*, Salzburg, Austria, 2007, pp. 64–71.

[12] K. Gronbaek, O. Iversen, K. Kortbek, K. Nielsen, and L. Aagard, “Interactive floor support for kinesthetic interaction in children learning environments,” in *In Proc. of INTERACT*, Rio de Janeiro, Brazil, 2007.

[13] M. D. Fairchild, *Color appearance models*. John Wiley & Sons, 2013.

[14] G.Succi, G. Prado, R. Gampert, T. Pedersen, and H. Dhaliwa, “Problems in seismic detection and tracking,” in *in Proc. of SPIE*, vol. 404, 2000, p. 165.

[15] G. Succi, D. Clapp, R. Gampert, and G. Prado, “Footstep detection and tracking,” in *in Proc. of SPIE*, vol. 4393, 2001, p. 22.

[16] H. Amick, “A frequency-dependent soil propagation model,” in *in Proc. of SPIE*, 1999.

[17] R. Vera-Rodriguez, N. Evans, R. Lewis, B.Fauve, and J. Mason, “An experimental study on the feasibility of footsteps as a biometric,” in *in Proceedings of 15th European Signal Processing Conference (EUSIPCO’07)*, 2007, p. 748–752.

[18] S. Winiarski and A. Rutkowska-Kucharska, “Estimated ground reaction force in normal and pathological gait,” in *Acta of Bioengineering and Biomechanics*, vol. 11, no. 1, 2009.

[19] M. Syczewska and T. Oberg, “Mechanical energy levels in respect to the center of mass of trunk segments during walking in healthy and stroke subjects,” in *Gait & Posture*, 2001, p. 131.

[20] V. Inman, H. Ralston, and F. Todd, in *Human walking*. Baltimore, London: Williams & Wilkins, 1981.

[21] D. Salvati and S. Canazza, “Incident signal power comparison for localization of concurrent multiple acoustic sources,” *The Scientific World Journal*, vol. 2014, p. 13 pages, 2014.

[22] D.Salvati and S. Canazza, “Adaptive time delay estimation using filter length constraints for source localization in reverberant acoustic environments,” *IEEE Signal Processing Letters*, vol. 20, no. 5, pp. 507–510, 2013.

[23] I. A. Veres and M. B. Sayir, “Wave propagation in a wooden bar,” *Ultrasonics*, 2004.

[24] S. Canazza, C. Fantozzi, and N. Pretto, “Accessing tape music documents on mobile devices,” *ACM Trans. Multimedia Comput. Commun. Appl.*, vol. 12, no. 1s, pp. 20:1–20:20, Oct. 2015. [Online]. Available: http://doi.acm.org/10.1145/2808200

[25] F. Bressan and S. Canazza, “The challenge of preserving interactive sound art: a multilevel approach,” *Int. J. of Arts and Technology*, vol. 7, no. 4, pp. 294 – 315, 2014.

[26] C. Fantozzi, F. Bressan, N. Pretto, and S. Canazza, “Tape music archives: from preservation to access,” *International Journal on Digital Libraries*, pp. 1–17, 2017. [Online]. Available: http://dx.doi.org/10.1007/s00799-017-0208-8