A Dynamic Interface for the Audio-Visual Reconstruction of Soundscape, Based on the Mapping of its Properties

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***Abstract* — The application of hi-end technologies in multimedia platforms provides the dynamic setting of the parameters for the reproduction of audiovisual stimulus from natural environments (virtualization through real-time interaction). Additionally, the integration of cartographic products that describe quantitative and qualitative spatial properties expands multimedia's capabilities for representations with geographical reference. The proposed interface combines data that are used for the mapping of a sonic environment, as well as sonic elements derived from field recordings and photographic material, in order to reconstruct *in-vitro* the soundscape of a protected area around Lake Antinioti, at northern Corfu, Greece.**

I. Introduction

Every place has its own distinctive sound picture, supplementing our own personal history, our social history and that of the world in general with important information. These characteristic sounds form "areas" of unique importance, in that a particular place has its identity not only in terms of geography or physical-temporal aspects, but also in its acoustic properties. On hearing, re-hearing or remembering them, we feel a deep sense of belonging. The discovery of these sounds, their recording and protection, is the work of an emergent school of thought called acoustic ecology [1]. For this purpose, Murrey Schafer [2] introduced the term soundscape to define an environment of sound (or sonic environment) with emphasis in the way this environment is perceived and understood by an individual, or by society [3]. The sound arriving at the ear is the analogue of the current state of the physical environment (Fig. 1), because as the wave travels, it is charged by each interaction with the environment [4].

Since a soundscape is shaped by both the conscious and subliminal perceptions of the listener, soundscape analysis is based on perceptual and cognitive attributes [3], various types of information are required to describe it [5], including intensity per frequency range, origin of the sonic events (human induced, biological or geophysical) [6] and significance (background or foreground) [3] and sound recordings as well. Furthermore, as sound varies according to space and time, information for soundscape has to be treated in both spatial and temporal scales [7].

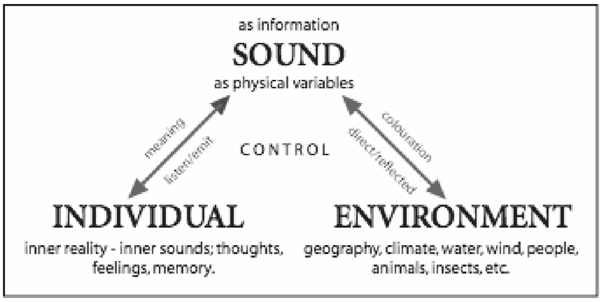

Fig. 1. Sound as a mediator between listener and the environment [4].

A. *Chartographic Represantations*

Some software products are able to give a 2D cartography of the sound, for example when a new motorway is planned. This kind of maps only produces sounds maps according to quantitative data, i.e. sound levels of urban traffic [8]. On the other hand Geographic Information Systems (GIS) are considered the most appropriate "tool" for the mapping of spatially referenced information, quantitative or qualitative, as acoustic properties are [5]. Regarding that describing the soundscape involves the representation of its evolution the interface that will be used for this purpose should be dynamic. Although GIS platforms can manage spatiotemporal data, they have to be customized in order to reproduce and moreover compose (or reconstruct) multimedia files (e.g. sound recordings, video and photos) with geographic reference (georeferenced) [9], [10], [11], [12], [13].

B. *Multimedia Trends*

Multimedia environments can provide the interface for dynamic parametric reproduction – reconstruction of audiovisual situations of real world (virtual reality) and may integrate geographic products (maps and data values) that describe quantitative and qualitative attributes of a given landscape. This concerns not only the visualization (thematic mapping) but also the calculation – estimation of attribute values at any position

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or time (using interpolation techniques).

Realistic soundscape synthesis is a well explored field from researchers and sound artists that incorporate techniques - based mainly in sampling of physical modeling to create electroacoustic music or interactive multimedia works. Also soundscape interfaces in a similar category have been proposed or realized, sometimes using dynamic resynthesis with various approaches [15] to [20].

C. Aim and Objectives

Sound (and its attributes), space (geographic coordinates), and time (annual, daily cycles) are the main axis for describing a soundscape. Taking into account the heterogeneity of the associated information (georeferenced quantitative and qualitative data, sound recordings and documentation material such as video and photographs) was born the idea for developing a convenient interface for their integrated management and representation. The aim of this effort is the creation of a modeling environment that will be used as a pilot, in the study of soundscape. The main objectives of that project include: a) the insertion of collected properties, that describe a given soundscape, in a database, b) their representation using techniques of spatial analysis with consideration to their spatiotemporal character, c) the estimation of soundscape' s properties at any given location and time (within the recorded limits), through programming modeling for the reconstruction of a sonic environment (soundscape) and d) the design of a platform that controls and represents dynamically the modeling procedure and which can be used for environmental training and research as well as for alternative music compositions.

II. MATERIALS

The base material that is used for the development of the interface is the result of a yearly long research dedicated to the study of the Greek soundscapes and which was conducted by the Hellenic Soundscape Research Group. The group has been formed by researchers from the Laboratory of Electroacoustic Music of Ionian University's Music Department, the faculty of Ecology at the Department of Biology of Aristotle University of Thessalonica and the Department of Acoustics and Music Technology of the Technical University of Crete.

A. Study Area

The pilot area is around Lake Antinioti, in the northern part of the island of Corfu, western Greece (Fig. 2) and it extends 2100 m (on the East - West axis) and 1600 m (on the North – South) and has been proposed to be included in the NATURA2000 network (as a protected site of special ecological interest). Several land-use types such as semi-urban sites, cultivations, wetland, coastal systems, primary forests, cultivation fields, meadows and extensive olive plantations characterize the landscape.

B. Dataset

In order to cover the annual cycle data contains recordings and observations from the four seasons according to solstices (March, June, September, and December).

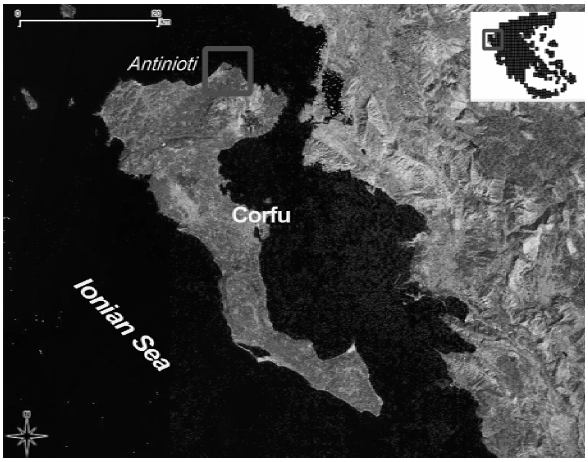

Fig. 2. Map overview. The study area is marked with a square.

During every season, has been defined eight periods (ten minutes each) during the day (1st period: 0-3 am; 2nd period: 3-6 am, 3rd period: 6-9 am; 4th period: 9-12 am, 5th period: 12-15 pm; 6th period: 15-18 pm, 7th period: 18-21 pm; 8th period: 21-24 pm) to cover the daily cycle and furthermore, each period contains forty sequential subperiods (fifteen seconds each) that are used to cover the evolution of the occurring sonic events.

The dataset is composed by four categories of data that has been captured from 15 sampling sites that cover the study area (regularly distributed over a grid): a) acoustic measurements, b) sound recordings, c) recordings for the origin of the observed sounds and d) recordings of the meaning and significance of the observed sounds. Acoustic measurements has been done with sound level meter with spectrum analyzer (Cesva SC-310) and resulted in the calculation of the Sound Pressure Level (SPL) per octave band. Sound recordings have been performed with a digital tape recorder (TASCAM DA-P1 - DAT) and an omni directional microphone system with a preamplifier (SCHOEPS VMS5U) and a windshield protection (RYCOTE). The origin of the observed sounds has been recorded in a specially designed form, which is used to estimate the percentage of human, biological and geophysical during each period. The meaning (description of source) and significance (background or foreground) has been recorded in another form.

Additionally a satellite image (or aerial photo) has been used as a reference (base) map, fifteen panoramic (360°) photographs from the sampling sites and video and other photographic material from various locations (within the study area).

III. PILOT DESIGN

The major issues that have been considered, for the development of the interface was: a) the immediate retrieval of all collected data, playback of recorded sounds and display of the associated maps and photos through an integrated environment, b) the potential of using seamless all collected and produced data for research purposes (e.g. environmental study and education, training and "virtual navigation" of blind people etc), c) to provide an information – educational platform, for inexperienced users, which reproduces in a realistic way (simulates) the acoustic environment (soundscape) within the study area of lake Antinioti.

With respect to the above, we created a virtual environment that describes in two spatial dimensions and over time (3D) the soundscape of the study area. The description is achieved through the reconstruction of the sonic events at any location of the given space in accordance to their geographic reference. Thus, the presented product is not only a sequence (time – series) of thematic maps for selected properties of the soundscape, but moreover a realistic aural reproduction through the virtual navigation with a mouse or pointer device.

IV. Methodology

In the case of representing and moreover reconstructing an acoustic environment (soundscape) an estimation of the sonic conditions at intermediate locations (between sampling positions), could be obtained using interpolation techniques for the mixing of recorded sounds (from the recordings of the nearest surrounding sampling positions). Although it seems to be easily adaptable, it is at a disadvantage because of soundscape's nature.

The proposed methodology follows an alternative approach that could be described as an interactive parametric 3D audiovisual reconstruction of a natural soundscape based on the mapping of its properties. This approach is based on the observation - recording and classification of the sonic events (of a given acoustic environment) according to their quantitative and qualitative attributes, their geographic reference and time / date of occurrence. Quantitative attributes include SPL per frequency range (octave bands) whereas qualitative ones have been estimated by the observations (hearing) of the sonic events. The sonic events are characterized as background (e.g. sea waving, wind gusting, rain, motorway etc) or foreground (e.g. frogs, bird singing, dog barking passing vehicles, speech etc). Additionally, each sonic event is classified according to its origin (human, biological or geophysical). Moreover each observation is associated to the recordings and obtained a spatiotemporal reference. Every distinguishable sonic event defines an acoustic sample (in connection to the music samples or the instruments in an orchestra).

This approach is based on the deconstruction of the sound recordings (soundscape's shortcuts) to its principal components (sonic events) relatively to their attribution (quantitative recordings and qualitative observations). Sequentially, the attributed principal components are used to reconstruct the soundscape for any selected location over a map.

A. *Soundscape Deconstruction*

All categories of collected data (sound recordings, acoustic measurements, observations and documentation material) are organized in a relational database. One table (Table I) is used for the sound recordings of the sonic events, two tables are used for the attribution of sonic events (recordings) with the quantitative properties that have been obtained by the measurements (Table II) and with the qualitative properties that have been calculated from the observations (Table III) and another for geographic coordinates and the panoramic photos of each sampling position (Table IV). The above tables are related with the field that describes the area number (ar).

TABLE I.
Sound Recordings of Sonic Events

Field	*Description*	*Data type*
sn	sound id	number (integer)
ar	area id	number (integer)
tr	time of recording (timestamp)	time/date
dr	duration in milliseconds	number (integer)

TABLE II.
Acoustic Measurements (Quantitative Attributes)

Field	*Description*	*Data type*
ar	area id	number (integer)
tr	time of recording (timestamp)	time/date
rg	registry (integer)	number (integer)
fA	frequency weighting A	number (single)
fC	frequency weighting C	number (single)
fZ	frequency weighting Z	number (single)
Fs	parallel scanning Fast	number (single)
Ss	parallel scanning Slow	number (single)
Im	Impulse	number (single)
Mx	Max	number (single)
Mn	Min	number (single)
SL	SEL	number (single)
Lq	Leq	number (single)
LqI	LeqI	number (single)
L1	statistical distribution L1%	number (single)
L5	statistical distribution L5%	number (single)
L10	statistical distribution L10%	number (single)
L50	statistical distribution L50%	number (single)
L90	statistical distribution L90%	number (single)
L95	statistical distribution L95%	number (single)
L100	statistical distribution L100%	number (single)
Pk	Peak	number (single)

Additionally one more table (Table V) has been produced from the co-processing of observed and measured data, which is used to describe the properties of each sound event.

"Spread" is a variable that describes the distribution of a sound over time (1-100). In a value of 100, the sound distributes evenly on a given time frame while smaller values tent to create packets of time where this sound appears more frequently than others.

TABLE III.
OBSERVATIONS (QUALITATIVE ATTRIBUTES)

Field	*Description*	*Data type*
sr	source description (bird, frog, car…etc).	text
ar	area number (id-integer)	number (integer)
tr	time of recording (timestamp)	time/date
or	origin (bio, geo, anthropo)	text
mn	meaning (background, foreground)	text

TABLE IV.
SAMPLING POSITIONS

Field	*Description*	*Data type*
ar	area id	number (integer)
lt	geographic latitude (dd.dddd)	number (single)
lg	geographic longitude (ddd.dddd)	number (single)
hg	height- altitude	number (single)
ph	panoramic photo file (path)	text

TABLE V.
PROPERTIES OF RESULTING SOUND

Field	*Description*	*Data type*
Dn	data id	number (integer)
Ar	area id	number (integer)
Tr	time of recording	time/date
An	anthropo volume	number (single)
As	anthropo spread	number (integer)
Bi	bio volume	number (single)
Bs	bio spread	number (integer)
Ge	geo volume	number (single)
Gs	geo spread	number (integer)
s	source (example "car")	text
f	frequency of appearance for source	number (single)
v	volume limits for source	number (single)
p	spread for source	number (integer)

B. *Spatiotemporal Representation*

The cartographic representation of the spatial variations for selected attributes of soundscape is based on the calculation of the values for any position between the sampling positions. Using the values that describe the recorded and observed attributes at each one of the sampling positions, was performed a regularized spline interpolation [5], [14] in order to produce one thematic map per period; total eight maps per attribute. In such a way have been produced the following maps: a) spatial variations of human, biological and geophysical sounds (Fig. 3), b) a composite color map of soundscape's origin assuming human as red, biological as green and geophysical as blue c) spatial variations of the intensity for background and foreground sounds and d) spatial variations of the acoustic measurements for SPL. To demonstrate the combination of soundscape's characteristics, it is performed a multidimensional representation [14], considering geographic dimensions (longitude, latitude) as x and y values, SPL values as z values and draping on the resulted relief the composite color map that describes the presence of human, biological and geophysical sounds (Fig. 4).

Fig. 3. Thematic mapping of the intensity of human (red), biological (green) and geophysical (blue) sounds.

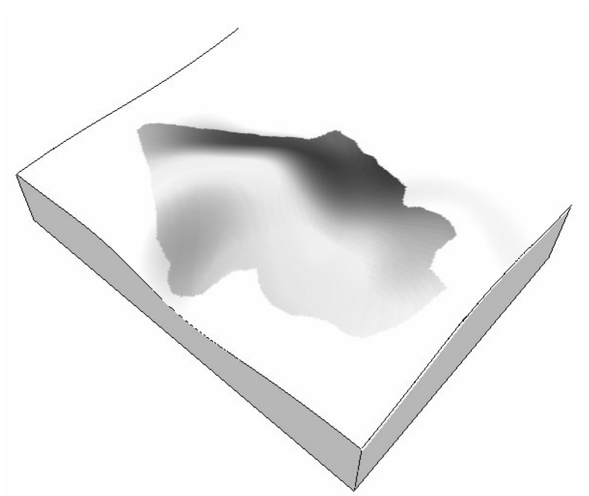

Fig. 4. The composite map describes the spatial variations of soundscape's origin and the relief represents the measured SPL values.

Moreover the simulation of the evolution for each attribute (during a day) can be achieved through the playback of the sequence of the time stamped maps and the related multidimensional representations.

C. *Modeling Architecture*

The estimation of soundscape' s properties at any given location and time (within the recorded limits), through programming modeling for the reconstruction of a sonic environment (soundscape) can be described as follows:

The program reconstructs the soundscape using samples (recorded on location) of each sound element that it consists of. Before the reconstruction process, the sounds are divided in two categories. Foreground sounds which tent to be shorter and easily recognizable and the sonic background where these sounds appear (for example the sound of the sea at a distance). Foreground sounds are continuous and tend to be ignored from the listener after a while. The sonic elements of each recorded soundscape (foreground and background sounds), are isolated using signal processing techniques, (editing, de-noising etc) and categorized in databases along with the data from the subjective measurements for each area.

D. Interface Development

Fig. 5 shows the basic structure of the soundscape reconstructor. It is developed in MAX/MSP and java. The cursor's position is read on a canvas, which is the Aharavi's area map (Fig 6.). The program looks for the closest points of reference (where measurements on the soundscape's structure have been carried out). By combining the information on the 4 closest points of reference (north, south, east, and west) and the current distance from them, it calculates the "weight" of each individual foreground sound that should be appearing at a specific location in the Aharavi area.

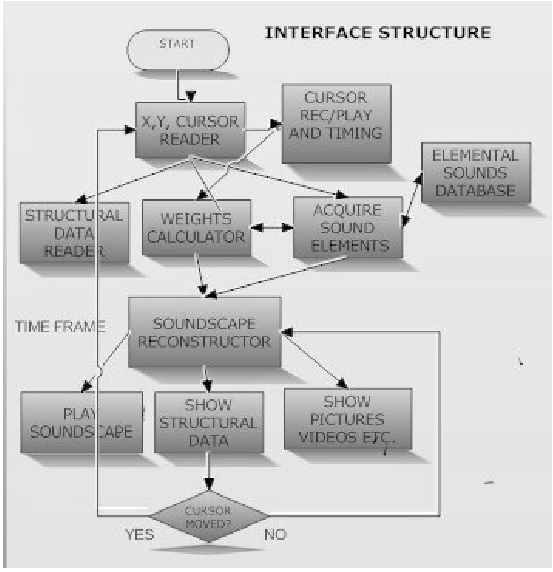

Fig. 5. The basic processing modules of the soundscape reconstructor

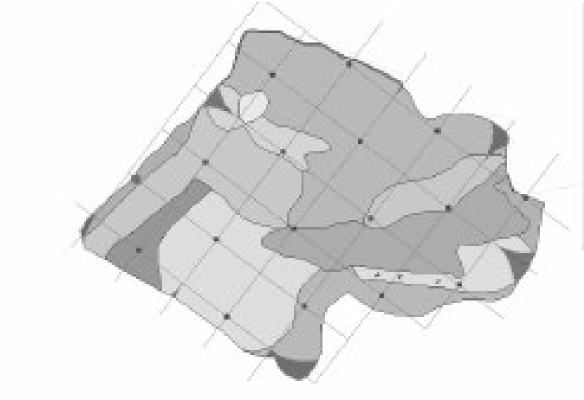

Fig. 6. The map of the study area (Antinioti) and the sampling locations.

The "weight" consists of the sound's frequency of appearance in a given time frame (in this case 10 minutes), and its volume range.

V. RESULTS

Every location within the study area is described over a sonic map respectively to the visualization (cartographic representation) of measured and observed acoustic properties. The virtual navigation over the map reproduces the sonic environment, as it has been recorded *in-vivo*. This allows the audiovisual reconstruction of the soundscape around Lake Antinioti.

The user can hear the sound recordings from selected sampling positions and time periods and watch the associated panoramic photos. Additionally, he may live aurally (relatively to virtually) the sonic conditions at any intermediate location or time, using a pointing device (mouse or stylus pointer) and scrolling over the timeline. During this operation the corresponding geographic coordinates as well as the measurements of recorded environmental conditions (temperature, humidity and wind) may be displayed dynamically. Moreover, one may construct a potential soundscape (based on the existing recordings and observations) by regulating-selecting the parameters that describe the given environment.

In Fig. 7 we can see an example on how we calculate the frequency of appearance for the sound of "frog" (fe) in the point E. The fe is given by the expression (1).

$$fe = (fa * (ds - da)) + (fb * (ds - db)) + (fc * (ds - dc)) + (fd * (ds - dc)) / (4 * (da + db + dc + dd)) \quad (1)$$

Where fa is the frequency of appearance of the sound of the frogs in point a, fb at the point b etc., da is the distance from the point a db the distance from point d etc., ds is the distance between the recording fields (maximum distance).

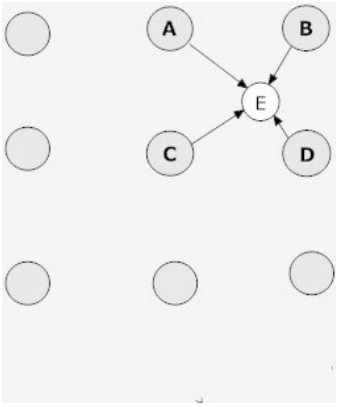

Fig 7. Obtaining data from the closest sources

The type of sound (biological, human or geological) is also considered so that the final soundscape contains the appropriate percentages between the different types.

A different method is used to reconstruct the background. Its sonic qualities are reconstructed by mixing the sonic backgrounds of the closest known locations taking also into consideration how static or dynamic the background is.

After the calculation of the structure the "soundscape reconstructor" acquires the necessary sounds from the foreground and background sound database (using samples taken from the closest to the cursor's position recordings) and reconstructs the soundscape based on its measured characteristics.

If the user moves the cursor, the new cursor coordinates are used as a basis for a new calculation that changes the proportions of the soundscape's content in real time.

A similar process is used for the "time shift" function where movement in the x,y axis is replaced by time change (acoustic measurements at the same areas at a different time) Here the change of the soundscape is not even as considerations have been taken about how the soundscape changes rapidly at certain periods of the day (like the dawn). As the program plays the sound it also displays the main characteristics of the soundscape at the given position.

VI. Discussion

Soundscape is an ever-changing version of a given environment, thus it presents great spatiotemporal variability. The major issue, during the presented methodology, was the estimation and furthermore the reconstruction of the acoustic environment at the intermediate locations (in spatiotemporal terms) between sampling positions or/and recording periods. During the visual representation (thematic mapping) of soundscape's properties, the issue of fragmentary observations and measurements was overcame by the application of interpolation techniques, provided by GIS software. The reconstruction method was based on the dynamic composition and playback of sounds that had been produced by the recordings in the field (at the sampling positions and during the defined periods). The limitation of the given resolution (15 points x 8 periods x 10 minutes) could be eliminated by the simultaneous and continuous recording (for the time scale) and the definition of a denser grid of points (for the spatial scale), fact that would require numerous personnel and equipment.

The originality of the described approach is that the technique for the realistic reconstruction (and reproduction) of a soundscape is provided through an interactive interface, relatively to the referred geographic space (over a map) and in accordance to measured and observed acoustic properties of a given environment.

The reconstruction process creates realistic soundscapes that carry the same characteristics of the original recordings but they have some advantages over them:

1. Their duration is limitless, because the dynamic re-sythesis of soundscape' s content (in real time) can be reproduced algorithmically by the program (and also interactively by the user by changing the cursor's position on the map or drawing a route to it) without repeating, as a sound loop would do. At the same time the size of the necessary sound data for the reconstruction process is much smaller from the source recordings material. The former fact allows easier manipulation storage of the program.

2. Their accuracy (in relation with the real sonic environment that they represent) can be improved without high cost for recording and observation teams. Since the sound samples that are derived from the flora and fauna does not vary from point to point in these scales of sampling and in an terrain with smooth relief, but rather by their combination in a soundscape, additional measurements for their frequency of appearance can enrich the reconstruction algorithms and databases for additional points and periods for which lack of data is noticed. So the sonic map of an area can be enriched at any time with new observations that can be carried out by one or two persons with minimal or no recording equipment, and low or no cost. Note, that this approach suggests a different location selection that a grid of equally spaced locations. Places of particular geomorphological interest (like for instance a waterfall at a certain location) are more important for supplying information about the overall soundscape.

3. The program can be improved at any time taking into consideration newer discoveries of environmental or zoological research. For instance the distribution and traffic of animals in a given landscape, depending on the season, or sounds that are produced by particular species during reproduction – mating period, could be participate in the formation of a reconstructed soundscape with regard to the selected season.

4. The system allows experimentation. The user can alter the characteristics of the soundscape by changing the quantitative or qualitative elements that it consists of, for experimentation, research or entertainment. For instance

one could alter a parameter of the soundscape and listen to the result of what would happen "If I follow this route and listen all the sounds except the ones that are produced by humans?" or "what would happen to the soundscape if "there were no passing cars at this location?"

5. The interface's design allows combinations of visual material like photographs, videos, graphs etc. to be synchronized with geographical data. Also it can be used in motion film production for supplying the sonic environment of an area where action happens (or it's supposed to happen).

In conclusion, the described procedure results in a platform that provides various operations for many application fields.

VII. Perspectives

Immediate applications of the presented interface includes the following:

A. *Evaluation of Observations*

The comparison between *in-vivo* and *in-vitro* observations (hearing) may be used for the evaluation of the observation method. The same observer can repeat (re-hear) the sound recordings and reclassify the sonic events. Furthermore, it may be studied the correlation between observations during various periods (e.g. winter - summer, day – night) and environmental conditions, when the visual or other stimuli vary.

B. *Suplementary Observations*

The playback of the recordings may be used for the estimation of the acoustic properties by other observers, including blind people (or with limited vision), and the comparison to the primer observations in order to assess the effect of subjectivity.

C. *Music Composition*

The proposed interface can also be used for musical purposes by replacing the original samples with other music sounds or updating the recordings with new sonic events. By this way can be achieved interactive music composition that will be based on a specific location's soundscape characteristics.

D. *Data Browsing*

The dynamic (real-time) interaction over a mapping environment provides immediate access/playback of any kind of related data (recorded, observed or produced) respectively to their spatiotemporal origin. This allows the direct comparison of attributes between different geographic locations and time periods and facilitates researcher's work.

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