Towards a Multidimensional Visualization of Environmental Soft Sensors Predictions

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Abstract

Soft sensors have been successfully applied to simulate physical and chemical measurements in specific locations of a monument.

They allowed monitoring the quality conditions of the monument surface for long periods of time. This is a not invasive process that provides a huge set of multidimensional data. They have been analyzed by the Cultural Heritage experts to find physical or chemical critical condition which could generate some degradation process.

Here we propose several multidimensional visualization techniques to represent the predictions of environmental parameters, given by several soft sensors, in a comprehensive and compact way. Visualization tools using both shape variation (glyph) and color are developed to realize an homogeneous communication paradigm. Moreover, each tool uses a 3D navigable model of the monument as visual support.

1 Introduction

As it is known that color is an important tool for human communication. However, in presence of multidimensional data it should be used jointly to other visualization tools.

In order to support the requests of the experts in Cultural Heritage, we have designed and developed a set of techniques, based on the visual tools of color and glyphs, to achieve comprehensible as well as not-conventional visualizations of multidimensional data that allow an overall and/or detailed presentation of the acquired data. Thus, the developed applications are equipped with time and space animation to improve the comprehension of complex physical phenomena, as the ones that cause degradation events of the material composing the monument [4].

The most of these tools use a specific communication paradigm jointly a navigable 3D model of the monument (in this case the Roman Theater in the city of Aosta) [1]. We underline that this 3D Model has been developed by others as part of a wider research activity carried on within Italian national project named SIINDA.

In this way the cultural heritage expert can observe how a specific set of data evolve during the time in every point of the monument. Obviously, this 3D model supports actions like zoom in, zoom out and gyroscopic point of view. Thus every part of the monument is always observable at each scale level.

Our implemented object-oriented software is based on the powerful Visualization Toolkit (VTK), a free C++ class library for visualization and 3D computer graphics. The used data are physical and chemical measurements regarding the quality of the surface of the Roman Theater in the city of Aosta.

In this paper we show how the multidimensional visualization model [4] can be theoretically applied to a set of data provided by soft sensors, working instead of the hard sensors, in order to realize a full virtual monitor system in the field of cultural heritage.

The soft sensors of various type have been used for obtaining measurements for solving the problem of not invasive monitoring in cultural heritage in [6],[5],[3]. In this field it is very important to have not invasive tools to monitor the physical or chemical conditions of materials composing a monument as well as the atmospheric condition around the monument. Moreover, the easy reading of several kinds of data is a fundamental step to verify the possible action of atmospheric agents and to prevent effects on the monument surface.

In section II the environmental data that are acquired to monitor the quality of the composing materials of the roman theater are reported. In section III the problem of the not-invasive monitoring of a monument as solved by means

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of the neural networks paradigm is described. In the section IV the visualization tools that have been chosen to represent multidimensional data, characterizing the quality of the monument surface and therefore used to provide the monitoring of the roman theater in a compact way are presented within some examples.

2 Environmental data in the study-case

During the research activity carried on the project SI-INDA, the Roman theater in Aosta city have been monitored for long time by acquiring historical data series of physical and chemical parameters, related to the atmosphere around it and to the composing materials, by means of appropriate sensors installed on the monument surface. In our study-case measurement of several atmospheric agents, besides the geometric information of the monument, have been considered:

- the photogrammetric relief of the theater and of a specific pillar of its facade, which was chosen as a particular object of the study-case;
- measurements of air temperature, contact temperature, and humidity, sampled hourly, which have been settled on the theater surface, by several hard sensors working for a period of one year. At this aim, 44 sensors have been located in the north (back) and south (front) facades; the sensors are subdivided in different types: 9 sensors for air temperature Ta, nine for relative humidity H and four for contact temperatures Tc on each facade and one anemometer to measure the module and direction of wind velocity on the top of the theater;
- measurements of air chemical pollutants such as SO2, NO, NO2, NOx acquired in the same period;
- measurements of temperature Ta and humidity H are also hourly acquired by an Air Ambient Monitoring Station (AAMS) at a location, placed nearby the theater, at ground level;
- predictions of temperature Ta, contact temperature Tc, humidity H computed by Elman soft sensors in four locations on the pillar in four cardinal directions (upper arcade).

The series of the ambient data (temperature and humidity) are acquired hourly by an AAMS that is located at ground level, at about 40 meters from the theater. The series of the ambient data on the pillar surface are hourly acquired by sensors installed on its four sides. In both cases it is possible a lack of data in the time series.

3 The not-invasive monitoring of a monument

The monitoring of an ancient monument is a long-term process, which obliges to maintain several hard sensors on its surface for a long time to periodically repeat the sample campaigns. Doing so, the process has high costs and becomes invasive, since it reduces the enjoyment of the monument itself.

Soft sensors based on Elman neural networks have been implemented to provide on site accurate virtual measurements at locations of the monument surface using only the measurements acquired by one (or more than one) Air Ambient Monitor Station located nearby the monument. Therefore, the hard sensors can be removed and the trained soft sensors can be used instead.

The modular system described in [6] and depicted in fig. 1 is based on recursive neural network of Elman type, it is able to predict ambient parameter values (such as air temperature, contact temperature and humidity) in specific locations on the monument surface (for example, placed on different cardinal directions on a specific pillar, or all on the south facade).

The input to the system are real measurements (such as air temperature or humidity) acquired by an Air Ambient Monitor Station (AAMS), located nearby the monument. Indeed, different types of soft sensors for the ambient parameters (air temperature, contact temperature, and humidity) have been developed and trained on the same set of data acquired for the theater [3], with the size of both the training and test set of N=1349 surveys to cover a period of almost six months.

The types of NN chosen in comparison are: multi-layer perceptron, Radial Basis Function model, Elman, SVR. Among these kinds of neural networks, the Elman Networks showed to have the best features to predict environmental data, possibly due to their recursive behavior. MATLAB Toolbox for Neural Networks and the Toolbox SVM-KM [2] have been used to simulate the used neural networks.

The system, and in particular each soft sensor, is trained using a rich series of data obtained both from the AAMS and the hard sensors located (only for the period, strictly necessary for the training) on the monument.

The training data set and the test set contain measurements of the atmosphere parameters acquired both by an AAMS and by hard sensors in several positions on the theater. The sets are formed by ordered pairs of measurements at the same time. From the training set, each soft sensor learns the associations among ambient parameters, measured by the AAMS and by an hard sensor on the monument, to predict values at a specific location on the monument in differed times. These predictions are to be validated using the test set.

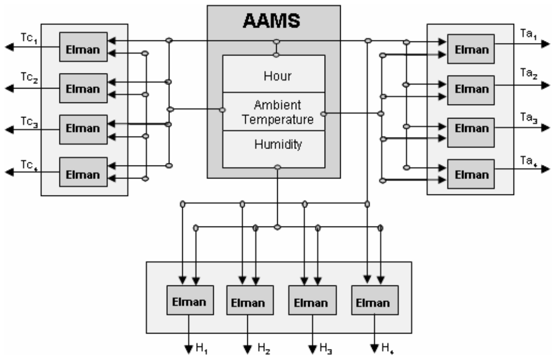

Figure 1. The AAMS and the connectionist system topology. Ta, Tc and H are the estimated air temperature, monument surface temperature and air humidity in 4 different locations on the monument surface

We underline that in this application a soft sensor is viewed as an "instrument" that provides indirect measurements, in fact the output is in a different geographical position from the location of the input and can be a different ambient parameter.

The performance of the soft sensor was analyzed and compared from a metrological and statistical point of view, showing a good behavior in monitoring the ambient parameters at each hour of the day and in all temperature range for a long period [6].

4 Visualization tools applied to the Roman theater

"Visualization is a method of computing" and "visualization offers a method for seeing the unseen", are some of the widely known statements that define Scientific Visualization.

Such visualization allows supporting researchers in the investigation of measured and simulated multidimensional data [7]. In our case "seeing the unseen" can mean, for example, showing the relation that exist among the simulated data and the decay event as related to the geometric location on the monument, where the phenomenon may appear. Moreover the monitoring of the monument for long period can be obtained by means of animation applied to the multidimensional tools that are available.

The development environment that has been chosen for our visual applications is VTK [9], that is C++ object-oriented freely available visualization toolkit. It offers a great variety of visualization techniques, so the pipeline may be designed and built freely and quickly. VTK pipeline or network becomes a cycle, when, using the rendering, the interactive part is emphasized.

The rendering step is actually outside the visualization pipeline, being a final phase that is concerned with graphics; it serves just as a way to display the results of the pipeline and, eventually, to close the pipeline in a cycle with the feedback.

In order to meet the needs of exploring and better analyzing the results of the climatic and environmental agents on the monument decay we have identified two approaches to visualization: qualitative, based on the classic visual tool of the color, and quantitative, based on shape variation as powerful visual elements [8],[4].

In both types of visualizations, the implemented programs allow the expert users navigating in both space and time. A custom method of interaction has been developed for the applications.

Typically, one can interact with the scene in the space dimensions, that is rotating, translating, zooming the dataset, and so on. Our approach was strongly influenced by the structure of the data, being series of time-dependent samples. Therefore it can be more interesting for the user to navigate in the time dimension as well; the scene becomes then animated, so that one can achieve a comprehension of the evolution of the data with respect to the time. The interaction method lets the user control the evolution during a whole day, and also go forward and backward in time.

4.1 The color tool

Qualitative tools have been developed in order to give an easy and global visualization of our multidimensional data. Color can be an appropriate instrument to describe global structure of data, since it can be perceived in a very natural way by humans, hence it plays a crucial role in our perception and interpretation processes [10].

In this work, the applications developed using color are the color maps. A visual color analysis of the climatic measurements of relative humidity, temperature and contact temperature, taken on selected points of the theater facade is described as follows.

Starting from environmental data acquired by the hard sensors for the facade or simulated by soft sensors in the case of the pillar monitoring, an interpolation method provides the facade color image, to generate data arrays that, mapped in pixel maps and rendered in synthetic color images, represent the values in every point of the image [7].

Following the principle of the color maps, different techniques have been developed. They are able to represent in an effective and immediate way the global state of the data in a given moment.

The color is applied to represent the physical or chemical data on the theater surface, so that one can see directly on it

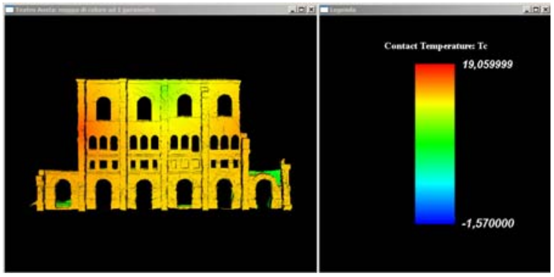

Figure 2. The color map applied to the south facade of the theater.

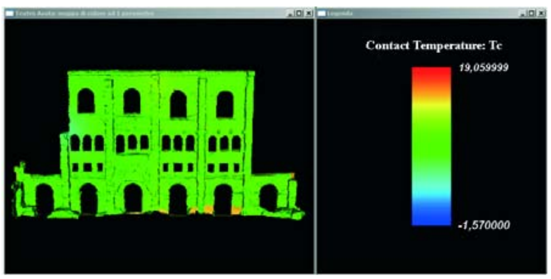

Figure 3. The color map applied to the north facade of the theater.

the variation of the parameters and to identify regions with particular behaviors.

Being multidimensional data, three applications were developed, using a different numbers of parameters.

In each application the user can act spatially (rotating, zooming, panning, 'flying to' a certain region), but also can handle the time variable (going back and forth, for instance); all this is performed with the use of the mouse and, occasionally, of the keyboard.

Our implementation is based on recognizing the four basic sides associated to the four directions "East", "West", "North" and "South". Then, in order to assign a color to every cardinal point, we have to recognize the subset of "competent" sensors, i.e. the sensors belonging to the same facade.

With functionalities developed in the classes we can distinguish the back and the front facade of an object, up to the four basic sides.

Two screen shots show the color maps of the south facade (see Fig. 2) and the north one (see Fig. 3), obtained interpolating the parameter of the contact temperature, relieved taken by sensors, located on the facades.

By analyzing the colors in the scene, and comparing them with the legend, one can understand the clear difference of contact temperature values present on the front and on the back facade.

The small yellow areas present in the bottom of north facade represent the parts of the south facade which remain visible. They are a acquisition problem, due to the slope of the theater.

The images of the pillar studied, located on the upper arcade of the theater, (see Fig. 4) are screen shot related to color maps obtained interpolating the air temperature Ta measure relieved by a soft sensor for each side of the same pillar. T he application is based on the sides recognition procedure, in this case a four-sides recognition has been utilized. These frames describe the situation on the 4 sides of the T_a parameter, measured by the soft sensors.

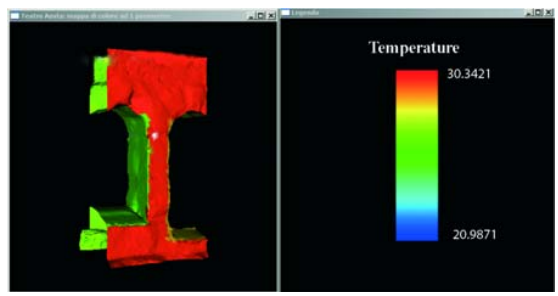

Figure 4. The color map applied to the pillar: image for air temperature data predict by the soft sensors.

4.2 Quantitative tools and the Superquadrics

The technique used for detailed information is the iconic visualization, that consists in representing data with icons (glyphs).

This technique is based on the perceptual power of the shape and of shape changing, which is based upon the capability for the human eye to perceive 3D shape variations in a pre-attention phase.

Formally a glyph is a graphical entity that represents data by geometric attributes, such as shape, direction, orientation and position, or appearance attributes, such as color, transparency and texture. The shapes chosen are based on a procedural glyph, namely the superquadric surface [8] .

Then the "flower" metaphor has been as application of two-dimensional iconic visualization [4].

$$S(\theta,\phi) = \begin{bmatrix} a_1 \cdot sign(\cos\theta\cos\phi)\,|\cos\theta|^{\epsilon_2}\,|\cos\theta|^{\epsilon_1} \\ a_2 \cdot sign(\sin\theta\cos\phi)\,|\sin\theta|^{\epsilon_2}\,|\cos\theta|^{\epsilon_1} \\ a_3 \cdot sign(\sin\phi)\,|\sin\theta|^{\epsilon_1} \end{bmatrix}$$

with $-\frac{\pi}{2} \le \phi \le \frac{\pi}{2}$ and $-\pi \le \theta < \pi$

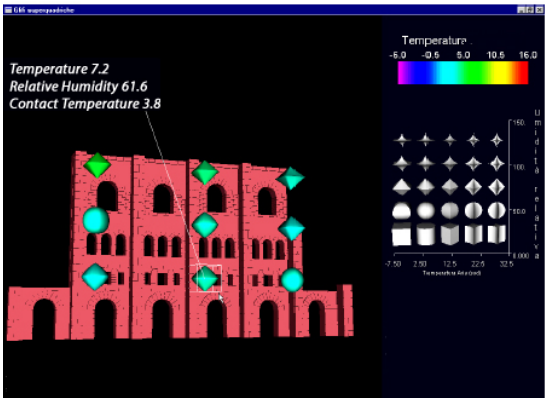

Figure 5. Screenshot of the 3D glyph application

The family of superquadrics can be subdivided in four main subfamilies, being superellipsoids, superhyperboloids of one sheet, superhyperboloids of two sheet and supertoroids. Among these we have chosen the superellipsoids to visualize different shapes.

Superellipsoids can therefore be obtained as the spherical product of a complete superellipses lying in the horizontal plane and a half superellipse lying in its orthogonal plane. The superquadrics equation depends on three parameters a_1, a_2, a_3, the scaling factors along the three coordinate axes. ϵ_1 and ϵ_2 are shape parameters are derived from exponent of the two superellipses components. ϵ_1 determines the shape of the superellipsoid cross section in a plane perpendicular to the (x, y) plane and containing the z axis while ϵ_2 determines the shape of the superellipsoid cross section parallel to the (x, y) plane. In our case, sixteen different and comprehensible shapes of superellipsoids, obtained varying the values ϵ_1 and ϵ_2 have been selected as in [4].

As shown in Fig. 5, the glyphs are placed where the acquisition probes were settled in the training period, in particular nine colored superquadrics are visualized on the theater.

They represent the measurements of air temperature (south side), relative humidity and contact temperature, related to the first cycle of measurements.

The user can get more precise information about a specific point by clicking on the glyph; a caption box appears to display the scalar values defining that shape.

The possibility to animate the visualization and go back and forth in time helps the user to perceive the exact variation of the data and to focus on the interesting regions and periods of time.

4.3 "Flower" visualization tool

As in [4] we adopted the "flower" icon with several petals, to represent the simultaneous variation of several environmental and chemical parameters, where a single parameter is associated to a petal.

It is based on sinusoidal spiral equation that can be formally defined by the polar equation: $\rho^n = a^n \cos(\theta)$ with $n \in R$. This graph is not a true spiral, in fact it acts as "spiral" but its radius increases and decreases "sinuously". In the figure 6 an example of this visualization is reported.

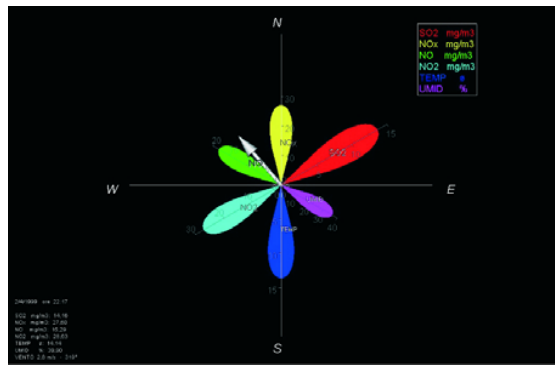

Figure 6. The colors and lengths of the petals, respectively, identify the values of four concentrations SO2, NO, NO2, NOx and of three climatic parameters dew temperature, air temperature and relative humidity.

The final image allows to communicate compact information about several parameters of different type, both scalar and vector, at the same time, thus realizing a multidimensional visualization.

The image where "flowers" are depicted in the nine locations on the theater facade, as already done in Fig. 5, is also possible.

Doing so, we realize a unique representation in the complex case of this cultural heritage study-case: this visualization represents a very flexible and eye-catching way to visualize multidimensional localized datasets.

To distinguish positive values of scalar data from negative ones we use full/empty visual information of the leaves/petals. Doing so, we represent both positive and negative values using the same visual paradigm.

Moreover, the wind parameter is displayed as an arrow glyph. This arrow is generate and superimposed according to the direction and intensity of the wind.

In Figs 7 example of representation by icon and color are shown. The little arrows represent local wind around

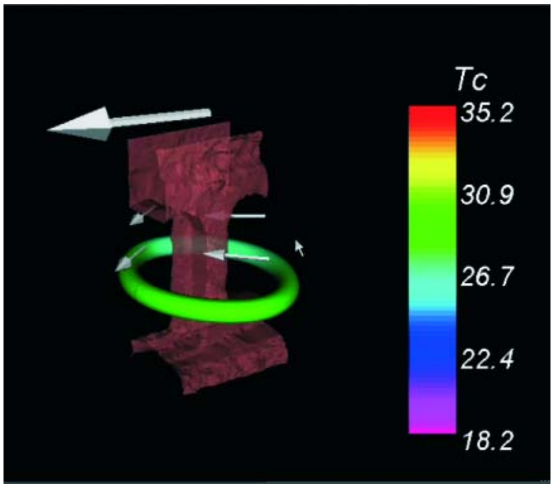

Figure 7. Wind data depicted by using an arrow glyph, oriented and scaled according to the direction and intensity of the wind.

the pillar, while the big arrow is the wind measured by the station located near the Theater.

The color ring is the visualization of a scalar parameter, that is the contact temperature Tc measured on the 4 sides of the pillar. This application can help the expert to study the action of local wind (Venturi effect), for example stressed areas on the pillar corners, compared with the wind present in the whole zone of the Theater.

5 Conclusion

The soft sensors, being able to implicitly construct a correct physical model for several ambient parameters, have been used to monitoring the quality of the surface of the roman theater in Aosta city.

The visualization tools based on the Visualization Toolkit (VTK) have been applied to support the quantitative analysis of the cultural heritage experts in order to better understanding evolving phenomena of physical and chemical degrade. First results have been obtained so far, but the study of this complex application in cultural heritage must be continued to provide an effective support to the complete the monitoring process.

Our efforts will be devoted to apply innovative visualization tools, which allow to combine different types of information thus enforcing the expert analysis in the ability of decision making for subsequent actions in preservation and restoration.

Future efforts will be devoted to support the cultural heritage expert in conservation actions by realizing a new family of visual tools, able to generate scenaria of damages evolution starting from critical conditions.

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