Multidimensional Data Visualization for Decay Study in Cultural Heritage: an Object-Oriented Implementation

Laura Chiappini,
Istituto per le Applicazioni del Calcolo CNR
Viale del Policlinico 137
Rome, Italy
laura@iac.rm.cnr.it

Rossella Cossu
Istituto per le Applicazioni del Calcolo CNR
Viale del Policlinico 137
Rome, Italy
cossu@iac.rm.cnr.it

Marco Di Lorenzo,
Istituto per le Applicazioni del Calcolo CNR
Viale del Policlinico 137
Rome, Italy

Abstract

The scope of this work has been to apply multidimensional data visualization techniques to the study of the ancient building decay events. With this aim we have created new visual tools based on the shape variation (glyph), that with more traditional techniques based on the color have been implemented in object-oriented software programs using the innovative and powerful Visualization Toolkit (VTK), a free C++ class library for visualization and 3D computer graphics. The data used are climatic, chemical and environmental measurements detected on/near the Roman Theatre in the city of Aosta, acquired in the ambit of an Italian research project focused on the restoration of ancient monuments.

1. Introduction

In the Cultural Heritage research, concerning the conservation state and the decay diagnosis of ancient monuments, the experts have to work with collections of different types of data, acquired and distributed on different and/or same locations of the examined surface.

New visual tools, based on shape variation, have been provided in order to give a quantitative reading of scalar and vector data.

The shape idea refers to the shape of graphical objects as glyphs or complex icons. The superquadrics surfaces have been proposed in order to visualize up to three scalar data simultaneously on a monument surface; moreover an original two-dimensional glyph has been created in order to visualize more scalar and vector data in the same location. In addition more traditional techniques, based on color, have been developed and made available to the experts

This work is part of the Italian Research Project SIINDA (Ricerche e Sviluppi di Sistemi Innovativi di Indagine e Diagnosi Assistita). The general purpose of the Project, is to test and produce an integrated system of knowledge, constituted by a set of methods, functions and data, for the investigation and analysis of the conservation state of a monument. The study case is the Roman Theatre in the city of Aosta (Italy).

In order to better combine our visualization tools into an integrated system of knowledge, we have chosen OO (Object-Oriented) software. VTK (Visualization ToolKit) is an open-source, object-oriented C++ library particularly suitable for scientific visualization and computer graphics.

2. The Study case

Our goal in the SIINDA Project is the development of techniques and methodologies focused on the simultaneous and comprehensible presentation of chemical and environmental parameters for analyzing decay events [1].

The Roman Theatre in the city of Aosta, shown in Figure 1, is the study case. The first century A. D. monument (age of Augustus), a rare example in the roman architecture of covered theatre, conserves the tiers, the foundations of the stage and the rest of the facade, high 22 meters, whose architecture is composed of a series of arcades and three overlapping orders of windows separated by buttresses. The materials used for the carrier structures are essentially

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puddingstone and travertine. The conservative state of the monument is quite critical. Measurement cycles of environmental data and a photogrammetric relief have been performed on the Theatre.

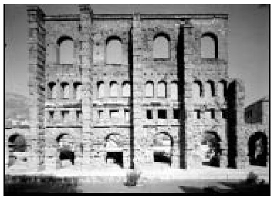


Figure 1. The Roman Theatre of Aosta;

3. Visualization toolkit

The need to link our visual applications to the final product of our project, which is the integrated system of knowledge, has led us to the OO strategy that allows easier embedding and combining various parts into a more complex system. Our attention has been focused on VTK, that is C++ object-oriented freely available visualization toolkit [2] [3].

4. Color analysis

In this section we will present an analysis by color of the climatic measurements [4]. Being multidimensional data, we developed three applications, each using a different number of parameters, based upon the principle of the color maps.

In order to estimate the action of atmospheric agents in every point of the monument facade,

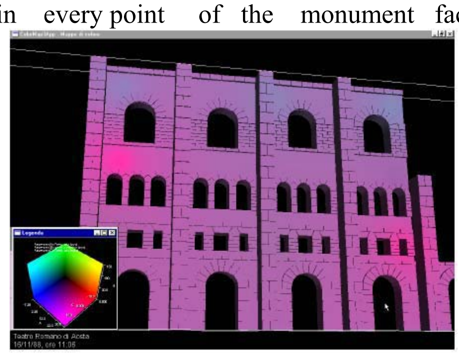


Figure 2. Color map of three scalar data (contact temperature, humidity and air temperature)

synthetic images have been generated by interpolating the measured parameters. The user can act spatially (rotating, zooming, panning, 'flying to' a certain region), but also can handle the variable time (going back and forth, for instance); all this is performed with the use of the mouse and, occasionally, of the keyboard.

An example screenshot of this application is illustrated in Figure 2. It depicts a facade of the Theatre, where the user attention is focused. By analyzing the colors in the scene, and matching them with the legend, one can understand that it is an instance of low humidity and high temperature, having a spot of even higher temperatures, located on the leftmost part of the facade.

5. Glyph analysis

In order to give more detailed information related to specific points or regions of the Theatre we have developed new visual tools for local and measurable representations of the data using the idea of shape variation. The technique used is the iconic visualization, that consists of the depiction of some icons (glyphs) in order to better interpret the data. This technique relies on the visual 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 [5] [6]. The shape chosen are based on a procedural glyph, namely the superquadric surface.

Another iconic visualization application has been developed, based on the "flower" metaphor.

5. 1 Superquadrics glyph

In order to visualize the scalar datasets of the probes on the Theatre, iconic visualization application has been developed. It uses procedural glyphs, since they are the most appropriate way to convey information about the continuous and smooth variation of one or more parameters [7].

The shapes chosen for the glyphs are implicit surfaces, belonging to the superquadrics family. Every shape is generated by mapping a scalar variable to a shape parameter. Since the superquadrics are defined by two parameters, we can thus represent two climatic variables at the same time.

We have chosen the superellipsoids to visualize different shapes.

Its equation in parametric form is:

$$s(\theta,\phi)=\begin{bmatrix} a_1\cdot sign(\cos\theta\cos\phi) & |\cos\theta|^{\varepsilon_2}\cdot & |\cos\phi|^{\varepsilon_1} \\ a_2\cdot sign(\sin\theta\cos\phi) & |\sin\theta|^{\varepsilon_2}\cdot & |\cos\phi|^{\varepsilon_1} \\ a_3\cdot sign(\sin\phi) & |\sin\theta|^{\varepsilon_1} & \end{bmatrix} \qquad \begin{matrix} -\pi/2\le\phi\le\pi/2 \\ -\pi\le\theta<\pi \end{matrix}$$

Varying the shape parameters ε_1 and ε_2 in the previous trigonometric equation, different superellipsoids can be obtained., as shown in Figure 3.

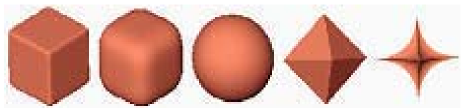


Figure 3. Superellipsoids

In our case sixteen different and comprehensible shapes of superellipsoids, obtained varying the values ε_1 and ε_2 have been selected [8].

5.1.1 Superquadric visualization

As shown in Figure 4, the glyphs are placed where the acquisition probes were, in particular nine colored superquadrics are visualized on the Theatre. They represent the measurements of air temperature (south side), relative humidity and contact temperature. This frame describe the state at 10 a. m. on 01/11/88

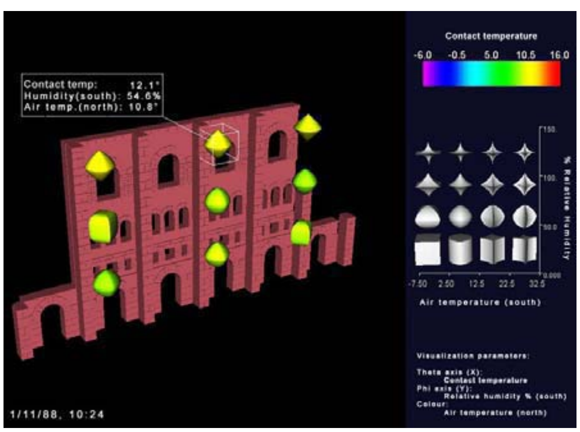


Figure 4. Screenshot of 3D glyph application

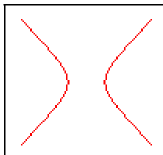
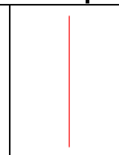
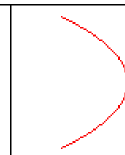
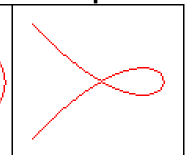
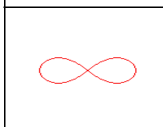
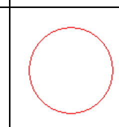
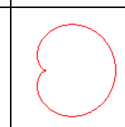
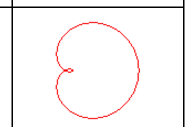
5.2. Flower glyph

In order to represent the dataset from the acquisition station near the Theatre, an innovative shape-based visualization has been developed. It uses the "flower" metaphor: each petal represents the variation of a single parameter, and the number of the petals is variable according to the needs.

The sinusoidal spiral, studied by the Scottish mathematician Colin Maclaurin (1698-1746) for the first time, can be formally defined by the polar equation : $\rho^n = a^n \cos n\theta$ where n ∈ R.

It is not really a true spiral, in fact it acts as "spiral" but its radius increases and decreases "sinuously". Many standard curves can be thought of particular cases of sinusoidal spiral as shown in Table 1.

Table 1. Examples of sinusoidal spiral

			
n = - 2 Hyperbola	n = - 1 Line	n = - 1/2 Parabola	n = - 1/3 Tschirnhausens's cubic
			
n = 2 Bernoulli's lemniscate	n = 1 Circle	n =1/2 Cardioid	n = 1/3 Cayley's sextic

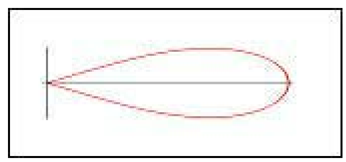


Figure 5. Base pattern for sinusoidal spiral

A sinusoidal spiral can be considered as a shape composed of a certain number of a base pattern, whose size can be controlled by an *a*-parameter. The curve is composed by a base pattern, shown in Figure 5, symmetric respect to the *OX* axis, obtained varying $-\pi/2n \le \theta \le \pi/2n$, transformed for all the rotations of angle $2k\pi/n$ where k integer. If n is a rational number $n = p/q \quad p,q \in \mathbf{N}$, the complete curve is obtained performing the *p-1* rotations of the base pattern varying $1 \le k \le p-1$. For our application we have chosen $n = p/2$.

Thus it is possible to associate one scalar data to each leaf/petal and consequently a *p*-dimensional scalar data to a sinusoidal spiral composed of *p* leaves/petals.

The full/empty visual information of the leaves/petals has been used to distinguish positive values from negative ones of scalar data. A full component of length *l* represents a scalar positive value of absolute value *l* while an empty component of length *l* represents a scalar negative value of absolute value *l*.

Figure 6 shows examples of shapes that can be obtained from a sinusoidal spiral assuming $n = p/2$, with $p = 5, 10, 15, 20$ respectively, and *a* variable.

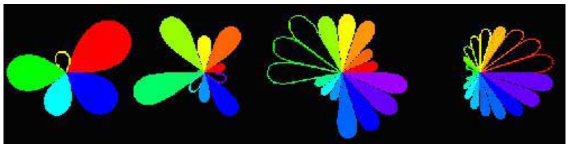


Figure 6. Examples from sinusoidal spirals (p=5, 10, 15, 20)

5.2.1 Flower visualization

In our applications mobile arrows around the spiral center have been added to the described curve, in order to contextually visualize acquired vector and scalar data. In Figure 7 an example is shown. The represented parameters are measurements related to the day 04/08/99 at 7 a.m.

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 empty petal shows the negative value of dew temperature, computed by the air temperature and relative humidity. The gray arrow represents the wind velocity vector. For instance in this picture, direction SE is easy readable by means of the wind rose centered under the flower. A little red dart is used to indicate whether on not there is an air pollutant that exceeds the legal limit.

The values measured are reported on the right side of the legend that allows for the immediate association of an element to a color and, then, to the corresponding petal. Since some measures are not properly comparable we have used different scales on the petals.

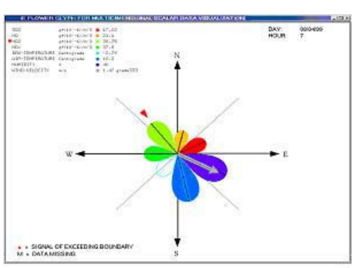


Figure 7. Screenshot of the 2D "flower" glyph application.

6. Conclusions

Our goal was to develop and realize an ensemble of visual techniques focused on the contextual representation of measured scalar and vector data for facilitating the analysis of the conservation state of ancient monuments. The OO strategy we followed allows these techniques to be easily embeddable into the integrated system of knowledge, which is goal of the Project SIINDA. The implemented software has been written in C++ language utilizing the VTK visualization and 3D graphics library that permits portability on a number of platforms and operative systems. The techniques and applications developed will be embedded into the general software system and will handle data from new acquisition campaigns; this will allow the experts to efficiently analyze the data as they become available. The integration of different visualization techniques into a single application is another interesting development for the future.

7. References

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