A system for the investigation of cracks

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This work aims to deal with the problem of identifying, analysing, and classifying cracks in figurative works. The recent, considerable progress made in techniques for processing visual information has broadened the number of scientific applications in which the display and graphic processing of data play a fundamental role. Cracks consist of many elements; distinguishing and studying them has made it possible to develop a classification that in some cases can also be used as tool to verify a work's authenticity. RESTART, the system presented here, is deemed suitable for use in numerous and varied settings, such as teaching, conservation, study and research. It is able to investigate, study, research and 'restore' the digital, in accordance with the criteria dictated by knowledge. Also of considerable interest is the investigation of a crack based on such characteristics as origin and pathology, and the possibility of analysing the cracks in a fresco. The use of RESTART for such case examples is investigated and proposed.

Digital image processing. Digitised paintings. Crack detection. Feature extraction. Morphological filters.

1. INTRODUCTION

As is well known, restoration on an art work must be preceded by collecting as much historical information and scientific research as possible for in-depth knowledge of the work. The scientific examination must represent the gathering of a set of information obtained by applying various analysis methods, whose elaboration will be the basis for collaboration between experts in the technical, scientific, and historic sectors. Study for the purposes of conserving and safeguarding artistic heritage thus requires strictly interdisciplinary approaches, in which the investigation methods and experiences of scientific disciplines are matched against those of the humanities. In recent years, information technology has seen sensational development in both basic research and technological applications, achieving entirely innovative and non-invasive tools of investigation, and techniques for communicating and processing data – and digital images in particular – with extremely high quality and great potential for application. The recent, considerable progress made in techniques for processing visual information has broadened the number of scientific applications in which the display and graphic processing of data play a fundamental role. As the applications of information technology gradually extend to cultural assets, workers in that sector are finding more and more areas in which to act. The opportunity to have tools useful for studying and conserving paintings has for some time encouraged experts from a variety of cultural backgrounds, restorers, and IT workers to tackle one of the main themes of interest – that of identifying, analysing, and classifying cracks in figurative works. The following is a presentation of the system developed with the aim of combining information technology skills with the restorer's experience.

2. OVERVIEW

In recent years, we have seen a growing use of information technology, and more specifically of image processing techniques, in analysing, conserving, capitalising on, and enjoying artworks. One sector of great interest – for both scientific and application – is referred to as virtual restoration, a method that acts not upon the object's actual material but upon its digital images; it is thus an activity lying entirely outside the theory and practice of restoration (Barni, et al., 2000; Nikolaidis & Pitas, 2001; De Polo, 2002; Bonacchi, et al., 2002; Becarelli, et al., 2008). Virtual – or electronic – restoration techniques have produced results of considerable applicative importance in the following cases:

- restoring the degradations introduced by the image acquisition process;
- simulating techniques to clean images of an artwork;
- eliminating cracks in images of paintings or frescoes, which by removing (only virtually) flaws and imperfections, allow for a different interpretation;

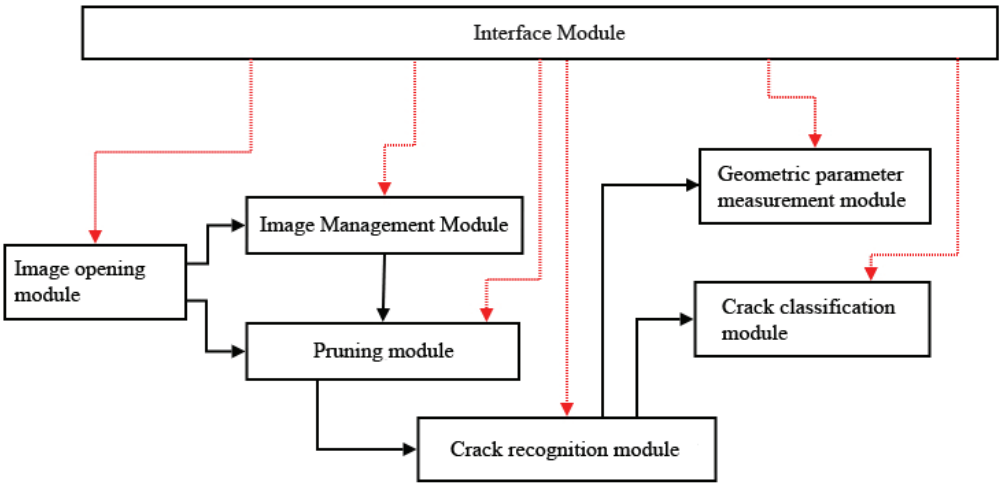

Figure 1: *The architecture of the system*

- filling in gaps in images of paintings or frescoes, to provide a tool to aid the conservator in planning the intervention.

As regards the problem of cracks, interesting studies have been performed since 1996 by Spike Bucklow (Bucklow, 1997, 1998, 1999, 2001) who made ample use of neural networks with the aim of directing his study towards seeking a correlation between the crack's features and the artist's technique in executing the work. From this particular kind of study, others have been initiated (Abas & Martinez, 2002, 2003), including use of the 'fuzzy' classification to recognise crack patterns. This problem has been particularly acute at the research and restoration centre at the Louvre Museum (the C2RMF - Centre de Recherche et Restauration des Musées de France) where a diverse range of imaging technologies has been applied to assist curators, restorers and researchers (Pitzalis et al., 2006; Pauchard et al., 2007). Another interesting research activity in image processing in the restoration sector has involved the visualisation of pigment distributions in paintings using synchrotron K-edge imaging (Krug et al., 2006). K-edge imaging has proven to be very successful in terms of mapping different elements on a pixel-by-pixel basis. It solves several basic problems that are incurred with other X-ray and neutron techniques. The information technology system, which will be the subject of discussion below, is with an outlook of being able to investigate, study, and 'restore' the digital, in accordance with the criteria dictated by knowledge.

3. THE RESTART SYSTEM

The objective of developing the system was to obtain a tool to support the crack analysis activity, suitable for use in such numerous, heterogeneous settings as teaching, restoration, study, and research. The system's architecture was thus logically subdivided into a basic component and three specialist components.

The base component consists of numerous modules dialoguing with one another, allowing the following operations to be performed:

- interaction with the user;
- image management;
- crack recognition;
- measurement of the cracks' geometric parameters;
- crack classification.

The RESTART system was thus implemented with the intent of providing a support to the restoration worker during the preliminary phases. The architecture involves using software modules aimed at processing the input image in the various phases. Figure 1 highlights in red the user's intervention in executing the module, with the passage of data from one module to the other shown in black.

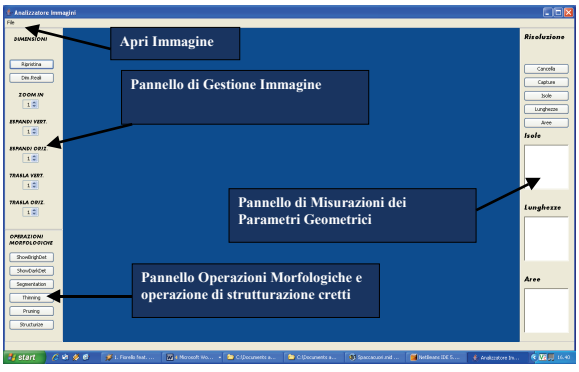

Figure 2: *The RESTART interface*

In detail, the module designated for **crack recognition** executes 4 passages prerequisite to the **measurement** and **classification** modules**:**

(i) Tophat or Bottomhat Filtering
(ii) Separating craquelures from background by OTSU Algorithm
(iii) 1 Pixel Craquelure Thinning
(iv) Pruning

The **measurement** module allows the user to identify the areas of interest and to extrapolate their geometric parameters by using simple commands. The **recognition** module deals with representing the cracks in digital format and using the Crack Following algorithm to create a network tree.

The network tree's characteristics are used for **classification**. For example, the bar chart of orientations for a crackNetwork provides information on the presence of a predominant direction of the lines of which it is composed.

Figure 2 shows the RESTART interface, while Figure 3 presents a system session example regarding crack recognition.

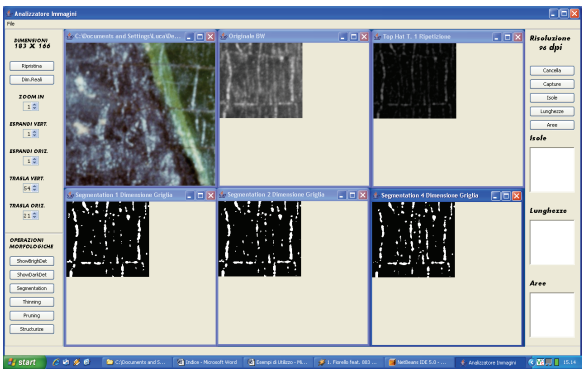

Figure 3: *A crack recognition*

To measure the geometric parameters, the system calls for interaction with the user. When the user traces the surveyed crack, the system provides its length (in cm). When its outline is traced or an island highlighted, the system provides its area (in cm^2). Moreover, the system makes it possible to trace a crack, highlight it in a new window, and enlarge it. Figures 4.1, 4.2, and 4.3 show examples of crack measurements. The classification process is activated through the structuring operation – that is, by converting the cracks into a structured form. Information such as the orientation and location of a crack's nodes help us to classify it correctly. Use of the 'Structurise' command – a button on the system's interface – makes it possible to open a window on which the information regarding the structure of the crack in question appears: number of nodes, number of segments, total length (Figure 5). The software was developed in Java for the Microsoft Windows XP operating system.

In the development stage, the recognition function is particularly helpful to the user, identified based on his or her training and/or professional level (three have been identified at this time): student, conservator, historian. When the recognition has been performed, the system will also provide information on the crack, for the type of user that has made the request.

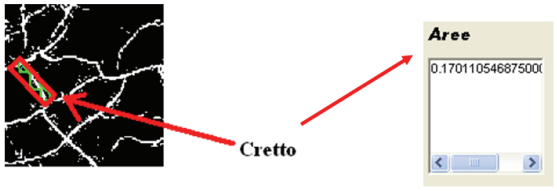

Figure 4.1: *Crack area tracing*

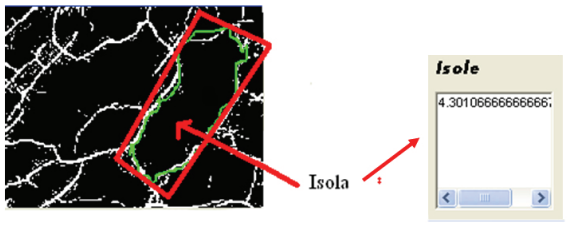

Figure 4.2: *Crack isle tracing*

Figure 4.3: *Crack length tracing*

Also of considerable interest is the investigation of a crack based on such characteristics as origin and pathology, and the possibility of analysing the cracks in a fresco. The following is a proposed use of RESTART for such case examples.

3.1 Case examples of RESTART

Identifying the cracks' origin and pathology involves architecturally broadening the already-developed software with new modules designated for this purpose. Current research in the field of ontologies allows possible implementations to be performed. Studies regarding Ontology Learning (Maedche, 2002), whose objective is to (semi-) automatically extract important concepts and relationships from a corpus in order to construct an ontology, are of key importance. Taking advantage of technology of this kind, the system may, over time and with human

assistance, be able to learn the information of greater importance and place this information in comparison in order to create a conclusive cataloguing, also with regard to earlier knowledge (as concerns origin and pathology). Above all, the possibility of analysing cracks on frescoes requires using specific technologies to scan the works in question. A study by Università degli Studi di Parma (Collini, 2009) highlights a non-destructive, no-contact technique for the diagnostics of ancient frescoes, based on the vibro-acoustic response of

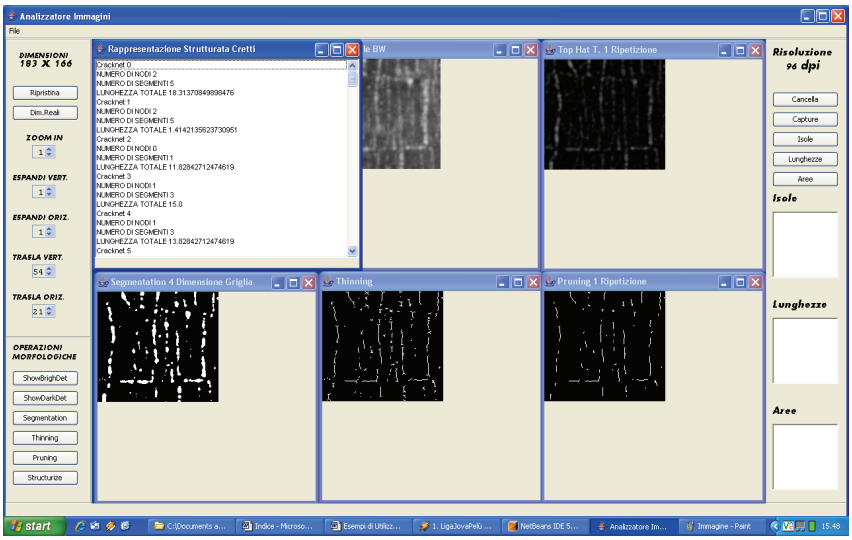

Figure 5: *The classification process*

the frescoed wall. Although several methodologies are being trialled, they share the common feature of analysing the vibratory response of surfaces where there is damage. Research is moving mainly on three fronts:

1. developing a completely non-invasive technique based on an acoustic structural vibration system and an optical system to measure the vibrations;
2. developing a hybrid technique to measure the local attenuation coefficient;
3. applicability of methods to actual frescoed walls.

In the second activity, an experimental procedure was proposed to diagnose the state of health of the frescoes based on the measurement of the local attenuation coefficient. Some interesting results emerged from the testing campaign:

1. the walls locally show responses in different frequencies: this indicates heterogeneities associated with the support's different compositions;
2. the method's in-situ application identified peaks in frequency characteristic of the supports for old frescoes, yielding a picture of delamination and detachment that may be defined as within the norm, or representative;
3. acoustic vibration is a good tool from the standpoint of investigation frequency, but it probably lacks enough energy to significantly move the entire wall without disturbing the signal or creating excessive background noise.

In this regard, for the analysis of cracks in frescoes, the proposal is to interface RESTART with a hardware instrumentation of the type just described, with the aim of producing a dynamic cataloguing of the most frequent damage and extrapolating their desired properties, through the use of an ad hoc network tree.

4. CONCLUSIONS AND FUTURE WORK

The idea of implementing RESTART for the investigation of cracks is not a particularly new one, but with this system monitoring can be done in a more efficient and non-destructive way. From a wider research perspective, this research is potentially useful for other applications, especially areas of research related to computer vision. Computer vision has been attracting considerable attention from art-related communities and institutions. For various applications, computer vision now plays an increasingly important role especially in quality evaluation of art images, as a tool for art analysis, and virtual enhancement, as well as restoration and image retrieval.

Steps can be taken in the future to improve and allow other possible applications. The system is also designed as a tool for professional training in a restoration school. Without cancelling every trace of the work over time, the information technology tool makes it possible to provide the restorer – especially by virtue of his or her interaction with it –

with information and knowledge on the characteristics of a painting work.

Fruitful collaboration between art and technology may be increasingly hoped for in order to achieve the objectives useful for both sectors, and this work is just a small but interesting attempt at it. The system's further development should regard developing the specialist components – all towards a more complete interaction between information technology and knowledge about restoration.

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