VASARI
A European Approach to Exploring the Use of Very High Quality Imaging Technology to Painting Conservation and Art History Education

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The VASARI project supported by the ESPRIT Programme of the European Community is carrying out applied research in the area of high quality imaging applied to paintings. This paper describes the project with particular attention to the technical results and the potential benefits for Museums and Galleries. A particular feature of the project is its cross-European multi-cultural, multi- site, museum/university/industry nature. VASARI is "user-driven" by its Museum and Art History education partners including the National Gallery, London and the Doerner Institute (Pinakothek, Munich), Direction des Musee de France (Louvre Research Laboratory) and Birkbeck College Art History Department.

I. GGINTRODUCTION

This paper provides a description of the VASARI project with particular reference to the results and targeted benefits for the international museum community. The first VASARI project, of 30 months duration, finishes in December 1991 and it is appropriate to provide for the first ICHIM in Pittsburgh a review of some of the key initial results for its prime immediate target "market": the world's leading Art Galleries and Museums, three of which participate directly in VASARI:

National Gallery Louvre Pinakothek (Doerner Institute)

The paper consists of three main elements beginning in Section II with a description of the origins of the project and its support by the European Technology Research and Development Programme, ESPRIT, described in Section III.

Sections IV and V then present the project as regards both its aims and nature as well as a description in non-technical terms of the approach used.

The first results of the project are described in Sections VI and VII with an assessment of the potential benefits for Museums and Galleries.

II. VASARI Origins

Like any flourishing plant, VASARI has many roots. The deepest and strongest were derived from real user needs. For example, the National Gallery's scientific research on colour change of priceless paintings, as reported in Saunders (1988), began in the 1970s. The second principal "user root" is Birkbeck College's Art History Department "pioneering work" in the area as reflected in its Masters Degree in Art History and Computing, a joint effort with University College, London. Munich's Pinakothek Museum's research group at the Doerner Institut identified the issue of painting damage assessment as a target application area for VASARI. The fourth "user root" was the Louvre's Research Laboratory which had carried out significant Image Processing in the artistic field with the support of the brilliant research group at Telecom Paris' Ecole Nationale Superior de Telecommunication (ENST). The industrial partners generally brought expertise from other areas. For example, THOMSON's Rennes Research Laboratory and its subsidiary SYSECA brought expertise developed primarily for military application. TUEV BAYERN's interest stemmed from its work in industrial testing and quality. SIDAC, the Italian partner, brought experience and expertise in multimedia and electronic publishing in the arts and industry. The consortium was also able to draw upon the work of the scientific and cultural communities, including especially participants in CHArt: Computers and the History of Art. The CHArt Conference in London in 1986 was the venue at which BRAMEUR, a research consultancy already active in European Community Research, participated in order to identify the UK leaders in the field as the first step towards its dream of creating the original VASARI Consortium in 1986, as a contribution to bridge-building in Europe between the Arts and Sciences. After over two years of planning, contract competition, negotiation and preparatory work, the VASARI Consortium began the project in July 1989.

The strong user-driven nature of the Consortium is indicated by the name VASARI, nominally an acronym to meet ESPRIT conventions (Visual Arts System for Archiving & Retrieval of Images) but in fact a suggestion by David Saunders of the National Gallery in honor of Giorgio Vasari, the "Father of Art History".

III. ESPRIT and European Community R & D Support

The European Strategic Programme of Research in Information Technology, ESPRIT, is a ten year US $10 billion programme (in Europe that now means over 10 billion ECUs - European Currency Units or approximately 6 billion British pounds, 60 billion French francs, 18 billion Deutsch-marks, etc.) initiated in the early 1980s to help Europe's computer industry to be competitive with the Japanese and USA. The intitial impetus for ESPRIT was created by the Japanese "Fifth Generation" project.

The main aims of ESPRIT are:

(1) to develop enabling technologies in key areas of Information Technology
(2) to encourage collaboration across Europe
(3) to pave the way to European and International Standards.

By the late 1980s, some 6,000 researchers and engineers across Europe were working in the ESPRIT programme in its four main areas:

Microelectronics Information Processing Systems and Software Advanced Business and Home Systems - Peripherals Computer Integrated Manufacturing & Engineering

The ESPRIT programme is not the only European Community R & D support effort although it is by far the largest. There are also a number of other initiatives all within the FRAMEWORK Programme administered by Community's Directorate General XIII which also includes:

RACE (Telecommunications) including the EVA MUSEUM NETWORK AIM (Informatics in Medicine) DELTA (Learning Technologies) IMPACT (Multimedia Technologies) including the NARCISSE project which works in collaboration with VASARI.

The ESPRIT programme is managed by a relatively small central unit in Brussels but the actual R & D work is carried out by consortia of companies, Higher Education Institutions, and research organisations across the entire European Community. In the second main phase of ESPRIT II in the late 1980s, over 200 different organisations participated ranging from the large electronic companies such as SIEMENS and THOMSON to very small companies such as BRAMEUR with 20 staff.

In order to encourage European industrial collaboration, it is a rule of ESPRIT that each project is carried out by a consortium including at least two industrial companies from two separate EC countries.

ESPRIT supports "pre-competitive, collaborative, research and development" to help achieve the three main aims listed earlier. The financial support consists of 50% funding of approved costs.

It is anticipated that due to the promising results obtained so far by VASARI and the other technology R & D projects in the cultural area, further R & D funding will be provided for this area but this will only be known in 1992 following a very competitive bidding procedure in which typically at least four out of five proposals are rejected.

IV. VASARI: Aims, Partnerships & Resources

From its early planning, VASARI was conceived as a project which would develop technology to help in resolving problems and meeting needs in the real world of the "user" of art and art history. By applying "state of the art" technology but also carrying out user- driven R & D, the VASARI Consortium aimed to:

- demonstrate the practicality of high resolution, colorimetric acquisition, storage and retrieval of images

- develop a prototype demonstrator system for an image database for Computer Aided Learning of Art History
- stimulate and support European IT industry to achieve a leadership position in the niche market of artistic image processing
- increase the level of awareness of this technology in suitable target sectors eg. visual encyclopedias/publishing.

The VASARI partners are as follows:

MUSEUMS & GALLERIES	INDUSTRY
Doerner Institute (Pinakothck) Germany Louvre, France National Gallery, UK	BRAMEUR UK (Coordinating Partner) SIDAC, Italy SYSECA, France
UNIVERSITIES/HIGHER EDUCATION	
Birkbeck College Telecom Paris/Enst - Telecomms	THOMSON LER, France London University, UK TUEV-BAVARIA, Germany Ecole Nat. Sup.

The total budget of VASARI is just under US $4 million with a grant from the European Commission of approximately US $2 million. This enabled a peak project staffing of over 30 scientists and engineers and museums specialists in a multi-disciplinary, multi-cultural team spread across four countries and ten sites. The corresponding coordination and management tasks were not inconsiderable.

The VASARI project began in July 1989 and is due for completion in December, 1991.

V. The Technical Approach

The VASARI team took advantage of state of the art systems and software engineering methodologies including in particular:

(1) A structured Prototyping approach using a specially developed version of the "Spiral" methodology
(2) Application of advanced Quality assurance methods at a level appropriate to each loop of the "spiral"
(3) An emphasis on User Requirements and Human Factors Analysis
(4) Development of standards, a vital aspect given the multi-location operations of the project
(5) Use of an "Open Systems" philosophy.

These aspects are discussed briefly in this general survey paper. They will be described in more detail in subsequent papers.

The technical approach taken has been a multi-disciplinary one including:

Museum Conservation specialists Museum scientists Art History specialists Software Engineers Human Factors Specialists/Market analysts

Considerable effort was given to try to balance the different viewpoints, but priority was given to "leading edge user" views particularly at the beginning of the project.

The VASARI "spiral" methodology used is shown in Figure I.1 illustrating how for successive prototypes the following main stages occur:

- REQUIREMENTS ANALYSIS
- DESIGN
- PROGRAMMING/TESTING
- EXPERIMENTAL APPLICATION

This general approach varied by sub-system. For example, five "spiral" cycles were undertaken for the Computer Aided Learning research work.

Quality assurance is a responsibility at four different levels in the project.

(a) Every partner
(b) TUEV-Bavaria for particular aspects such as "mechatronic" testing due to their specialist capabilities
(c) Project coordination
(d) Six monthly ESPRIT Reviews at which a panel of independent experts conduct a full day in depth examination of the project.

User Requirement Analysis, with particular attention to human factors, has been a critical aspect of the project as reported by Granger and Lindermeier (1991). This work benefited enormously from the participation of the three VASARI Consortium members. Their role of "leading edge users" is a vital one in driving the project forward.

Software and hardware standards are important in any system development project; in a multi-cultural, multi-organisation, multi-site project they are a sine qua non. Therefore this was a priority area for the system architectural design of the project leading to:

- selection of UNIX and C to ensured maximum portability of software between partners, i.e., an "open systems" philosophy.
- selection of a standard "platform", a SUN Workstation
- the specification of a number of detailed project standards on topics such as computer image files.

One of the important side-benefits of the project was the opportunity for team members to gain experience of these and other advanced Software Engineering methods.

The project was divided into six major Work Packages as follows:

1. SYSTEM DESIGN

In this Work Package, user requirements were identified and integrated. Human interface requirements and current knowledge of the state of the art were added to produce a comprehensive set of user requirements. A conceptual system design was then developed for a "family" of products of which the main one was the "full" image chain system for production and installation at the National Gallery, London and the Doerner Institute, Pinakothek, Munich.

2. SYSTEM PRODUCTION AND INSTALLATION

"The Work Package is the essence of the whole project; it converts the system design into an installed system" (VASARI Project Technical Proposal). It included:

Computer System Construction Scanner System Construction Physical Environment study Basic Software development General Image Processing Database production System integration

As described earlier the development process used a prototyping approach based on a "spiral" approach. In this Work Package therefore, there was considerable reiteration of the design process.

3. COLORIMETRY AND COLOUR DIFFERENCE MEASUREMENT

The aim of this Work Package was to demonstrate the feasibility of a system capable of measuring colour and small colour differences on the surface of a painting. This work included:

- Spectrophotometric characterization of paintings
- Coding for spectrophotometric images
- Experimentation
- The National Gallery took the lead in this Work Package.

4. MECHATRONIC POSITIONING SYSTEM & SURFACE TEXTURE ANALYSIS

Because of the sophistication of the repositioning system (the high precision "mechatronic" positioning system on which the camera itself is mounted as described later) and its particular importance in damage assessment for example, craquelure analysis, this was given particular attention in this Work Package, the responsibility of the Doerner Institute. Substantial effort was needed to carry out the detailed design (only partly carried out in Work Package 1) and procurement from specialist suppliers. This work includes a major emphasis on identification and analysis of damage to "Art in transit" caused by environmental and physical stress during travelling and during loan.

5. COMPUTER AIDED LEARNING

This Work Package was conceived as a "bottom-up" approach with a PC based sub-system to produce a prototype demonstrator which would include the potential feasibility of linking up to the main high resolution systems developed in preceding work packages. As "Educational User" in VASARI, Birkbeck College took the lead in this Work Package.

Work Packages 6 and 7 are devoted to follow-up Project Planning and Project Management. These include dissemination, the leading example of which is the London Electronic Imaging & the Visual Arts Conference/Exhibition beginning in July 1990 and repeated in July 1991.

These major work packages were broken down into detailed tasks and sub-tasks to permit work allocation between partners and to facilitate management control.

VI TECHNICAL RESULTS

The technical results achieved at the mid-point of the VASARI project centre around the work packages previously described. The main areas cover the acquisition of very high resolution multiband colour sub-images, mosaicing these into a single file, software to calibrate and display colorimetric images on colour CRT monitors and software to analyze colour, colour difference and surface texture.

Successful implementation of these technical results are prerequisites of the VASARI system, which aims to acquire very high resolution colorimetric images which can allow not only the detailed quantitative analysis of changes to colour and surface texture but also the creation of a variety of VASARI subsystems. This is shown in figure II in diagrammatic form. The selection of the level of both spatial resolution and of colour data was closely examined since the multiple reusability of the original data captured by the VASARI scanner system is a key to its long term success.

Conventional colour photographic materials can resolve detail of up to around 100 line pairs/mm. However, when a full-frame general view is taken of a painting the spatial resolution of the object compared with the format of the film material becomes reciprocal. If the object is, say, a painting measuring 10 x 8 inches and the camera is of the same format, then a 1:1 reproduction can be made. Thus the 100 line pairs/mm spatial resolution of the film will record 100 line pairs/mm from the object. However, using such a paradigm, this reciprocal means that the reproduced spatial resolution of the object declines in proportion of its size compared to the film format.

A system which would satisfy both the scientists and art historians requires both accurate colour and high spatial resolution. Many discussions about resolution of detail fall foul of misunderstandings regarding three primary considerations. Firstly, the resolvable detail on the original, i.e. the painting; secondly, the resolution of the imaging device, i.e. the camera format and/or film; thirdly, the resolution of the display device, i.e. a photographic or photomechanical print, a colour transparency or a CRT monitor. Therefore, detailed study was undertaken into the question of an object-independent standard spatial resolution. A standard in the region of 20 pixel/mm was seen as being necessary though this should be seen as a minimum requirement since the examination of micro craquelure requires even higher levels of spatial resolution.

Currently no electronic digital camera, such as a charge coupled device (CCD) camera, can match the overall functionality of a 35mm camera in terms of a single, short (i.e. 1/60th of a second) camera exposure to produce a 3600 x 2400 pixel full colour image. To date two technologies have evolved around CCD. These are the area and the linear CCD array.

1) CCD two dimensional area array cameras have the advantage of geometric stability but are limited in terms of spatial resolution to around 2000 by 2000 pixels.

2) The CCD linear array technology uses a system whereby a linear array is moved by stepper motors across the image plane to produce a "high" resolution image though a single scan has to be a carried out three times in order to acquire the red, green and blue data necessary to create a full colour 24 bit image. However, the spatial resolution of current CCD linear array digital cameras only just surpass that of a 35mm camera and the geometric stability is lower than the array, separate scans being out of registration by as much as one or two pixels. The equivalent pixel resolution of a 10 x 8 inch large format camera is approximately 25,000 by 20,000 pixels. This gap between the ability of conventional photography and that of electronic digital cameras to originate, in a single camera exposure, large amounts of visual data is unlikely to narrow in the forseeable future.

The CCD camera which was finally selected for the VASARI project was the Kontron ProgRess 3200 designed by Dr. Reimar Lenz of the Technical University in Munich. This camera uses a CCD area array with 500 x 290 pixels. High resolution images of up to 2994 x 2320 pixels can be produced through moving the CCD by Piezo-controlled aperture displacement (PAD).

The CCD is mounted between Piezo-ceramic actuators which, when stimulated by an electrical current, move the array in two dimensions by sub micron increments.

In order to create an image of a painting at the standard resolution IT is therefore necessary to position the camera in front of the object and take a series of sub-images (or details) which can then be integrated or mosaiced together by software to produce a single general view. The number of frames is primarily determined by the size of the painting. To mount and move the Kontron camera it was necessary to design a repositioning device which would accurately move the camera in the X and Y axes in front of the painting. This would enable individual camera frames to be captured with as high a degree of geometrical accuracy as possible. This is an important consideration for only highly geometrically accurate frames would enable the subsequent software "mosaicing" to take place. A British firm, Time & Precision of Basingstoke, has designed the first full "Mark II" prototype scanner which was installed in the VASARI laboratory in the National Gallery, London in November 1990. An earlier "Mark I" version provided useful design feedback for "Mark II". Birkbeck College and the National Gallery installed the camera onto the scanner and interfaced it with a UNIX workstation. In the first instance this was done through a 386 PC etherneted to a SUN workstation. A "Mark III" scanner has recently been built in the Doerner Institute in Munich. Mosaicing software using overlap correlation techniques devised by ENST and Birkbeck College images can now mosaic together frames to produce a single, integrated file.

In order to acquire sufficient data for the accurate measurement of changes in colour, studies were carried out by ENST and the National Gallery on methods of using a number of broad band interference filters to modify a standard light source. The conclusion is that using seven or eight such filters should give sufficient information for the measurement of Just Noticeable Difference of one within the CMC (1:c) formula of the Society of Dyers and Colourists Colour Measurement which compensates for the non-uniformity of the CIELAB 1976 colour system. Thus each frame is scanned up to eight times using a specially designed filter wheel placed between the light source and the optical fibres which transmit the light to form a "ring" lighting system.

Accurate display of the colorimetric data on CRT colour monitors has produced other technical results. CRT displays have a restricted colour gamut. The reasons for this are primarily centered on the characteristics of the different types of phosphors used. For a variety of reasons colour CRTs cannot display certain yellows, oranges, browns, magentas and cyans which may be termed the "problem" colours.

The VASARI project has neither the time nor the budget to design and build a new CRT monitor. Therefore the most suitable approach was to quantify objectively the interrelationship between the gamut produced by artists pigments and how this is related to the gamut of a CRT. Test samples of artists pigments were mixed, painted out on a prepared ground and spectrophotometric readings were taken from them. Other measurements were incorporated from other published studies on the colour gamut of artists pigments.

The results of this study indicated that very few traditional artists pigments fell outside the gamut of a standard CRT monitor using the standard P22 set of phosphors. This study therefore proved that it was theoretically possible to accurately display the colour of most artists pigments as RGB signals on a CRT. The problem still remained of how to be able to measure the colour accuracy of a CRT and calibrate it as necessary. Birkbeck College and the National Gallery approached the Belgian monitor manufacturers BARCO to discuss the project's aim and the necessity for "What you see is what you get" (WYSIWYG) colour display. BARCO considered the VASARI project to be examining an area in which it had a direct and significant interest since the company had recently launched a new monitor named the Calibrator.

The Calibrator monitor is designed to reproduce, consistently, very accurate colour through self-calibration using an internal CPU which monitors and corrects as necessary the maximum and minimum luminance of each of the three phosphor sets. The National Gallery London has developed software which accurately displays colorimetric data through changes of luminance rather than either the hue or the chroma.

One of the aims of the VASARI project is to carry out research into computer-aided learning (CAL) visual arts. The first prototype demonstrator was a CDE-ROM working on a standard PC-AT platform produced by SIDAC with another from Birkbeck College. This prototype has colour VGA images of a selection of Dutch paintings from the National Gallery, Alte Pinakothek and Louvre together with a textual database designhed around the data given in the illustrated general catalogue of the National Gallery. Currently work is being carried out on other prototype CAL demonstrators and evaluation of 24 bit colour combined with image compression techniques using standards such as JPEG and de facto standard graphical user interfaces. CD-ROM is seen as being an important short to medium term low-cost delivery platform for the PC environment. However, higher quality low-cost systems are needed for the move towards the ultra-high quality of the full VASARI system. The "quality" versus "affordability" trade-off is a vital one. The multimedia diversity of CD-ROM, CD-I and others constitute a maze of opportunities.

VII. Potential User Benefits

The VASARI project intends to stimulate the use of electronic digital imaging within the visual arts through a combination of technology push and market pull exploiting both a top-down and bottom-up approach. The premise taken is that while it is possible to create images for a CD-I, a videodisc or a colour VGA PC-AT from the VASARI multiband high resolution images, this cannot work in reverse. However, stimulation of the market through comparatively low quality, but above all "affordable" electronic images, acquisition, storing and display devices will play an important role in the development of the various facets which will make up the future of electronics in the visual arts. Reusability of existing datasets should enable considerable cost benefits in terms of a mass domestic consumer market which in turn should raise additional income to help cover the costs of original image acquisition.

The potential user benefits should be very significant across all areas of the visual arts. Within museums and galleries there is a growing need to adopt and adapt information technology for a variety of reasons. Collections management has been dominated over the past few decades by text databases. These frequently could not be easily ported since a wide variety of operating systems and custom built software programmes had been adopted. This situation is improving but now the arrival of digital imaging has added another dimension of possible incompatibility. However, it is believed that the machine independent platform of UNIX and C will mean that the VASARI system is creating images that have a long term future.

Museums collections management covers a number of constituent areas including the scientific study and conservation of objects and the VASARI system aims to produce a highly accurate digital image which will be stable and permanent. These characteristics will enable the detailed monitoring of aspects such as changes in colour and surface texture which may have significant effects on the display and transportation of objects. The creation of sub-images from the original VASARI image files will enable all those professionals involved in the running of museums and galleries to have access to both image and text databases which should have a significant effect on the productivity and efficiency levels.

Museums and galleries are the repositories for a wealth of cultural heritage which is being ever increasingly exploited. For instance the reproduction fees charged by museums and galleries already bring in very significant levels of income. Over the past decade these institutions have received a growing number of visitors which has been reflected in the demand for books, posters, postcards. Electronic digital imaging is already extensively used in reprographics though the use of photographic transparencies as the object to be reproduced persists. Now with the possibilities introduced by digital file transfer through systems such as ISDN, it is becoming feasible to transmit digital image files between a central database and a reprographics house. Thus a printer could call up a museum, log in to the publisher's image database, select an image of the object which is to be reproduced, select the spatial resolution, colour bit-depth and send the file directly to the printing system. The image file, taken directly from the painting would be fully coded so that the reprographics house would merely have to put the file into a software programme which would select the exact ink dot percentage values necessary to reproduce the file using the inks and papers held in stock. Such a system would greatly speed up the process of printing hard copy images and significantly improve hard copy image quality. Furthermore, the financial transactions involved could be easily integrated into such a system.

There was a dramatic increase in the use of electronic public access and point of information systems within museums and galleries during the 1980s. The videodisc remains a popular technology though the digital systems at the Musee d'Orsay in Paris, and latterly the Information Room of the National Gallery London, have pointed to what could be one of the largest areas of potential market growth in the 1990s. Coupled to these systems is the related question of electronic publishing. Several museums and galleries produce commercially available videodiscs though sales in Europe have been extremely limited due to the failure of this technology failing to acquire a significant domestic consumer market base. However, optical storage formats such as CD-ROM, CD- I, CD-PHOTO and CD-TV are opening new avenues for flexible learning whether it be for the professional or amateur and it is likely that by the middle of the decade many museums and galleries will have electronic publications using such formats for sale. Whether they become electronic publishers in their own right, museums and galleries will have new avenues through which to commercially exploit visual and textual data related to their collections.

VII. Conclusions & Outlook

Through a high degree of collaboration and technology exchange the VASARI project has exploited European expertise in museums and galleries, universities and IT industries to create prototype demonstrators which can acquire very high resolution multiband images directly from paintings. The specialist software which has been written to examine colour change and surface texture is of great significance to the scientific study and conservation of elements of our cultural heritage. Furthermore the results which have already been achieved have aroused considerable interest in Europe's commercial and industrial sectors, notably in the reprographic industry and specialist applications of computer-aided design and manufacture where colorimetry and surface texture analysis are paramount.

The CAL CD-ROM and subsequent prototype demonstrators have underlined the feasibility of cheap programmes which exploit a clear relationship to an existing technology base, in this case the PC-AT computer and the domestic CD player. How the PC platform will develop during; the next half-decade is as yet unclear though the sometimes apparently impenetrable jungle of multimedia will, to some extent, determine this.

The first VASARI project did not include aspects such as printed output and telecommunications. This was due primarily to the need to focus efforts in a limited budget. However, it is to be hoped that other research projects will concentrate on such issues.

The dissemination work carried out by VASARI has resulted in over two hundred people attending the first two annual Electronic Imaging & Visual Arts Conference/Exhibition in London in July 1990 and 1991. We hope that the research and the dissemination work will be continued and contribute to practical applications. Visual Arts, aided by the latest technology, have an important role to play in Europe and the World as regards not least in promoting mutual understanding. We hope that subsequent projects will find VASARI a useful stimulant.

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