3D Imaging Collaboration Between the National Research Council of Canada and European Museums and Cultural Organizations

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3D Imaging Collaboration between the National Research Council of Canada and European Museums and Cultural Organizations

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Abstract:
The National Research Council of Canada (NRC) has developed three families of high resolution 3D imaging systems which have been applied to a variety of museum and heritage recording projects. Several of these projects have been undertaken in collaboration with European museums and cultural organizations as well as with several other international partners. The systems have been used to scan archaeological site features, paintings, sculptures and architectural elements on historic buildings for a variety of different applications.

1. Introduction:

The Visual Information Technology Group of the National Research Council of Canada (NRC) (http://www.vit.iit.nrc.ca/), has developed and patented three high resolution 3D digital or “laser scanner” imaging systems which have been applied to a variety of museum and heritage recording projects. By "museum applications" we refer to 3D imaging of ethnographic collections, paintings and objects typically housed in a museum. "Heritage applications" refers to scanning archaeological site features, architectural elements on historic buildings and larger sculptures found in the built environment.

Some of these projects have been undertaken in collaboration with the Canadian Museum of Civilization, the National Gallery of Canada and the Canadian Heritage Information Network. We have also collaborated on international demonstration projects with institutions in Europe including the Centre de recherche et de restauration des musées de France and in Italy with the Universites of Padova, Ferrara, Stanford and Florence. In addition, we have participated in projects with partners in Israel and China.

These projects have shown that the 3D data can be used for a variety of museum and heritage recording applications including archival documentation, research, conservation, replication and interactive 3D VR theatre applications (1-3). Consistent with our mandate at NRC to develop new technology for commercial development, two of the systems described in this paper and their applications have been transferred to Canadian companies. The purpose of this paper is to present an overview of the NRC 3D technology and the collaborative projects undertaken with our European partners to date.

2. NRC 3D Imaging Technology:

The three NRC systems used for museum and heritage recording applications are designed for different types of objects and imaging applications. In digitizing a museum object or a site feature, the systems scan a set of overlapping images from multiple points of view over the complete surface. This is accomplished by moving the scanner (mounted on a tripod or on a three-axis translation system) around the object or by rotating the object on a rotating table in front of a stationary scanner. Once scanned, data modeling and display software is used to merge or integrate the multiple view data sets into a seamless archival quality high resolution 3D digital model of the object. The software also enables the data to be used for a variety of heritage applications.

2.1 High Resolution Color Laser Scanner:
The High Resolution Color Laser Scanner (Figure 1), has been developed for digitizing a range of "traditional" museum objects including archaeological and ethnographic collections, paintings, small sculptures and natural history specimens in color (4-8). The scanner, mounted on a three-axis translation system, scans a small low power "white light" laser spot from a RGB laser source on the object through a synchronized laser scanning and triangulation detection system. The 3D shape and color are recorded simultaneously with high resolution and in prefect registration. The system can also be operated on a tripod and used for high resolution monochrome digitizing applications.

In its maximum resolution configuration, this system provides a depth resolution of 10 microns (0.010 mm) in the z direction at sampling intervals in the x and y directions of 50 microns (0.050 mm). This resolution is sufficient to record fine brush stroke details on paintings as well as tool mark features on sculptures and archaeological objects.

On a commercial basis, NRC has licensed this technology to Arius3D (http://www.arius3d.com). Arius has opened a series of Content Creation Centers and initiated a museum imaging service.

Figure 1. The High Resolution Color Laser Scanner (left) imaging the Tsimshian Stone Mask from the Canadian Museum of Civilization. In this configuration, the scan is made by rotating the mask 360° on a rotation table. The scanning mechanism projects a white laser spot (white line profile) on the mask from a RGB laser. The Scanner mounted on a tripod (center) is used in monochrome mode operation (red laser spot) to scan tool mark details on the leg of Michelangelo's David (right).

2.2 The Biris 3D Laser Camera:
The Biris 3D Laser Camera is a portable digital 3D imaging system based on NRC's patented BIRIS dual aperture technology. It is a compact monochrome system and is ideally suited for field recording applications, where a record of the three-dimensional shape of an object or feature is required (9). The camera, controlled by a laptop computer, is mounted either on a conventional tripod or on a motorized linear translation stage

(Figure 2). It has been used to digitize architectural building elements and sculptures in Italy, a section of a Hieroglyphic Stairway at the Peabody Museum and archaeological sites in China.The Biris camera has a maximum range (camera to object distance) of 2 m and an accuracy of 0.08 mm (80 microns) at a range of 0.3 m and 1.8 mm at 1 m.

The system is available commercially as the ShapeGrabber™ from the ShapeGrabber Corporation (http://www.shapegrabber.com/). Innovision Géomatique provides a commercial heritage scanning service using this scanner (http://www.innovision.qc.ca/).

Figure 2. The Biris 3D Laser Camera (left) is a compact and portable monochrome imaging system and is ideally suited for field recording applications. The camera is shown (center) attached to a motorized rotation stage mounted on tripod. The cases for carrying the system and laptop computer controller are in the foreground. On the right, it is shown mounted on a linear translation stage scanning a section of the Hieroglyphic Stairway at the Peabody Museum.

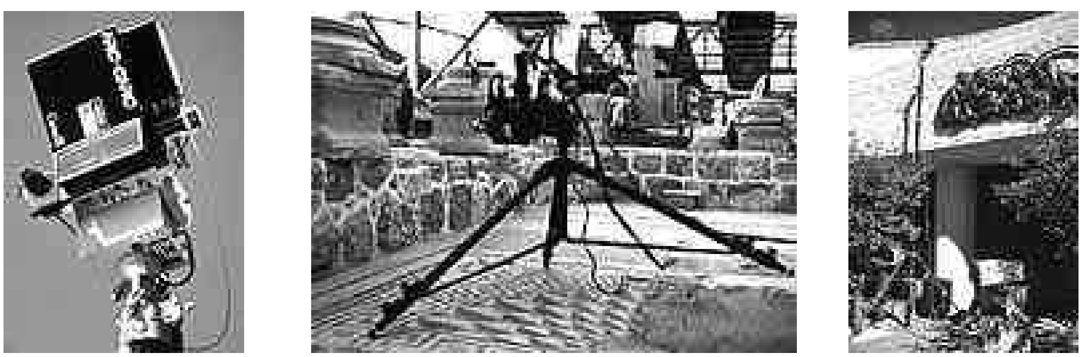

Figure 3. The Large Field of View Laser Scanner (left) mounted on pan and tilt unit. The system includes a video camera to facilitate remote positioning of the scanner. In the center image, the Scanner is shown mounded on a conventional tripod to scan archaeological site features at Caesarea in Israel. On the right, it is shown mounted on a telescoping tripod to scan the sculpture <u>Mythic Messengers</u> at the Canadian Museum of Civilization. The sculpture is mounted 4 m above ground on an exterior wall and measures 9 m long x 1.2 m wide.

2.3 The Large Field of View Laser Scanner:

The Large Field of View Laser Scanner is also based on NRC's patented synchronized laser scanner technology. It is a research prototype system under development for high-resolution monochrome 3D digitization of large structures, which generally are larger in size than those recorded using the Biris System (10). The scanner can be mounted either on a conventional photographic tripod or on a custom designed telescoping tripod, which can be raised to a height of 10 m (Figure 3). The system has been used to demonstrate applications for recording archaeological sites in Israel as well as for digitizing large sculptures at the Canadian Museum of Civilization. The system allows 3D recordings at a camera to object distance (camera standoff) which ranges from 50 cm to 10 m. At a standoff of 50 cm, it provides a resolution of 0.07 mm (70 microns) which increases as the square of the distance. For example, at a 10 m standoff, the resolution is 2 cm. The Large Field of View Laser Scanner is not commercially available.

2.4 Data Modeling and Display Software:

For the modeling and display of 3D image data recorded using NRC 3D imaging systems, we have collaborated with InnovMetric Software Inc. (http://www.innovmetric.com) on the development of the suite of PolyWorks™ software tools. Using PolyWorks on a Unix or Windows (NT and 2000) platform, the multiple view data sets recorded by the scanner are merged into a seamless archival quality high resolution 3D digital model of the object (11). PolyWorks also contains editing and data compression tools and a module, which enables the creation of texture maps for reduced models for web applications. It also enables the 3D model to be transferred into different formats and used for a variety of heritage recording applications.

3.0 Collaboration with European Partners

During the research and development phase of the technology, we have collaborated on a number of projects to test and demonstrate the museum and heritage recording applications with several Canadian and international museums and cultural agencies. Some projects have included demonstrations of the “heritage applications” for recording remote archaeological site features, architectural building elements on historic buildings as well as large sculptures. Other projects have included testing "museum applications" by scanning objects including paintings, sculpture and archaeological objects. Information on these projects can be found in the Museums and Heritage section of our web site (12).

As indicated above, several of these projects have involved collaboration with partners in Europe - the Centre de recherche et de Restauration des musées de France (CRRMF) as well as with the Universites of Padova, Ferrara, Stanford and Florence in Italy.

3.1 Paintings: Centre de recherche et de restauration des musées de France:

In 1995, we were contacted by the CRRMF concerning the 3D imaging of brushstroke details on paintings by Corot in preparation for the Corot retrospective held in 1996. The laboratory at the CRRMF employed a variety of techniques including x-ray, infrared, ultra-violet to scientifically examine and interpret details on paintings. The results had been published and released on a series of CD's, including one on the EC sponsored NARCISSE Project.

The CRRMF scientists, whom we had met at previous EVA, were interested in knowing if the **High Resolution Color Laser Scanner** could be used to record the surface relief or fine brush stroke pattern details on the paint layer of a Corot painting which had been varnished.

Rather than transporting a painting from Paris to Ottawa, arrangements were made to scan the Corot painting Auvers, Street Descending from the National Gallery of Canada - also a host of the retrospective. With its varnished surface, Auvers appeared to the eye to be a relatively flat painting with little surface relief or impasto effects from the brush stroke details. However, as illustrated in Figure 4, the image captured by the system revealed the 3D surface relief definition from the brushstroke under the varnish layer.

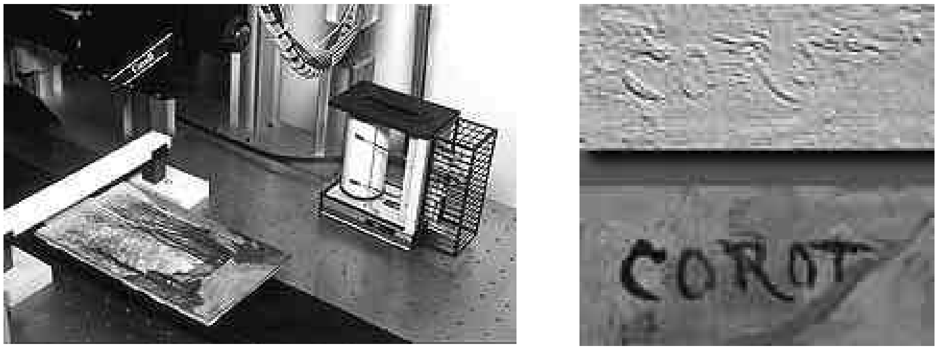

Figure 4. The High Resolution Color Laser scanner is shown in scanning the Corot painting, Auvers, Street Descending from the National Gallery of Canada. A detail of the signature area recorded by the scanner is shown in the lower right image. The upper right image shows the same area with the color removed and artificial shading applied. The surface relief details of the signature paint layer are clearly visible. Similarly, brush stroke details on other areas of the painting can be examined.

The explanation for the surface relief definition is that the 3D image captured by the system originates from the paint layer under the varnish rather than directly from the varnish surface. The laser light beam, used to scan the painting, is transmitted through the varnish and is reflected back to the camera directly from the surface of the paint layer. As a result, a detailed image of the surface relief or 3D structure of the paint layer from brush stroke details is recorded directly through the varnish which can be displayed with or without the colour data. This is a unique application of the technology for the examination of paintings.

The CCRMF included the results from this project on the CD, Corot 1796-1875; 85 Paintings from the collections of the Louvre - Scientific Analysis (13).

3.2 Sculpture: University of Padova

Two projects have been undertaken in Italy to demonstrate the applications of the portable **Biris** system for remote heritage recording applications.

In 1997, in collaboration with the University of Padova, it was used to digitize the sculpture Madonna col Bambino by Pisano in the Cappella degli Scrovegni in Padova. The primary goal was to digitize as complete a three-dimensional record of the object as possible. To digitize it, overlapping multiple view scans were recorded from a series of viewpoints completely around the sculpture. These views were then merged into a complete archival quality3D digital model of the object (Figure 5). This record can be used as a conservation record to document the condition of the sculpture as well as to prepare accurate scale replicas.

In addition to the Pisano, a bronze bas relief by Donatello in Saint Anthony's Basilica and a section of a crack in a wall at the Palazzo Della Ragione in Padova were also scanned. Further information on this project can be found in References 9 and 15.

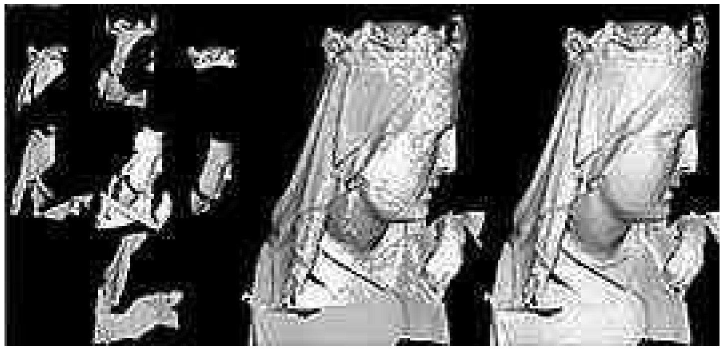

Figure 5: This sequence illustrates the scanning and model making procedure for the sculpture Madonna col Bambino by Pisano. The seven images on the left, are individual scans of the head and shoulder area. In the middle image, the individual scans are merged - each color represents a separate scan. Note that adjacent scans have areas of overlap. The resulting model is shown on the right.

3.2 Architectural Elements: University of Ferrara

In 1998, in collaboration with the University of Ferrara, the **Biris** system was used to digitize a number of architectural building elements on the facade of the 8th century Abbey of Pomposa, near Ferrara. The building elements included scans of a rosone (Figure 6), a peacock, a column as well as a large 2 m x 6 m area of the façade. For heritage preservation applications, the image data documents the surface condition of features at the time it was digitized The data was also used to fabricate a 1/10th scale replica of one of the elements.

Details on this project have been reported in reference 15.

Figure 6. The Biris camera is shown mounted on a conventional tripod (left) scanning a rosone (middle image) on the façade at the 8th century Abbey of Pomposa near Ferrara, Italy. A photograph of the digital model of the rosone recorded by the system is shown on the right. The digital model records the surface shape and condition of the object after 1100 years exposure to the elements.

3.3 Tool Mark Details: Digital Michelanglo Project, Stanford University

In addition to the use of the **High Resolution Color Scanner** for digitizing high resolution color images, it can also be operated on a tripod and used for high resolution monochrome digitizing of specific surface details. In 1999, in collaboration with the Digital Michelangelo Project (16), led by Dr. Marc Levoy of Stanford University, the High-Resolution scanner was taken to Florence and used to provide images of specific surface details on seven of Michelangelo's sculptures. The sculptures were the David (Figure 1), four of the unfinished sculptures (three Unfinished Slaves and the St. Matthew) in the Galleria dell'Accademia and two sculptures, Night and Day, in the New Sacristy of the Church of San Lorenzo.

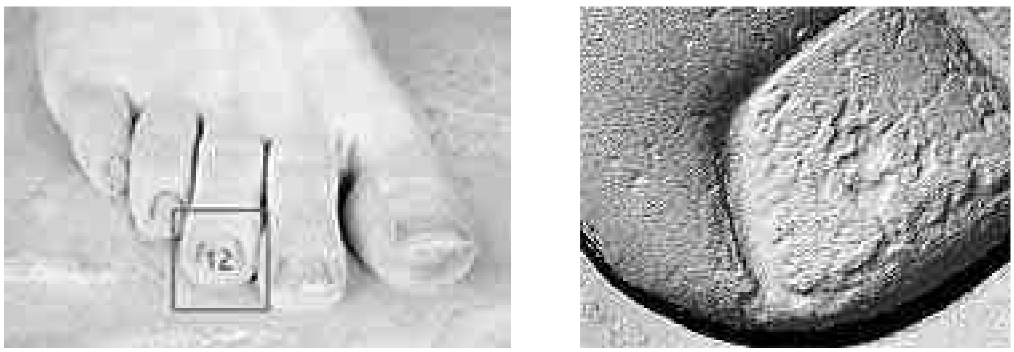

Figure 7. A scan detail (right image) of the middle toe on the right leg of David.

High-resolution images of various types of tool marks were taken on selected areas of the sculptures, which exhibited different levels of finishing and marble types (Figure 7). More than 1 million data points were recorded on each area, on a square grid of approximately 5 cm x 5 cm. The points were recorded at intervals of 50 microns (0.05 mm) in the x and y directions with a depth or z measurement resolution of approximately 10 microns. The resulting data provided a detailed representation of the shape of the tool marks. Details are reported in reference 17. This project also led to further research on measurements marble surfaces using laser scanning techniques (18).

3.4 Digital 3D Imaging Laboratory for Heritage Applications: University of Florence

The University of Florence is currently developing plans for the establishment of a digital heritage preservation center in Florence, which will include a 3D imaging and modeling laboratory. By applying the latest non-contact 3D technologies and methodologies, this center intends to create a bridge between expectations of art historians and curators, and the people promoting new 3D technologies (19,20).

In an initial project, the University of Florence, the Museo dell'Opera del Duomo and NRC have agreed to carry out a collaborative pilot program. The project team consists of 3D imaging scientists and technicians as well curators and conservators from the Museo dell'Opera and the Opificio delle Pietre Dure. A 3D imaging system was purchased from Optonet Srl along with Polyworks modeling software from InnovMetric Software Inc. The initial object scanned in this project was Donatello's polychrome scultpure, the Maddalena (circa 1446-1450) which measures about 188 cm in height (Figure 8). A second object, a *Formella* or bas-relief by Andrea Pisano has also been scanned. In the

3D modeling process, special attention is focused on the accuracy of the model. Calibrated test objects and verifications through photogrammetric techniques are used.

As this project continues, the longer-term research goals are to investigate the effect that materials used for works of art such as sculptures and paintings have on the accuracy of active and passive 3D techniques, define and assess the level of dimensional and photometric accuracy required by museum curators and finally to assess the need for 3D databases. Other experiments will explore the potential of 3D vision for applications in heritage or as an input to virtualized reality environments.

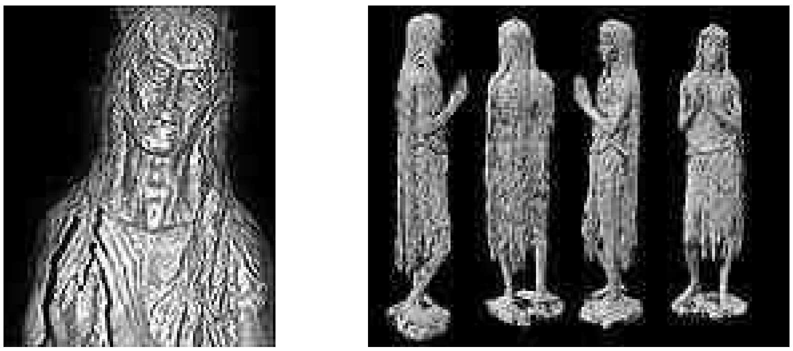

Figure 8. Detail (left) of Maddalena by Donatello in the Museo dell'Opera. The complete object, which measures 188 cm high, has been scanned in the initial phase of the project to produce a digital model of the object (right) which can be used for conservation applications.

4.0 Collaboration with Canadian and Other International Partners:

In addition to the projects we have undertaken with partners in Europe, we have also participated in several related projects with Canadian partners as well as those in other countries.

In 1996, in collaboration with the Israel Antiquities Authority, a pilot project to demonstrate the heritage recording applications the **Large Field of View System** for heritage and conservation professionals was undertaken in Israel. The system was used to scan the Tomb of St. James in Jerusalem (Figure 9), the Holy Sepulchral Lintel in the Rockefeller Museum as well as several archaeological and architectural site features at Caesarea. Each site was used to demonstrate the use of the system for a different heritage recording application (21).

As a result of the construction of a hydroelectric dam on the Yangtze River, in the Three Gorges area of China, an estimated 800-1000 heritage sites will be flooded and lost by 2009. The recording of these sites represents a significant challenge for Chinese heritage officials. In September, 1999, The Canadian Foundation for the Preservation of Chinese Cultural and Historical Treasures in collaboration with the State Administration of Cultural Heritage (SACH) organized a pilot project to demonstrate the application of **Biris 3D** technology for recording some of these sites.

The project was undertaken by to one of our industrial partners, Innovision Géomatique Inc., (www.innovision.qc.ca/). As noted above, Innovision is a professional geomatics company and is licensed by NRC to provide a commercial service based on the Biris 3D imaging technology. This project enabled Innovision to design and assemble a portable field system for recording archaeological site features which will be used for further recording work in China in October 2002 (22).

In March 2001, the Canadian Heritage Information Network launched the new web based Virtual Museum of Canada (www.virtualmuseum.ca). Among the inaugural exhibits, NRC collaborated with the Canadian Museum of Civilization on the production of **Inuit 3D**. The exhibition features an interactive 3D exhibition of Inuit objects from the Museum's collection. It fuses together several technologies to enable visitors to navigate through a virtual museum and interactively examine 3D models of Inuit objects, as well as view introductory movies to each section.

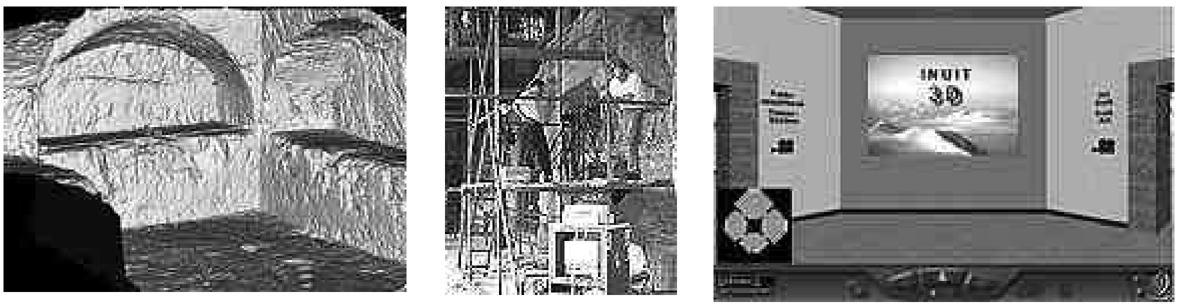

Figure 9. The Tomb of St. James in Jerusalem (left) was scanned using the Large Field of View Scanner in 1996. Note the level of detail captured by the system. One of NRC's industrial partners, Innovision Géomatique used the Biris scanner to scan archaeological sites in China (middle photo). NRC collaborated with the Canadian Museum of Civilization on the production of the interactive web exhibition Inuit 3D for the Virtual Museum of Canada (left).

4.0 Conclusions:

Our collaboration with our European partners on these projects to date has been very beneficial - particularly with our colleagues in Italy. From initial informal contacts, consultations and "pilot" tests, it has led to new developments and applications of the technology, to new professional relationships and business opportunities and to formal international agreements, workshops and tutorials. For example, in 1999 NRC hosted the a Canada-Italy Workshop on the Heritage Applications of 3D Digital Imaging. In October, 2000 the Canadian Embassy in Italy sponsored a "Canada Days Giornate" in Florence which included a Workshop on New Imaging Technolgy for Cultural Heritage". This was followed by a second Italy-Canada Workshop in Padova in April 2001. These workshops - particularly in Italy - were well attended. These opportunities to collaborate with our European partners has clearly advanced the state of 3D technology and its museum and heritage applications for NRC, our industrial partners and for our European partners.

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