Three-Dimensional Object Modeling

Towards Improving Access to Collections by Virtualizing Reality

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Abstract

The paper describes the recent evolution of a laser scanning technology which is used to digitize objects in three-dimensions with colour.Data sets are turned into computerized models that can be manipulated, displayed, measured, and compared, and which can be shared on networked systems. The technology should improve the electronic access to museum collections.

Introduction

Interactive digital media play an increasingly important role in the museum and conservation profession. They facilitate access to the artwork itself and to related information. While early applications primarily served inventory purposes, more recent ones share more complete information -text, sound, pictures, video sequences, animations etc. - among experts an non-experts in disparate fields. In most cases, the direct information, eg. the weight of a vase, and the indirect information, eg. the link between that vase and, say, a movie, can be accessed because someone anticipated the possible queries and filled in the appropriate fields in the database.Nobody, however, can predict all the possible future queries. The question what sound is emitted by that vase when it is hit by that stick?, which may lead to the discovery that the vase was in fact a musical instrument, is hard to anticipate and may come at a time when the object has been lost, stolen, broken, destroyed, repatriated, or is simply too fragile to be hit by a stick.

An approach to this kind of problem is to gather and store on digital media most complete computerized physical models to serve, in place of the object themselves, for solving the querries. The project we have been working on for a number of years now goes in that direction and involves modelling of museum objects into computer data structures that synthesize intrinsic information about their shape and colour appearance. We have developed for this a sensor that has the ability to sample, at high density and accuracy, the spatial coordinates and colour brightness of the visible parts of an object placed in front of it. Methods have been developed to put into registration data taken from multiple viewpoints, and to eliminate the illumination effects on the colours. The models that result make possible a variety of applications that would otherwise require access to the real objects.

This paper relates the short history of this technology in the context of the museum and conservation application. Its purpose is to increase peoples awareness of new possibilities in a way to encourage further development and a more wide spread use.

Range imaging

Development of the sensor originates from a need of the manufacturing industry for rapid, non-contact, 3-D measuring devices. Information such as conformity of an assembly part or tool paths for automated machining and assembly were to be extracted from the 3-D data. A considerable research and development effort has been carried out world wide and has lead to the design of a number of 3-D cameras covering a wide spectrum of performance and applications.1

The range camera developed in our laboratories is one of the more unique instrument of this type. It basically samples the elevation 'z' of a surface at grid points along the lateral 'x' and 'y' directions, producing an array of elevation values that is called the range image of the object. The density of grid points is adjustable and can be as high as 40 samples per millimetre (1000 samples per inch). The resolution of the sensor, i.e. the smallest elevation difference it can discriminate, is typically better than 25 micrometres (.001 inch). The uniqueness of the system is that this performance is obtained over large working volumes, at high speed, and with the convenience of a compact camera head.

1 P. Besl. "Active, optical range imaging sensors." *Machine Vision and Applications 1*. pp. 127-152. 1988.

The Canadian Conservation Institute(CCI) was first to recognize the great potential of this system in the field of conservation. The first applications can be traced back to the mid 80s and dealt with non-contact replication as well as with inspection.

An experiment was first carried on in connection with the replication of a Tsimshian Stone Mask. This mask was collected at the Tsimshian village of Kitkatla and is thought to be an important key to the culture and mythology of the Tsimshian people. It is part of the Canadian Museum of Civilization (CMC) collection and is regarded as one of Canadas national treasures. A request came from CMC to CCI to replicate the mask. After examination, it was found that the red and green pigments on the mask had been applied without a binding medium, thus ruling out direct moulding. Instead, a polyurethane foam model was machined using photogrammetric contour plots as guides. This model was hand finished and casted into epoxy. Correction of errors and distortions from the photogrammetric model were very time consuming and the final model did match the original to only ±3 mm (1/8 inch) in certain areas.2 It was decided for future reference to test scan the epoxy replica with the NRC high resolution range camera and to produce a second generation replica using numerically controlled machine milling. This method proved to be faster and much more accurate.3 Indeed, modern rapid prototyping techniques such as stereolithography can now build a solid model of that size, accurate to ±0.1 mm (.004"), in a matter of hours, and it takes only a few minutes to scan the mask at this resolution. Other objects such as a funeral lead plaque, painting impasto, live human faces and even a fingertip have since been scanned and reproduced accurately, either 1:1 or to scale.

Another early application was the examination of an estate stamp impression on a painting attributed to Canadian artist Tom Thomson. This was to rule out the possibility of the impression being a forgery. The original estate stamp was borrowed from the National Gallery of Canada and was scanned along with the impression. Range images of both objects were matched on a computer, showing no difference to within .07 mm (.003"). This information as well as data from the paint analysis helped support the attribution of the painting. Similar analysis work has been performed on various types of objects: the shape of a dried sea urchin was compared before and after parylene treatment, a rubber mould of a petroglyph was compared with the original petroglyph, the impasto of a painting was monitored at different stages of a relining process etc..4 In all those cases, the range images of the objects to be compared could be matched and then subtracted one from the other to show the difference.

2 Ian N. M. Wainwright, Stan Frydryn, Rollo H. Myers and P. (Tom) Sawyer. "The Examination and Replication of a Tsimshian Stone Mask form the North Pacific Coast."*J.IIC-CG*, vol. 18. pp. 17-23. 1994.

3 P. Boulanger, M. Rioux, J. Taylor and F. Livingstone. "Automatic replication and recording of museum artifacts." *Proc. 12th Intern. Symp. on Conserv. and Restor. of Cultural Property*, pp. 131-147. Tokyo, 1988.

4 R. Baribeau. "Range sensing for the monitoring of three-dimensionnal changes." *Computer Technology for Conservators - the 2nd Wave*. pp 43-49. Edited by Rob Stevenson, 1994.

Computerized rendering in colour

The technology took a new direction in the visual art domain with the advent of two new products on the market: white light lasers and high performance 3-D graphics workstations.

A 3-D graphics workstation is a computer system with special hardware and software that can render and animate 3-D objects on a display screen. Most of the time, the rendered object is purely synthetic and the data structure behind it is not too large. For example, a molecule will be represented by spheres of different sizes and colours (the atoms) linked by solid lines (the chemical bond), and the model of the molecule will be a data structure holding the various locations, radius, colours etc.. This data can be fed in manually or can be the output of some simulation programs. The detailed 3-D rendering of real objects such as sculptures calls for a more efficient way to generate the much larger data structures required. This modivated the incorporation of a white light laser into our range sensor to turn it into a high performance colour and shape digitizer.

The laser range sensor obtains surface coordinates by electronically measuring the position on a CCD detector of the image of a laser spot. This laser spot results from the projection from within the camera head of a laser beam toward the object. The brightness of the image is measured as well and is a function of the reflectance of the object. When a monochromatic laser is used, the equivalent of a black-and-white picture is recorded along with the shape. A mixture of red, green and blue lasers (RGB "white laser") at the projection, and the separation and individual reading of the RGB brightness on the detector, allow for the recording of a colour brightness image, in perfect registration with the range data.

A raw 3-D colour image captured with the sensor has the array data structure. This means that connections between data points and their nearest neighbours are known. The sensed object can be imagined as being actually covered by a mesh of four sided polygons, each vertices representing a sample point. When rendering the object on a flat screen and for a given viewpoint, each polygon on the object projects into another flat polygon on the screen. There is no limit to the number of screen pixels comprised inside those screen polygons. The colour of each individual screen pixel is interpolated from the colour values at the vertices of the polygon surrounding it. This results in smooth colour transition between screen pixels at any zoom level.

When the colour values used for the rendering are the RGBs recorded, the object is rendered in more or less realistic colours. Another display mode assigns a grey value to surface elements according to their slope angles. This results in shaded renderings where the object appears as if it was made of white material and was observed under point source illumination.

These various renderings are performed dynamically by the computer while the user chooses and modifies the viewing parameters (viewing angle, zoom factor, illumination angle). Stereo pairs can also be produced and viewed with stereoscopic glasses for a spectacular 3-D effect.

Further data processing, described below, is required however for the colour 3-D imaging technique to deliver its full potential.

Physical modelling

Physical modelling is a process used to extract from colour and range images those physical properties of an object that are responsible for its appearance. Generally speaking, appearance is the direct result of the interaction of light with matter, and physicists have proposed a number of mathematical models to describe this interaction. When such a model is known for an object, it becomes possible to calculate how it would appear under all kinds of hypothetical lighting and observation conditions.

The method we have developed for physical modelling allows for the recovery of a small number of parameters for each surface element. These relate to the colour reflectance of the material and to its shininess. This is obtained through careful calibration of the sensor and by processing of the brightness image taking into account the 3-D geometry.

The difficulty of extracting physical parameters increases with the complexity of the object to be represented. Physical modelling was first tested on simple objects such as painted spheres and was successful at recovering the underlying parameters.[5] In practical cases however, one must often limit the scope of the model and constrain the recording strategy accordingly. For example, paintings have been assumed by our model to have zero shininess and they have been scanned in a way to avoid specular reflection. The extracted models adequately render the paintings except for critical viewing conditions where highlights should be present. Shininess can later be added on by empirical adjustment of the appropriate parameters, resulting in even more realistic renderings.

A similar strategy was used recently for the capture of unrolled images of Mayan vases, which are now part of CMC World Wide Web (WWW) exhibition *People of the Jaguar*.[6] The vases were scanned "off axis" while slowly rotating on a rotation stage. A colour reflectance image was recovered and transformed into colorimetric CIELAB space. It was left unrolled and saved in Tiff format under Adobe Photoshop, to be later included in the WWW as well as to serve for the production of high quality colour prints.

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5 R. Baribeau, M. Rioux et G. Godin. "Color reflectance modeling using a polychromatic laser range sensor." *IEEE Trans. Pattern Anal. Machine Int.*, 14(2). pp. 263-269. 1992.

6 Current WWW location: http://www.cmcc.muse.digital.ca/cmc/cmceng/mmj01eng.html

Physical modelling not only results in more realistic renderings on computer displays, but it is also a necessary step to go through when complex objects must be synthesized from multiple scans. Extracted models also constitute device independent records of the physical state of the object and are suitable for analytic tasks.

Geometric modelling

Many objects necessitate the integration of data from multiple scans for their complete description. This is the case for objects larger that the field width of the scanner and for those with hidden parts on any single view. In both cases, the spatial coordinates from multiple scans must be reported in some common reference system. There are two basic approaches to this problem: viewpoint calibration and software alignment. With viewpoint calibration, the object is moved between each scan in a constrained way using precisely controlled moving stages. For instance, a large painting can be digitized in multiple bands, with the painting moved by a known distance in a known direction between each band acquisition. Similarly, opposite views of a sculpture can be put in registration by rotating the sculpture 180 degrees around a precisely calibrated axis.

Software alignment offers more flexibility with the data acquisition but requires more human assistance. Any two views to be put in registration are first displayed one next to the other, and common features are identified. The spatial coordinates of those matching features are fed to a computer program that establishes the coordinate transform between the two views. This transform can be further refined by having the software consider the whole overlapping surface from the two views. Software alignment eliminates the need for expensive and bulky motion stages. Holding the object also becomes less problematic. On the negative side, as this method necessitates substantial overlap between adjacent views, more views need to be captured, there is more manipulation of the object, larger unprocessed data set need to store and more of the operators time must be devoted to the task.

These strategies were used for the scanning and modelling of a test bed collection of museum objects that included paintings, sculptures, ethnologic material, natural specimens and scientific instruments.7 The viewpoint calibration approach worked fine for paintings, but in the case of sculptures and similar objects, it failed to deliver 100% of the surface data points. This is because those objects usually had to rest on supports that hid part of the surface, and also because they could not be moved with all six degrees of freedom in a controlled way. Software alignment of unconstrained additional views was necessary to complete those data sets.

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7 R. Baribeau, M. Rioux, L. Cournoyer et G. Godin."Applications of colour and range sensing for the recording and study of museum objects." *EVA92*. London 1992.

Once all the 3-D views from a given object are aligned, the whole object can be rendered on the graphics workstation by having it display all the views simultaneously. Associated colours must be physically modelled, as described in the previous section, otherwise a colour mismatch occurs between adjacent screen pixels that originate from different views. Aligned 3-D views can also be merged into a single closed model. In this case, the resulting data set consists of a mesh of triangles that encloses all the surface and that preserves its topology (the mesh "wraps" around holes etc.).

The latest application of those techniques was for the virtual display of a set of palaeolithic figurines for CMCs exhibition *Mothers of Time*.8 These ice-age artifacts, that take the form of thumb-size female nudes, fascinate scholars as well as non- experts but are hardly accessible due to their fragility and value. They were scanned and rendered into closed digital 3-D models that were displayed in stereo on a large projection screen at the exhibition site. Visitors to the exhibition can admire the precious figurines behind a glass case, and can also examine and manipulate high resolution, accurate 3-D colour renditions of the sculptures. This also enabled detailed examination of features such as toolmarks which, otherwise, are difficult to observe.

One collaborator to the above project, Innovmetric Software Inc., produces 3-D compression software which reduces the size of the polygonal models and makes use of texture mapping techniques. The software lets the user control the amount of geometric and colour detail to be preserved. This speeds up rendering and allows display of complex models on smaller computer systems. It also facilitates the share of information on distributed systems. Actually, 3-D models obtained with the scanner can easily transform into VRML emerging standard for network-based viewing in 3-D. The delivery of virtual collections on mass media such as CD-ROMs and Internet is looked at now as being a promissing market for the whole 3-D colour recording technology.

Conclusion

The laser scanning system has evolved from a purely dimensional analysis tool to what could be called a sophisticated object virtualizer. It can deliver data that will satisfy the needs of museums who want to offer better and wider access to their collection. It can also satisfy the needs of the specialists who need to compare, measure and study the objects in high detail. A given high resolution data set captured with the scanner is likely to satisfy the demands of future developments, and this should preclude re-scanning of objects in foreseeable futures.

8 Communiqué at WWW location http://www.cmcc.muse.digital.ca/cmc/cmceng/pr01eng.html