Capturing Content for Virtual Museums: from Pieces to Exhibits

Bradley Hemminger, Gerald Bolas[1], Doug Schiff[2]
School of Information and Library Science, University of North Carolina
Chapel Hill, NC 27599-3360
[1]Ackland Art Museum, University of North Carolina
Chapel Hill, NC 27599-3400
[2]3rdTech 119 E Franklin St, Chapel Hill, NC 27514

Email: bmh@ils.unc.edu

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ABSTRACT

Virtual museums provide ways to capture the content of a real museum in a digital (electronic) form and make this digital form more universally available. This paper describes a novel method for digitally recording not only individual museum pieces, but entire museum exhibits (consisting of one or more rooms or spaces). The methodology allows anyone with access to the internet or a PC to experience anywhere, anytime, any part of the museum's collection or exhibits (past, present and future). Users can explore the museum exhibits in a virtual reality that is both spatially accurate and visually compelling. All objects and 3D scenes are seen in precise full color photographic quality detail. The scene and objects are polygonal meshes representing the surfaces of objects. This permits making measurements directly on the scene with millimeter precision. The methodology, its application to capturing museum exhibits, and examples of exhibits recorded using this technique are described. This work is part of the Virseum project (http://ils.unc.edu/bmh/virseum) at the School of Information and Library Science at the University of North Carolina at Chapel Hill (UNC).

In addition to the capture of items and exhibits for virtual access, this methodology opens the door for many other applications, including capturing a record of an exhibit for archival purposes and for communication between curators, and for the design of virtual (never physically implemented) exhibits and pieces based on actual pieces and settings.

Categories and Subject Descriptors (ACM)

• H.3.7 Digital Libraries • I.4.1 Digitization and Image Capture • H.5 INFORMATION INTERFACES AND PRESENTATION (e.g., HCI) • J.5 ARTS AND HUMANITIES

Keywords

Digital library, virtual museums, virtual exhibits, 3D digitization, 3D object scanning, 3D visualization.

1. INTRODUCTION

Recent improvements in 3D digitization technology and 3D visualization applications allow us to reliably and accurate record the shape and visual appearance of objects and scenes. This has helped spark an interest in the idea of virtual museums. By virtual museums we mean methods that allow the user to experience the content of the museum virtually, i.e. in a place or time physically separate from the museum. This can be done by recording, or digitizing the content of the museum, and presenting this digital information to the user via an interactive display such as a computer monitor. Having a digital copy of the museum's content allows any user the ability to view and study any part of the museum content at any time, from any place.

We discuss and classify the various techniques that have been used to digitize cultural heritage items and scenes. We review challenges that museums face in making their content available. We then summarize the advantages to museums and museum patrons that could result from digitization and visualization of museum content (items and scenes). We discuss the novel methodology we propose for capturing high quality, accurate digitizations of complete museum exhibits, and contrast this with prior work. Finally, we present some initial static images from pilot Virseum projects. High quality virtual reality presentations of the digitized exhibits have been shown at conferences at UNC, at the Joint Conference on Digital Libraries (JCDL 2004), and at American Computing Machinery Special Interest Group on Computer Graphics (ACM SIGGRAPH 2004), and are available from the Virseum web site (http://ils.unc.edu/bmh/virseum), and from 3rdTech (http://3rdtech.com).

2. BACKGROUND

Museums have always recorded information about their content, by individual items, collections, and exhibits. With the advent of photography, and especially recently with digital photography, museums increasingly record 2D pictures of items and sometimes scenes to complement text descriptions. In addition to using this descriptive information for their own uses, museums are beginning to make some of this 2D content available via the web. The ability to conveniently take multiple photographic views and laser scanned representations of single objects has made possible increasing realistic and accurate recordings of objects. These methods allow for the capture not just of the visual appearance of the object, but also an accurate 3D spatial representation. This spatial information is of high enough quality to allow scholarly study and comparison of objects (Rowe 2003b). The methodology in this paper builds on previous work to capture both visually accurate information (photographic texture and color) and spatially accurate information (laser scanning) and integrate them into a combined virtual reality model. Below we discuss the different methodologies used to capture 3D representations of objects and scenes.

It is important to distinguish true 3D scene scanning from methods that capture multiple 2D images, and stitch them together for a panoramic view or interpolate between them to estimate other views. Sets of 2D images do not capture the spatial information in a true 3D scan, nor do they permit the viewing of the 3D scene from arbitrary viewpoints, or with arbitrary choices of lighting and visualization conditions. The methodology proposed in this paper as part of our Virseum project captures museum exhibits (setting and artifacts) precisely. We use techniques that capture spatial geometry accurately (laser range finder covering a full 360 scan in the azimuth and 270 degrees elevation), plus 2D high quality images to capture color and texture of polygonal surfaces in the scene (tied to laser range finder data), and very high quality 2D images for capturing the texture color for important object close-ups (paintings, sculptures, etc).

A 3D spatial model of a scene may be constructed several ways. The goal is to "produce a seamless, occlusion-free, geometric representation of the externally visible surfaces of an object", or in the general case a collection of objects (Levoy 1997). Modeling a scene by abstracting objects as simple geometric surfaces (such as with a computer aided design program) makes the representation of the scene simpler (fewer triangles describing surfaces). The tradeoff is that it is not as accurate (abstraction rather than measured), and it is simplistic in appearance because of the simpler representation of surfaces and their textures. Examples include early work at creating models of historic sites, or the more simplistic movie special effects of early computer animation films. More accurate and realistic models can be generated by sensor readings of a scene. These fall into two categories: passive sensing (camera recorded images) and active sensing (laser range finder recorded spatial coordinates). A good discussion of active sensing versus passive sensing is given in Levoy (1997). Passive sensing requires reconstructing a scene by solving for scene illumination, sensor geometry, object geometry, and object reflectance given multiple static 2D photographs taken of a scene. This continues to be a difficult to solve problem in computer vision primarily because it requires accurately finding corresponding features (points) between the different images. Active sensing devices such as laser range finders can be used to produce lattices of measurements of distance from the sensor location(s) to objects in the scene. The challenging part of this process is reducing the "clouds" of points measured by the multiple scans into a small enough number of polygons for real-time rendering. This is done by discarding redundant points from multiple scans, and by combining very small polygons into larger polygons when appropriate (e.g. large flat surfaces such as walls).

2.1 Digitization of 3D Objects

Most work on 3D digitization has been of scanning individual 3D objects. Laser scanning systems optimized to record precise measurements for small volumes are utilized. A number of researchers and digitization project teams have previously described 3D digitization of individual objects (Landrum 2003, Rowe 2003a, Rowe 2003b, Clark 2002). While many projects have used prototype scanning systems, some of the larger projects are utilizing commercially available systems, for example the Prism Digital library project at Arizona State uses Cyberware to scan objects up to 30 inches maximum dimension (Rowe 2003b), and the National Research Council of Canada (NRCC) uses the Innovision system (Lapointe 2002).

2.2 Query of 3D Objects

An important recent extension to this area has been to propose methodologies for shape descriptions so that digitized 3D objects can be accurately described using common terminology, and searched or compared using these standards (Rowe 2003a, Rowe 2003b, Paquet 2001).

2.3 3D Archives

Another important extension is the work by the Digital Archive Network for Anthropology (DANA) to promote a distributed database of digital 3D collections supporting multiple formats (Landrum

2003). Other authors have also proposed digital archives, and begun to address issues such as cataloguing, searching, security, and copyright (Rowe 2003a, Levoy 2000).

2.4 Digitization of 3D Scenes

One of the largest application areas is for digitizing 3D scenes is virtual archeology. DANA has made significant contributions to this area. A summary of their work and its relevant value is well described in Clark (2002). Modern archeologists have recognized the value in capturing accurate digitizations of archeological sites for later study. Work initially was of 2D pictures, or collections of 2D pictures to re-create arbitrary viewpoints later. Most recent work has focused on obtaining accurate spatial measurements of sites, and utilizing laser range finders. For a survey of recent work see (Reilly 1991, Lockyear 1990, Higgins 1996, Forte 1997, Barcelo 2000, Burenhult 2002). The 3rdTech Deltasphere scanner has been used by researchers at the University of North Carolina and the University of Virginia to scan and create a museum exhibit of Monticello (Williams 2003). It is currently being investigated for application to archeological sites.

The Institute for Information Technology of the NRCC has an industrial partnership with Innovision 3D (Quebec Canada) to conduct 3D scene scanning of archaeological sites using NRCC's scanning technology (Lapointe 2001, Godin 2000). This technology, while similar to what is presented in this paper, covers a small field of view (320 degrees with sensor field view of 40 degrees). They have scanned complex archaeological sites in Copan Honduras, Quebec City, Canada, and Dazu, China (Lapointe 2001).

A new area pioneered by 3rdTech is the recording of crime scenes. Laser range finder based scanners can quickly capture the original state of the crime scene and allow investigators to view and take measurements from the scene at any later time.

Single devices cannot scan very large areas at very high resolution, so often a combination of different scanners are used to digitize a site. For instance the Innovision 3D uses two scanners, one for areas up to 150 meters (20,000m^3/scan at 6mm precision), and one for small areas with an accuracy on the order of 0.1mm (Lapointe 2001).

2.5 Combining Digitized Objects and Scenes into 3D Environments

An area that is just beginning to receive attention is the digitization of both objects and scenes, and combining these together as a 3D model with which the user can directly interact. Work in this area builds upon the recent progress in generating high quality digitizations of individual objects (sub-millimeters to centimeters) as well as large scenes (centimeters to hundreds of meters). Paquet (2001) proposed digitization of historical artifacts and sites, and presenting this 3D information virtually. They envision presenting the information to the observer in a virtual reality interface where the user can also manipulate the environment, for instance changing objects on display. Paquet suggests presenting digitized artifacts in appropriate settings (which could be under user control), as well as individually. This may help the user by providing context when navigating through large collections of similar or related objects. Their methodology is similar to the methodology described in this paper except that they use photogrammetric techniques (multiple 2D camera views) to extract 3D scene information instead of laser range finders. Thus, the information is not as accurate or complete as a true 3D scene capture method.

We believe that in the long term museums and similar institutions will employ both small field scanners like the Konica Minolta Vivid 910 and large field scanners like the 3rdTech DeltaSphere-3000. Small field scanners will be used to make digital copies of all small content items, while the large field scanners will be used to capture exhibits or sites. The two sets of geometric information can easily be combined, in the same way that the high resolution digital photography images are integrated into the 3D virtual scenes of 3rdTech's SceneVision viewer currently. This hybrid solution marrying inexpensive high resolution capture of individual small sized items with high quality digitized environments should provide a complete method for capturing and displaying real and virtual environments.

2.6 Visualization

Digitization methods that capture only 2D images can generally only reconstruct 2D images from recorded viewpoints, or viewpoints interpolated between recorded viewpoints. Digitization methods that capture the 3D structure allow rendering of the 3D scene from arbitrary viewpoints with high fidelity. They generally produce a "cloud of points", which is reduced to polygons (usually triangles), which then have colored textures applied based on spatially correlating the information from the photographed scene with the laser recorded points of the scene. The major difficulties are in combining multiple scans of a site to handle overlapping (redundant) data points, getting colors of the same surface captured from different viewpoints to match, and simplifying the final dataset by reducing very small polygons into larger ones.

Some new work is also being done on image-based rendering which may allow more accurate depictions of a 3D object from multiple recorded 2D images (Levoy 1996). This would have an efficiency advantage over object based methods since the complexity of rendering using object based methods increases with the complexity of the object (number of polygons representing the surface).

2.7 3D Spatial Modeling of Interior of Objects

A related topic not covered in detail in this paper is the scanning of the interior of objects, such as by CT or MRI scanners commonly used for scanning human bodies, but also inanimate object scanning. These datasets can be rendered either by polygonal surface methods, or by direct volume rendering methods. Such datasets allow the user to cut into an object to study the interior as well as the exterior surface Hemminger (1995).

3. METHODOLOGY

There are many important advantages to virtual museums. As part of our methodology, we attempt to summarize the 3D digitization process, challenges facing cultural heritage institutions, and advantages of virtual museums.

3.1 3D Digitization Process

Identification of content. The particular items and scenes to be digitized must be chosen. Also items that require particular emphasis (for instance paintings if we want to be able to view them close-up) must be identified.

Planning. Site planning, including making the exhibit available for scanning (and not for other uses), site preparation (removal of exhibit item protective containers), appropriate lighting.

Data collection (scanning). This phase involves the actual scanning of objects and scenes. It may involve the use of multiple scanners. Information recorded must include sufficient descriptive information (location, view angle, time, lighting conditions) to allow it to be properly integrated with other scans of the same physical space.

Data cleanup. Most digitizations will require multiple scans. This necessitates integrating information among multiple scans where there may be overlapping information. Issues include how to handle redundant descriptions of points or surfaces in the same space, how to match colors among color textures of the same or adjacent spaces (that may be based on photographs from different angles, under different lighting conditions, etc), how to reduce the number of polygons to what can be rendered in real-time by current PC graphics cards.

Visualization. Interactive viewing packages that support 3D environment description and can be controlled in real-time by users are required. Stereo viewing may be used to provide additional 3D visual cues.

3.2 Challenges facing Museums

Museums currently face many challenges. Clark et al. (Reilly 1991, Clark 2000, Clark 2001) describe the challenges faced by museums as cultural heritage institutions:

- Increasing amount of content (physical items), and at the same time a decreasing storage space for the items (SAA 2000, NSF 2001, NPS 2000).
- Memory institutions are relatively few in number, and unequally distributed which causes inequities in what is chosen to be stored, and what is accessible.
- Access to content is severely limited due to travel costs. And again there are inequities

due to many groups having little to no funding.

- Many antiquities are too fragile to travel, or to allow repeated handling and exposure.
- Handling of culturally sensitive materials may not be permissible or appropriate.
- Content items or sites are lost to natural hazards (floods, fires, volcanoes, earthquakes), theft, warfare, or economic development.
- Sites may not be available

3.3 Advantages to Virtual Museums

There are many advantages to digitizing content, both individual items and exhibits (even the entire museum). Having a digital copy of items or exhibits allows them to be accessed by anyone, at any time, from any place. It allows any number of people access at the same time. It preserves a nearly complete record of the object, which can be accessed without damaging the original. 3D digitization and display potentially solve all the challenges listed above. The advantages that virtual museums provide are listed below:

- Imagery and spatial measurements are mechanically recorded and not subject to human interpretation.
- Everything can be recorded, in complete detail, in their original setting, with limited human effort.
- Precise, repeatable measurements are made that are equally or more precise than human measured ones.
- Objects can be viewed virtually and virtually dissected for study for any amount of time, with no cost or damage to the content.
- Morphological comparison of related material is facilitated through qualitative visual comparisons or quantitative shape-based comparisons.
- The system is non-invasive, in that it does not touch or affect the samples or site. This is important for conservation.
- Because the data is digital it can be conveniently archived and made available anywhere, anytime, to anyone 24/7/365.
- Different interfaces, or visualizations, can be provided depending on the observer, their task, and the material. For instance a scholar may desire a shape comparison display while a neophyte may wish to simply browse the different exhibits.

3.4 Equipment and Methods

The equipment used for scanning the scenes is the DeltaSphere-3000 (3rdTech, Chapel Hill, North Carolina, http://3rdtech.com/DeltaSphere.htm). It combines laser rangefinder technology, professional digital photography, and state-of-the-art computer graphics software in a portable instrument that can be mounted on a photography tripod (Figure 1). The DeltaSphere-3000 employs an embedded time-of-flight laser rangefinder--a device that measures the distance, or range, to any point the laser hits. It uses a rotating mirror to scan a vertical slice, and a rotating motor in the base that rotates around the vertical axis for the next slice (see Figure 1). This process is repeated until the specified field of view has been covered. The coordinate system used is much like the latitude/longitude system on the surface of the earth, or the azimuth/elevation coordinates used in surveying.

Computer control of the internal positioning motors at the base, and the revolving mirror allow the DeltaSphere to automatically scan a complete room or scene with the laser rangefinder. The default setting of 13.33 samples/degree is appropriate for scanning rooms or large scenes for virtual museum digitizations. Using this setting the scanner records the range and position of several million sample points for distances up to 50ft (15m) from the scanner in approximately 20 minutes.

Figure 1 DeltaSphere 3D Scene Digitizer.

The acquired set of sample points can be automatically converted to a simple 3D model. This model can be rotated, scaled, and displayed from arbitrary viewpoints. It can be used as input to other software packages for creating realistic views of the 3D scene in color from any viewpoint. Finally, range data from multiple scans can be combined to create a single 3D model. For example, scans of multiple rooms or multiple parts of the same room can be combined to create a complete detailed model.

The second step is to use a professional digital camera to capture the color image data for the scene. We used a Fuji FinePixS2Pro with non-fisheye lens AF Nikkor ED 14mm f/2.8D for the examples in this paper. The captured color digital images are correlated with the laser range finder spatial points. This allows the generation of very realistic views of the 3D scene from any angle. An example of a static 2D rendered image from one viewpoint is seen in Figure 2. While most range finder based digitization systems can provide 3D scene views, the images are generally of lower quality. The 3D environment recorded by the DeltaSphere 3000, however, is of very high quality, nearly indistinguishable from a photograph of the scene as seen in figure 2. While static 2D images can be used to view the digitized 3D environment, it is more effective to view it using real-time viewing applications that display the 3D scene on a 2D computer display maintaining some of the 3D visual cues (lighting, shading, obscuration, stereo (if stereo viewing glasses are used), user controlled changing of viewpoint) (Hemminger 1995). This supports a virtual reality experience where users can actually feel as if they are in the museum, as opposed to seeing photographs of the museum. Techniques that photographically capture scenes, or that do not integrate the color image textures with the range finder data cannot provide such visualizations. Figure 3 shows the actual sample data points (after reduction) underlying the visualization seen in figure 2. The output of the process of combining the color texture from the digital photographs with the laser range finder sample points is a VRML format data file. This is a standard format for texture mapped polygons, and supported by most 3D viewing applications.

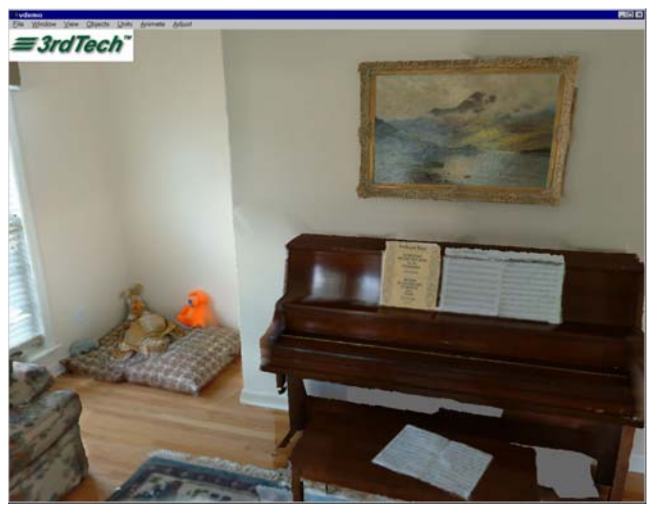

Figure 2. Single view captured from the interactive 3D scene. This is from the final model after all post-processing has been completed, and data from multiple scans has been integrated.

An optional part of the second step of digitally photographing the scene, is to take close-up photographs of areas of interest, for instance of paintings or manuscripts. These high-resolution close-up photographs are then linked into the environment in the same fashion as the regular room photographs. This provides high quality image

Figure 3. Single 2D picture captured from the same 3D scene capture as figure 2, and seen from the same viewpoint as figure 2, but with the rendering changed to display the polygon with the interior colors turned off. Thus, objects in the picture seem transparent, and the number of polygons used to depict objects can be appreciated.

details when the user moves or zooms up close to these objects in the room. An example is shown in figure 4 where the piano instruction book by Ferdinand Beyer on the left was captured at high detail with a close-up view, while the open one on the right was only recorded during the general room scan. The close-up view (from the vantage point of someone playing the piano) shows how the high quality of the piano book on the left is maintained while the one the right appears fuzzy.

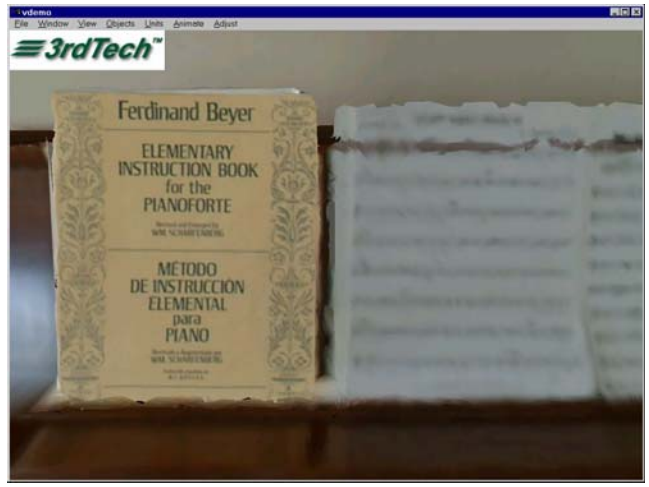

Figure 4. Close-up view of the music books on the piano. The book on the left had a close-up digital image incorporated into the model, while the one on the right did not.

The longest part of the process comes after all the range finder and color image data have been acquired. The major effort is to properly match colors between different scans, and to reduce the sampled polygons from multiple scenes to just keep the sets that best describe the objects in the room when there are overlapping scans. Reducing (simplifying) the number of polygons is also important in order to keep the rendering speed interactive (multiple frames/second) for the large datasets generated which may contain millions of polygons. Third party software is used for this work. Packages commonly used for this include PolyWorks/Modeler from InnovMetric Software, RapidForm from Inus, and I-Site Studio from I-Site 3D. The examples in this paper were prepared with Polyworks/Modeler. These tools support

- Aligning the data from multiple scans into a single scene. In this way, objects can be scanned from all sides to create a solid model.
- Simplifying the data – intelligently reducing the number of points – to make the data more usable without losing useful information
- Creating a 3D model for use in image generation and animation. This enables creating images, or even animations, of the scene from any viewpoint – even from vantage points that are physically

inaccessible, like overhead or underneath a scene. Note that these 3D images are not recreations – they are displays of actual, measured data.

The time required for an average complicated room scene, such as the figures in this paper, is on the order of 3 hours setup (site planning) time, 12 hours scanning time, and 100 hours post-production time. Only the scanning and part of the planning needs to occur on site.

3.5 Initial Museum Exhibit Digitizations

We are working with the Ackland Art Museum at the University of North Carolina at Chapel Hill to test this methodology on exhibits and content items at the museum. Working with Gerald Bolas, the director of the Ackland Art Museum, we have digitized one of their most important recent exhibits, *Plum, Pine, and Bamboo: Seasonal and Spiritual Paths in Japanese Art, Oct 19th 2003 to Jan 4th 2004*, which has now been taken down, and will likely never be exhibited in this form again. We spent one day (12 hours) scanning the two exhibit rooms and the entrance foyer, including digital pictures and close-ups of all significant pieces. A total of 22 scans were taken. Five of the scans were close-ups of a statue, 14 were small field of views (less than 90 degrees), and 3 were large field of view (360 degrees). Figure 5 shows a view from the center of the main exhibit room looking towards the large tiger panel. Figure 6 show a view from above looking down into the entire exhibit space.

Figure 5. View from the center of exhibit space of the *Plum, Pine, and Bamboo: Seasonal and Spiritual Paths in Japanese Art* exhibit. At the center of the image is *Tiger in Bamboo*, 1861-1863, after Nagasawa Rosetsu, six panel, ink on paper.

Figure 6. View from outside and above the same exhibit space seen in figure 5. At the front of the visualization is the entry foyer where the exhibit begins, and continues into a single large room, partitioned into subparts through the use of wall panels. The tiger panel seen in figure 5 is on the backside of the first freestanding wall panel (slightly green) just beyond the entrance doorway.

The viewpoint used to create figure 6 was set to be outside of the exhibit rooms, and above the ceiling height to give a 3D perspective of the exhibit environment. The rendering was set to show only front facing polygons, so that we could look through the ceiling into the rooms. In some cases the spaces behind objects, such as behind the 6-fold tiger panel, will not have laser scan data describing them, and will arbitrarily be depicted as black. These are areas where the laser range finder was obscured from taking measurements, and would require a follow-up small angle scan from a different location to fill in the "holes".

In our early stages of evaluating this methodology, we have noted several important things:

- Scanning rooms with many free standing objects (such as sculpture gardens) require significantly more scans from different locations to capture all the detail on sculptures.
- Laser finders do not perform well on very black surfaces (which don't reflect the light). We chose to use an infrared laser for our digitization to minimize this effect. However, for collections with large numbers of black colored items it may still be a significant issue.
- Many display items are protected from the elements or museum visitors by being encased, typically in a box with transparent surfaces (glass, plexiglass) to look through. Transparent surfaces may cause reflections, and possibly distortions in the laser range finder measurements or the photographs. For our digitization the museum removed most all of the enclosures. This suggests that digitization might best be done at the installation or de-installation of the exhibit to avoid removing and putting back the exhibit item enclosures.

3.6 Feedback

This work has been presented at the JCDL 2004 and SIGGRAPH 2004 conferences and was very well received. Users have interacted with the visualization on laptop screens, workstations screens, large projection screens, and half-domes (Elumens, Durham NC, elumens.com). A simple user interface utilizing the mouse for 3D movement worked reasonably well. Age was a factor, as most kids and teenagers were able to immediately move through the virtual reality without needing instructions. The presentations were very effective in all formats, although some users were less comfortable using the half dome display. Users had a strong preference for the high spatial resolution large screen and projection displays, probably due to an increased sense of immersion in the virtual museum space due to more of their field of view being occupied by the virtual reality. One previous tradeoff of the standard projection systems was lower resolution; however, this appears to be addressed as manufacturers have begun releasing higher resolution (1200x1600) projectors that maintain the quality of the image when projected on large screens.

The Ackland museum staff have reviewed the digitization of the *Plum, Pine, and Bamboo: Seasonal and Spiritual Paths in Japanese Art* exhibit and are very excited about its potential. The director stated that "Good exhibitions are larger than the sum of their parts because works of art can be seen in meaningful juxtaposition with each other and in relation to education and other contextual material appropriate to the themes of the exhibitions. This is why documenting an exhibition as a group of objects in meaningful juxtaposition is significant as compared to having images of the individual works of art in a show available; the visitor can witness the artistic event that an exhibition comprises." In addition to thinking this will be effective for visitors, the museum director suggested that this representation could greatly facilitate communication between directors and curators about exhibits, and that the digitization is effective for creating an additional archival record of the exhibit. The other obvious extension that we have begun to explore is the linkage of additional related information to the virtual reality. Clickable hotspots or 3D links are added to the virtual reality. This allows the user to call up additional information in the context of their interaction. For instance by clicking on an object in the museum, the visitor can see an individual high resolution scan of the object, be offered the opportunity to view other similar objects, read further museum prepared information it, or have the ability to link to additional content (web pages) related to the object. This puts large amounts of contextually related information at the user's fingertips (a click away) without cluttering the view of the exhibit.

One drawback the director noted was that because museums' make a significant investment when creating exhibits, they go to great lengths to construct the exhibit as perfectly as possible. The virtual reality appearance, while very realistic, often has small inconsistencies in places like corners, or edges of walls where lines may not be captured perfectly straight. These artifacts can catch the attention of discerning museum professionals and be distracting.

Because of the success of the digitization, Ackland plans to make the interactive visualization available as part of their educational resource center, so that visitors to the museum can visit the exhibit in virtual reality.

Overall, we expect the most significant impact to occur when the exhibit's virtual reality presentation can be viewed through standard web browsers, and the potential audience of an exhibit instantly becomes hundreds of millions of viewers. Today, however, because of the large size of the datasets, it is impractical for most viewers to load the dataset quickly or to achieve the interactive update rates necessary for a virtual reality experience. Given the continued increases in performance of personal computers and the internet, we believe this will become feasible in two to three years. We have made the complete Ackland exhibit available for download via our Virseum web site (http://ils.unc.edu/bmh/virseum/). The download includes the viewer and dataset. We are planning on further evaluations when the exhibit is shown at the museum educational resource center and when web browsers can directly visualize it.

3.7 Major Remaining Challenges

While we have demonstrated that systems available today can be successful in digitizing scenes and objects, there are three areas in which advances would bring about significant improvements. Of these, the first is the most significant factor as it consumes an order of magnitude more time than the others.

- Automatic reduction of multiple point cloud sensor samplings to a single collection of triangles representing the scene.
- Automatic determination of minimum (or close to minimum) scanner positions necessary to properly record a scene.
- Correctly mapping color to geometry, representing the actual color under specific lighting conditions, and correctly blending the color from multiple scans.
- Better navigation and visualization interface to more naturally allow inexperienced users to navigate the space as easily as they do a "real" physical space museum.

4. DISCUSSION

We believe that this methodology for digitizing museum content, including items and exhibits, into a format suitable for interactive viewing applications will allow the user to experience an exhibit through virtual reality. Museums will be able to accurately record all their content and make it accessible at any time to everyone.

Currently, the cost of digitizing is primarily determined by the capital cost of the digitizing equipment and the manpower (time) required to perform a high quality digitization (mainly the post-production work). At this time, it is likely that only large museums could afford to purchase digitization systems ($40,000-$50,000) and more routinely digitize exhibits. Smaller museums would likely choose to only digitize special exhibits and particular items due to the cost. This is possible as digitization services are quickly appearing (3rdTech), and digitization costs are only a fraction of the cost of the entire exhibit. Because the digitization requires little human time, and produces a very accurate model, this also compares favorably with the alternative of modeling exhibits, which requires more human time, and does not result in as accurate or realistic of a virtual reality.

In the near future, we envision several changes that could make this become standard practice for museums. First would be the advent of the "microwave oven" small field scanner. You place your object on the rotating platter, close the door, press the button and a minute later you have a perfect digital copy. Second, would be for the large field digitizers to evolve into consumer grade "point and shoot" 3D cameras (scanners) that will capture large 3D scene environments and automate the post-production process. Third, is that the virtual reality systems used for gaming (Xbox, Playstation, GameCube, etc) could easily be adapted for visiting virtual museums, and through the use of avatars could allow virtual communities and interactions between people to take place in the virtual museums. When these changes occur, museums will be able to conveniently and inexpensively digitize all their material and exhibits and make them available on the web, and most households will be only a click away from visiting their favorite museum.

We also propose a new area of museum and artistic expansion, "virtual exhibits", where the virtual exhibits are created only abstractly in digital form, never in physical space. Museums may use this to help plan their future exhibits, similar to how architects and builders can now visualize buildings in virtual reality before construction.

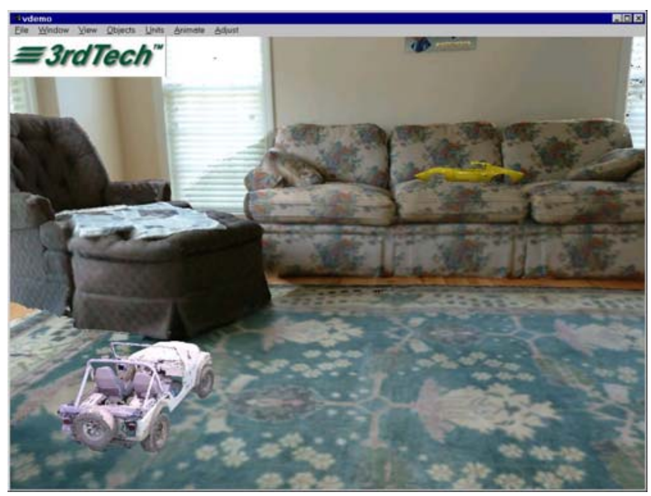

Figure 7. The living room scene shown in figures 2 and 3 has been modified by adding rough digitizations of two cars.

An even more interesting extension would be the freedom to create virtual exhibits through the combination of any objects or scenes available in a digital form. For instance a curator interested in a particular type of pottery used in a certain region in 500 BC could create an exhibit based on a setting from that time period (perhaps an archeological site that has been digitized), and place within it pottery examples from collections at 100 different museums around the world that had been digitized by their museums and made available. A primitive example of this is in figure 7 where two real cars, a Jeep and a Jaguar, have been turned into toys in the same living room scene shown in figures 2 and 3. The cars were roughly scanned and not at as high quality as the living room. It is easy to imagine scanning insects from the Smithsonian and having them come alive life-size in virtual exhibits or movie special effects.

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