2D open-source editing techniques for 3D laser scans

M.J. Olsen[1], K. Ponto[2], J. Kimball[2], M. Seracini[2], F. Kuester[2]

[1] School of Civil and Construction Engineering, Oregon State University, USA, *michael.olsen@oregonstate.edu*
[2] Center for Interdisciplinary Research for Art, Architecture, and Archaeology (CISA3),
University of California, San Diego, {kponto,jkimball,mseracini,fkuester}@ucsd.edu

Abstract

Recent technological advances in terrestrial laser scanning (TLS) allow for rapid collection of massive amounts of point cloud data for various cultural heritage, archaeological, and engineering applications. Commercial packages designed to edit these data in 3D environments are generally proprietary, require high-end computing platforms to run effectively, and in many cases, have shortcomings when dealing with imaging artifacts encountered in typical field environments. We present a method to edit TLS data using common 2D image editing techniques and software, providing powerful data processing techniques while easing the learning curve. This methodology provides an intuitive approach for simple clipping edits as well as non-traditional edits using color value, intensity, and range, which can be selectively grouped and screened. While these methods are not intended to replace 3D editing tools, they provide users with the ability to process their data swiftly in straight-forward and cost-effective ways. The application of this method is demonstrated on TLS data collected at the Palazzo Medici in Florence, Italy in 2008.

Keywords: LIDAR, laser-scanning, open-source.

Background of Terrestrial Laser Scanning

Terrestrial laser scanning (TLS) uses LIght Detection And Ranging (LIDAR), a line-of-sight remote sensing technique, which rapidly determines the coordinates of objects relative to the scanner origin using either time of flight or phase shift information. High speed, phase based terrestrial laser scanners compare phase shifts between a modulated laser beam to determine distance to a target at close ranges. Time of flight based scanners measure the laser pulse travel time and the angle of return to determine the coordinates and are more suitable for larger ranges than the phase based scanners. Various laser scanners are currently available with varying speeds (typically 2,000 to 120,000 points per second), maximum resolutions (typically 1mm to 100mm at 50 m), and accuracies (typically 3 to 10 mm at 100 m).

Most scanners concurrently photograph the scene to provide realistic color RGB values for each scan point or allow for images from a calibrated external camera to be mapped to the collected 3D data points. Scanners also typically provide an intensity measurement showing signal degradation, which can vary with material type.

Because of the speed at which data can be collected, TLS has gained popularity in historical preservation projects for the 3D acquisition and subsequent modeling of buildings, sites, and works of art. BERNARDINI et al. (2002) used TLS to analyze Michelangelo's Pieta statue. DAL PIAZ et al. (2007) modeled and analyzed the stability of a historical structure using TLS. GUARNIERI et al. (2005) also presents the application of a TLS to a cultural heritage and structural analysis problem by creating 3D models for and dynamic stress analysis using finite element analysis. LEVOY et al. (2000) started the Digital Michelangelo Project to model and study Michelangelo's David statue and has developed many useful tools for application of TLS to cultural heritage.

A typical data acquisition workflow for laser scanning is shown in (Figure 1). In addition, BERNARDINI AND RUSHMEIER (2002) discuss a typical processing pipeline for TLS data, focusing on acquisition. Scans need to be collected from several locations to obtain a complete model, and uniform alignment of the scans can be achieved through methods such as target-based, direct georeferencing (Figure 2) and software feature alignment.

Direct georeferencing (e.g. SCAIONI 2005) methods use objects as targets (Figure 2) that have known coordinates to align the scans together or surveying in control points where the scanner is set up. These coordinates can be obtained through GPS, Total Station,
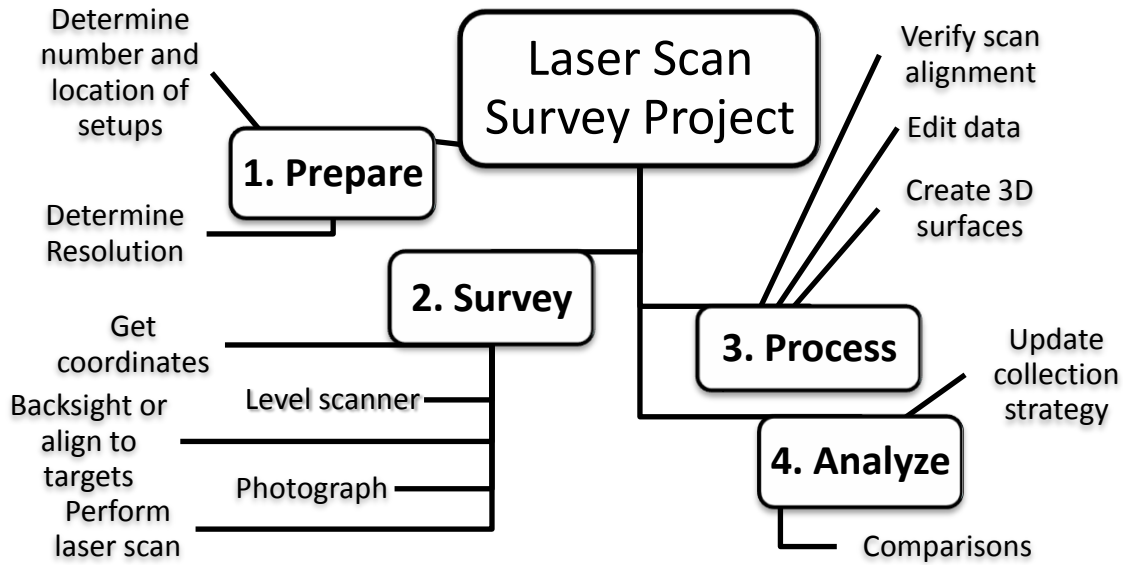
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Figure 1: *Terrestrial laser scanning workflow.*

Figure 2: *Leica ScanStation2 setup and Reflective targets used to align multiple scans.*

or other survey devices. Software registration, determines the optimal alignment of a scan based correlation of similar features in on neighboring scans to merge the scans together, and is comparable in accuracy to direct georeferencing for close range scanning (ALBA 2007). This can also be done by manually selecting corresponding points in adjacent scans to tie the scans together.

Once scans are aligned and merged, artifacts are removed from the dataset through manual editing, which can be extensive, tedious, and time consuming. Specialized software is generally required to display, interact with, and edit the point cloud collections. This software tends to be expensive and requires a steep learning curve and associated skill set to perform the editing tasks efficiently. While a wealth of point-cloud data sets have become available, broad adoption has been limited as a result of the software-level availability and limitations. This paper presents image-processing techniques to edit 3D point cloud data from TLS surveys, in the context of established mainstream 2D image processing applications.

While some tasks might be easier in a 3D environment, 2D editing has several advantages. Editing a 2D image requires substantially less computational power, can be done in open source or inexpensive mainstream image-processing packages, provides access to a broad collection of tools, and offers an environment more familiar to most users. In addition, existing automated algorithms for 2D photo feature extraction can be implemented for editing.

Related Work

Rapidly editing 3D models using 2D views is an active research area for computer graphics (VAN OVERVELD, 1996; ZHANG ET AL., 2001; WU ET AL., 2007). BERNARDINI ET AL. (2002) discuss the application of 2D editing techniques in a cultural heritage application to segment various sections of a 3D model. FAROUK ET AL. (2003) discuss editing range images for display of 3D objects on the web. FRANKEN ET AL. (2005) discuss texture mapping of 2D images to 3D models. This paper seeks to expand this previous work to use multiple 2D versions of 3D datasets simultaneously and to establish a workflow to assist those applying laser scanning to various projects within cultural heritage and archaeology. Further, this work focuses on exploiting valuable information such as intensity and range, in addition to photographic information for simplified editing processes.
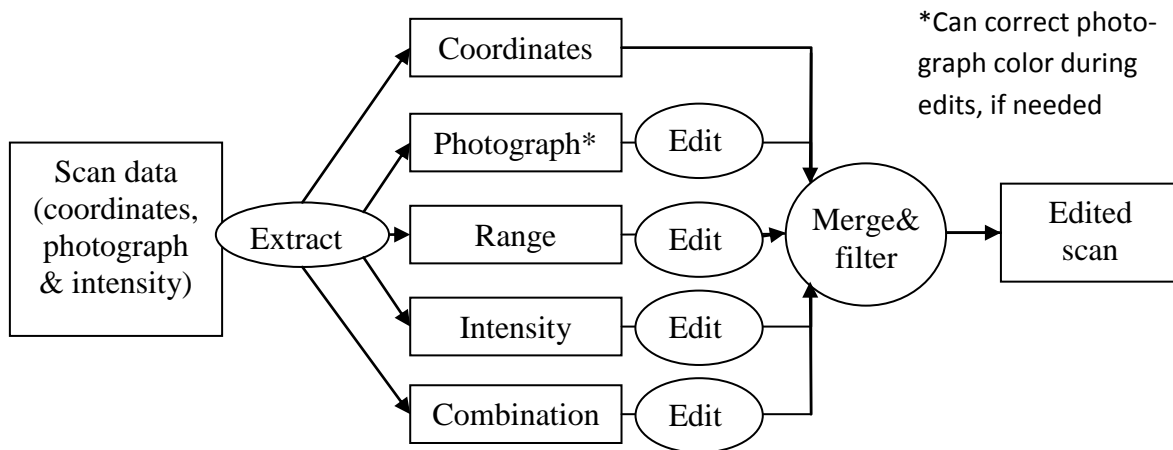
Figure 3: *Editing workflow using this method. Rectangles denote datasets and circles denote processes.*

Methods

Figure 3 shows an overview of the presented method, which allows subdatasets to be extracted from the scan data, edits to be performed using these subdatasets, and the datasets to be merged using filtered points based on the edits. Scanners operate on a spherical grid format with measurements separated by a fixed angular offset as opposed to a final resolution on a target surface. Figure 4 shows the spherical envelope of the scanner used for this research project, a Leica Scanstation 2 (Figure 2). Multiple scans can be collected from a setup at varying resolutions to closer approximate the desired end point density on a target surface.

Each scan is performed on a grid, which allows for direct mapping of the photographic data. The process of extracting the image from the scan data simply requires exploiting the grid format of the scan and storing the color values of the scan in a 2D image file. Each pixel in the image will correspond to a scan coordinate and these images will use a spherical projection (Figure 5A). The coordinates are available in the original file. For this project, the data was exported from the scanner's acquisition software to a ptx format, preserving the grid format of the scans.

The derived grid images can then be imported into a standard 2D image editor. Editing in such an environment ensures that all data for that scan can be seen and will not be occluded by objects in the scan, which can cause accidental deletion of data points in a 3D environment. Conveniently, most image editing tools have several useful capabilities which work well for data editing. For example, selection by color range allows for objects with fairly consistent coloring to be rapidly removed from the dataset. Polygons can be used to rapidly delineate features for deletion or processing techniques used to apply color corrections to the whole image or

selected target areas. Since scans are commonly collected sequentially, i.e. at different times, different lighting conditions can cause artifacts to appear when combining and visualizing multiple scans.
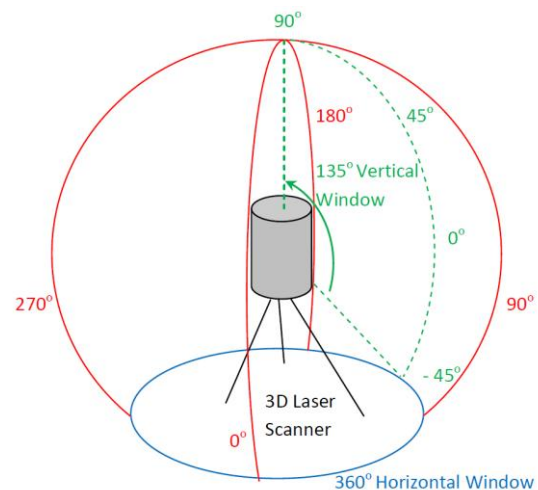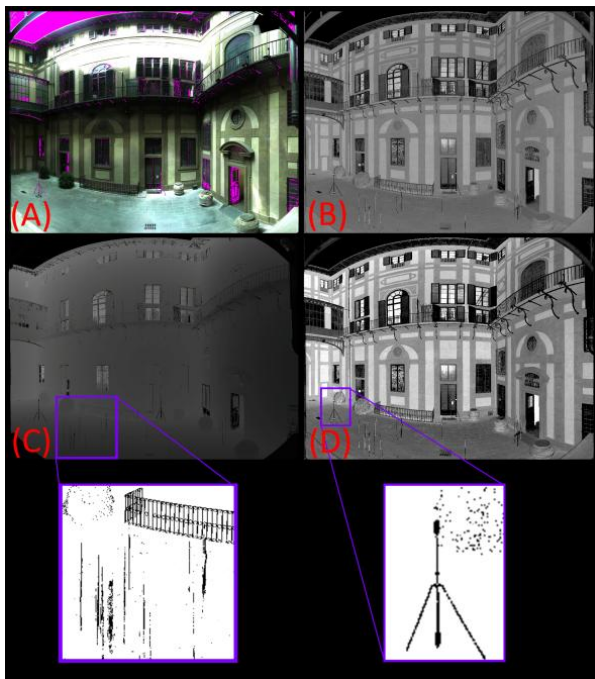

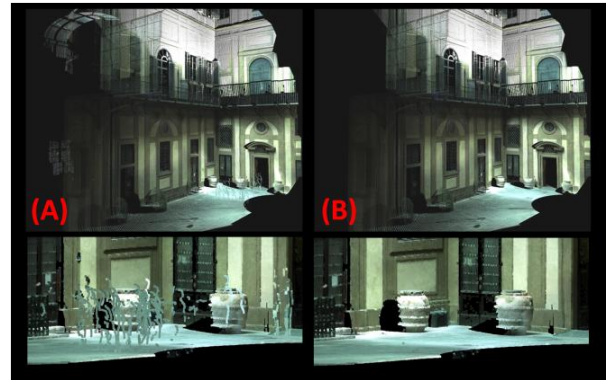**Figure 4:** *Spherical envelope for the Leica Scan-Station 2 laser scanner.*

In addition, a range map (Figure 5B), obtained by mapping range from the scanner to a grayscale image, can be a useful tool in the editing process. Certain objects further from the scanner may be undesired. Also, objects that are inconsistent with their surroundings can be seen and clipped using the range map. For example, if a person walks in front of the scanner as it is scanning (Figure 6), inconsistent streaks appear in the scan data. These unwanted points can be easily expunged by selecting their range values as shown in Figure 5. This can also be determined through using the intensity map (Figure 5C). Further, different materials will have dif-

ferent reflectivity properties, influencing the signal degradation as the pulse is returned to the scanner. Applying this to the editing process, features can be easily extracted that differ from their surroundings. Multiple layers can be used in conjunction to highlight features which need to be removed, facilitating the editing process. For example, Figure 5D shows a blending of the range map with the intensity map using a linear light method, which highlights people who walked in front of the scanner. Figure 5e shows the extraction of people from a laser scan through evaluating the contrasting areas on the merged intensity and range maps. Figure 5F shows the extraction of a reference target from merged intensity and range maps.

The 2D editing process for 3D scans can be performed by marking the unwanted data as transparent or using a specific key color (Figure 5). Transparency is preferred because it avoids potential conflicts if similar colors to the key color are found in the dataset. Following the editing process, the edited image files determine which points to filter from the original dataset. Points associated with transparent or color-keyed pixels can be screened when extracting the coordinate data from the original scan.

Figure 6: *Laser scan data in 3D space (A) unedited with close up of people (B) edited with close up of same region. Note elimination of people and distant objects*.

In addition, many tools in image editors use feathering to blend layers which can cause some remaining data points to be blended with the key color, which will either remove them from the dataset or cause their bleeding of the key color. If the scan photograph was not taken precisely from the same location as the scanner origin, parallax can occur which can cause offsets when mapping color data to the scan data. Typically this offset will be minimal, if the scanner camera has been properly calibrated. To compensate for this in the editing, one can increase the deletion areas by a few pixels. Preferably, the range and intensity maps, which do not have parallax effects, can be used on separate layers as guides to determine the edges of objects.

Storing multiple versions of data edits can be useful when analyzing different aspects of the data. Often, because of inconsistent lighting conditions, some areas of a scan may conflict sharply with better image data. However, these data points could be useful for analysis purposes. Using 3D editing software requires inefficiently storing several versions (unedited, edited for analysis, edited for visualization, etc.) in separate files with the complete coordinate and color information. The X, Y, and Z coordinates for each data point would be redundantly stored as floats (12 bytes) or doubles (24 bytes) in every version of the scan data. Conversely, using separate image files would only require the coordinates to be stored in one file. The image files are much smaller than the coordinate data, requiring only 4 bytes (RGBA) per point in a RAW format, which can further be reduced by well-established image compression techniques.

Figure 5: *Images extracted from a 3D laser scan of the Palazzo Medici (A) Photograph with no data values shown in magenta, (B) Intensity values with white being the strongest, (C) Range values with white being the farthest, (D) Range values combined with Intensity values through Linear Light blending to emphasize inconsistent features, (E) extraction of people from background scan data, and (F) extraction of target from background scan data. Note the spherical distortion in images.*

Results

This approach was applied to edit laser scan data collected at the Palazzo Medici in Florence, Italy using a Leica ScanStation 2 capable of acquiring data at millimeter resolution. The Palazzo Medici was built in the 15th century and was home to the powerful Medici family. Scans of three courtyards were performed over 10

days in May 2008. The TLS data provides a baseline model for the characterization of historic artifacts, a snapshot in time that when combined with future scans can be used to detect changes in the structure. Swift and continuous identification of these changes provides vital clues about the health and integrity of the structure. For the presented case, the TLS data is also being used to assist engineers in Florence as they perform renovations on the structure.

However, to arrive at a holistic model, multi-spectral imaging techniques are required to capture information about the physical and chemical surface, sub-surface and volume composition. The surface model derived from the laser range scans serves as the reference frame for data derived from other techniques such as microwave, ultraviolet, infrared, thermal and x-ray imaging. The target resolution for the courtyards was <1 cm spacing between points. The resulting dataset consists of approximately 190 million points collected from scans from 25 locations. Reference targets (Figure 2) set up at consistent locations each day, were used to accurately align the scans.

Figure 6 shows a scan before (A) and after (B) the editing process illustrated in Figure 5. Several features such as people standing in the courtyard or walking through it, objects not statically positioned within the space, noise and erroneous readings have to be removed from scans to ensure consistency. This example shows several people passing through the courtyard as the scan data was acquired. Other items subject to removal were the reference targets used to align multiple scans, distant points resulting from scans penetrating windows. The photograph was used to eliminate the targets from the scene, and the points were easy to distinguish via the range and intensity maps. The range (Figure 5B) and intensity (Figure 5C) maps were useful to highlight and remove erroneous data from people passing in front of the scanner. Extraction proved more efficient with range and intensity maps combined (Figure 5D).

Figure 7 shows another example of an edited scan where distant buildings were removed based on the range map. Additionally, an extension cord used to power the scanner was removed by editing the photograph. This extraction proved difficult in 3D space because it was difficult to separate from the ground surface. Figure 8 shows the scan before and after edits in 3D space Figure 9 shows merged point clouds from three scan setups in a courtyard before and after editing, showing the removal of the buildings, unwanted objects, and reference targets. Simple and quick photograph and range edits removed most of the neighboring buildings and the undesired objects. Complete extraction was then possible by iterative editing and viewing of the data in 3D space.
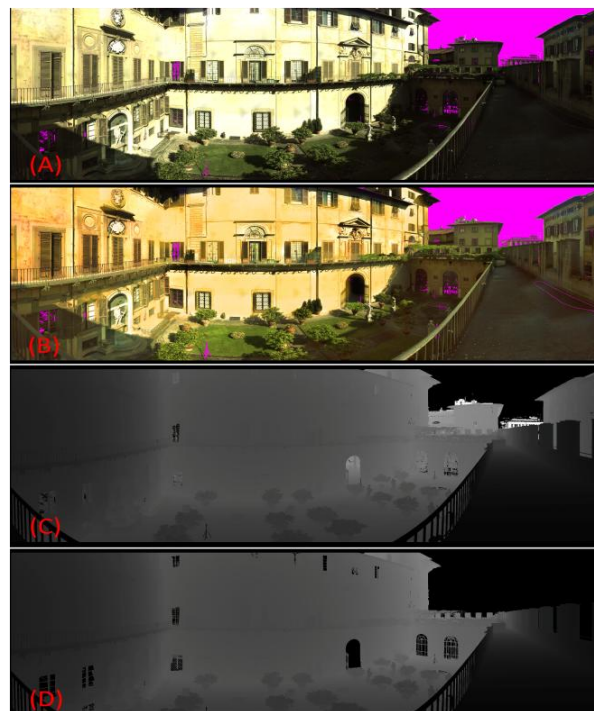
Figure 7: *Courtyard scan from Palazzo Medici (A) scan photograph before editing and color correction (transparent regions shown in magenta), (B) after editing and color correction, (C) scan range map before editing, and (D) after editing*
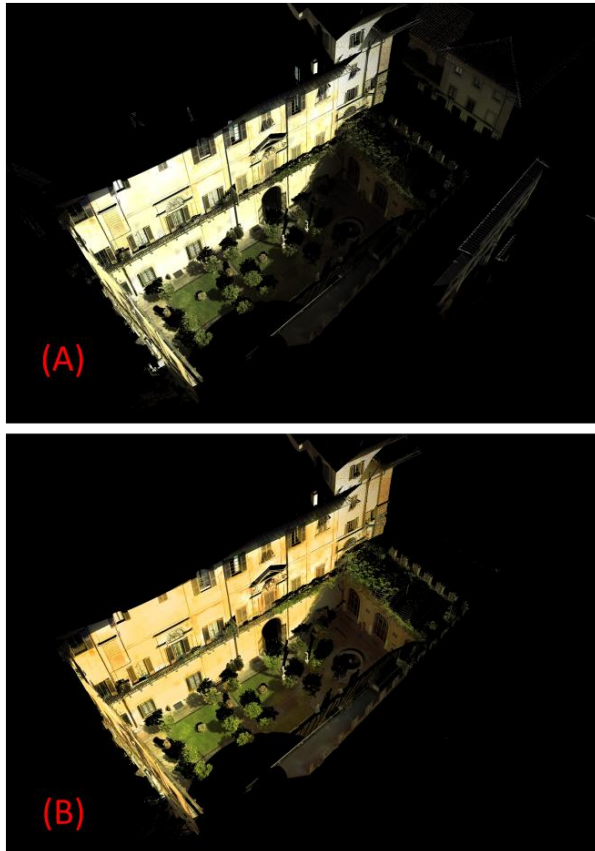
Discussion of Results

The application of this editing method to the 3D scanning of the Palazzo Medici has shown that this method can be implemented to speedily process a large number of scans. The method proposed in this paper works well for the deletion of unwanted or inconsistent objects. Difficulties in the method arrive when attempting to remove all points from behind a window, which are difficult to distinguish in the range maps. However, these points represent a very small minority of the points behind the window, and were generally acceptable to remain in the dataset.

Conclusions

An efficient, fast and intuitive, image-based technique for the editing of LIDAR point cloud data using open source software is presented. Image processing techniques are used as the foundation for the characterization of the point cloud, removal of artifacts, undesired objects and enhancement of image and model quality. Minimal computing power is necessary to work with 2D images compared to the resources needed to display and manipulate massive 3D point cloud datasets. Common tools available even in a 2D image editing application such as color selection and polygon selection provide an easy and intuitive method to manipulate data. Further-

more, this method can reduce storage requirements for multiple versions of scan data. These techniques can be implemented to augment the 3D editing environment, which the user may already be familiar with. While some tasks may be simpler in 3D space, 2D image based editing offers a practical, efficient, and inexpensive alternative to high-end 3D software and hardware.

desired edits. Thus, the user can easily switch between the photographic, intensity, depth maps, etc., depending on which is the easiest to use for removing a particular object from the dataset. Furthermore, multi-touch devices enable a collaborative working environment, in which multiple users can simultaneously view and edit a single dataset.

Figure 8: *Garden scan in 3D space (A) before and (B) after edits and color correction*
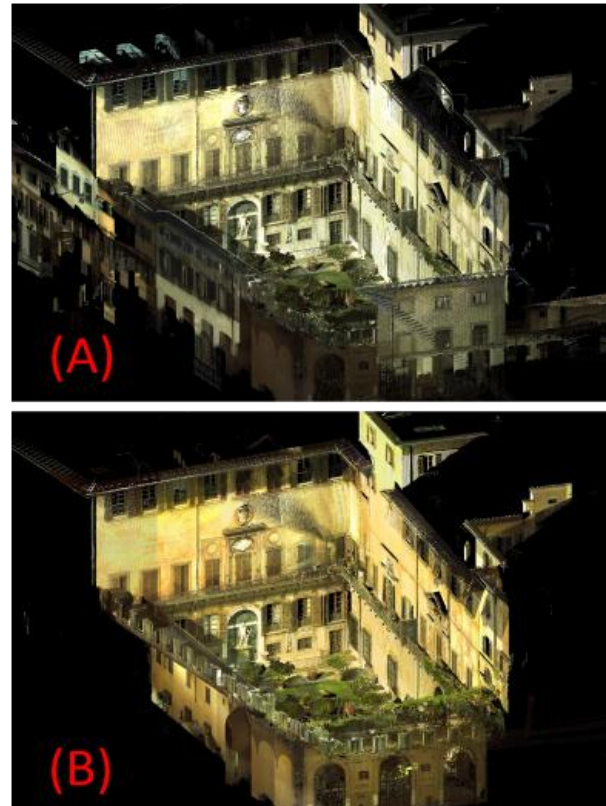
Figure 9: *Three merged scans from the outdoor garden courtyard at the Palazzo Medici (A) before, and (B) after editing and color correction*
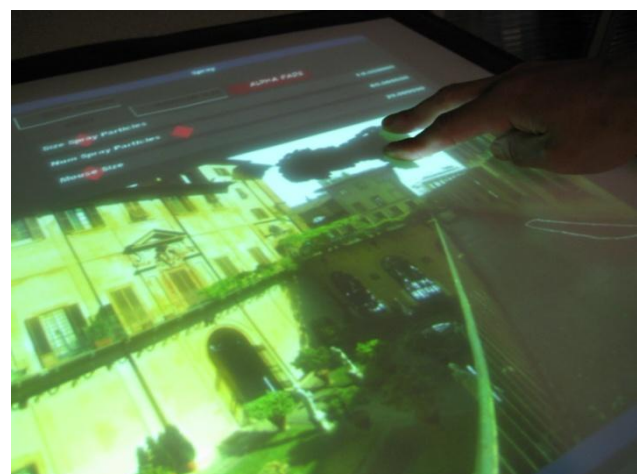
Future Work

This paper presents a general method for editing 3D laser scans, which can be widely used. Future research will involve integrating new technologies to improve human interaction for laser scan editing tasks by providing more intuitive interfaces. For example, multi-touch devices have ushered in a new era of interfaces for human computer interaction. These devices enable hands-on analysis, as shown in Figure 10. Figure 10 shows an example of editing a 3D laser scan that has been exported to 2D image, as discussed in this paper. In this way, users can simply wipe away areas they want to discard (Ponto et al. 2009).

Additionally, with such devices, multiple layers can be displayed and/or blended together, allowing the user to quickly switch between each layer to perform the

Figure 10: *Editing of the laser scans using a multi-touch table interface*

Acknowledgements

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