Terrestrial Laser Scanning for Digital Documentation and Damage Assessment of Cultural Heritage

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Introduction

Historical structures are one of the most essential element of cultural heritage. They reflect history, lifestyle and tradition of a country and society. They are damaged through the years due to human activities and natural hazards and, therefore, digital documentation of structures and monuments is critical for preservation, sustainability and protection of cultural heritage. Documentation of cultural heritage requires simple, quick and easy to use multi-sensor approaches to determine the state of conservation of monuments and heritage sites. Structures with archaeological or heritage value need constant monitoring in order to assess their condition and devise strategies to ensure their longevity. One would require comprehensive documentation of a structure to be able to better understand its condition. Such documentation may be in the form of detailed descriptions and engineering drawings, photographs, 3D models and historical records. It is an added advantage if such documentation is in the digital format as storage, analysis and dissemination of the information is a lot easier. Therefore, 3D digital documentation is a very effective way of monitoring structures over a period of time.

There are a lot of damages that can affect built heritage. The recognition of these damages and their evolution over time is an important task in the documentation work. Manual mapping of these damages is expensive and time-consuming. Besides, data capture depends either on the accessibility of the building, its emplacement and dimensions, and on the way of inspection and analysis. Therefore, the use of terrestrial laser scanning combined with terrestrial images can assist in the task and provide damage maps of the monuments. Light Detection and Ranging (LiDAR), as implemented in Terrestrial Laser Scanning (TLS), and Close Range Photogrammetry (CRP) are efficient techniques for obtaining three dimensional information of a structure without physically interacting with the same. This is an essential requirement in the case of historically important structures so as to avoid any further damages due to repeated human interference or natural events. The data obtained as a result of implementation of these methods may be further analyzed to extract necessary information. Several software which automate many tasks have been developed as result of cumulative and ongoing research in this field. There is, however, a broad scope for the application of innovative ideas to extract novel information from such data.

The study demonstrates practical use of TLS in documentation of heritage monument. The study also focuses on damage detection using TLS point cloud and terrestrial optical data. The study was carried out on two date TLS data of Buddha statue located in the Mindrolling monastery, Dehradun, India. The laser data was collected from multiple scan points to cover the entire statue.

Data acquisition:

For proper digital documentation, the data can be acquired from imaging and non-imaging sensors. Further the data from multiple sensors needs to be integrated. This section details the procedures for data acquisition and integration

Photogrammetry data:

1) A high degree of overlap (atleast 80%) and super lap must be ensured while capturing images of the object.
2) It will be essential to know the location of each of the points where images are acquired in order to calibrate the images with the laser scanner.
3) Ensure that the object that is to be photographed is illuminated properly. This important in order to detect features on the images.

Laser Scanning:

1) TLS scan positions are predetermined.
2) Setup the instrument at the first predetermined location and input the estimated settings.
3) The area that is to be scanned will have to be cleared off any obstructions and human/object movement while scanning should be avoided.
4) The location of each station should be acquired precisely. Preferably on the same platform as that used for obtaining the position information for the camera.
5) Reflective material in the form of reflective plates mounted on stands or stickers used appropriately may be used to obtain markers in the resulting point cloud. These markers will be used in registration of the point cloud in order to bring it the scans from each position into a single coordinate system.

Total Station/GPS:

1) Establish a total station point with precise location information. Using this position (or positions) as reference, the location information of the markers will have to be measured precisely.
2) The information obtained will be used for geo-referencing the point cloud.

Data Processing:

Pre-processing:

1) Photogrammetry data is to be processed in order to generate a point cloud. Tradition photogrammetry or Structure from Motion will result in generation of point clouds from the images. This step is avoided in case of laser scanning as the output is directly in the form of a point cloud representative of the surface of the object.
2) Point cloud from TLS and photos contains a lot of noise elements which are irrelevant to the processing of the data. The noise from each of the scans will have to be removed so that we are left with only essential information which represents the object only.
3) If acquired from different positions, the multi-scan data will have to be represented on a common reference system by performing co-registration. The process is carried out by making use of the markers. This basically involves identification of the common markers on adjacent scans. Based on the location of the markers, one of the scans will be

transformed in order to bring the coordinate system of the other scan. The process is repeated till all the scans registered in this fashion.

4) The cleaned scans may then be used for further analysis.

Integration:

1) The process of registration is in itself a method to integrate the point clouds. However, the photogrammetric processing may generate a point cloud which will not display the markers clearly.
2) Therefore, it will be greatly beneficial if an automated technique to calibrate the images and laser scans based on the location information.
3) The registration process may be used to coarsely integrate the point clouds
4) Iterative Closest Point algorithm will then be used to improve the alignment of the resulting scans.
5) The resulting point cloud may be improved upon by using the colour information from the images in order to colour the point cloud so as to get a photorealistic 3D dimension model of an object.

Data processing:

After initial processing and integrating the 3D points are projected using equi-rectangular projection. The gridding pattern in equi-rectangular projection is shown in figure #

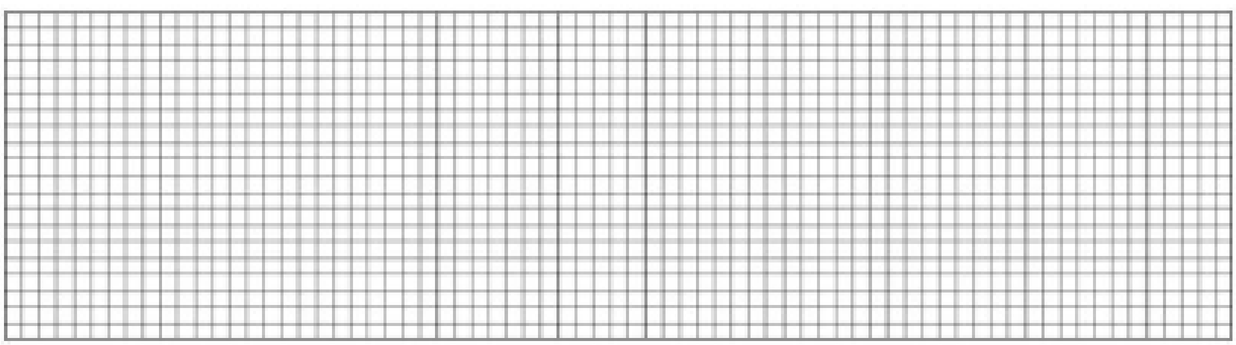
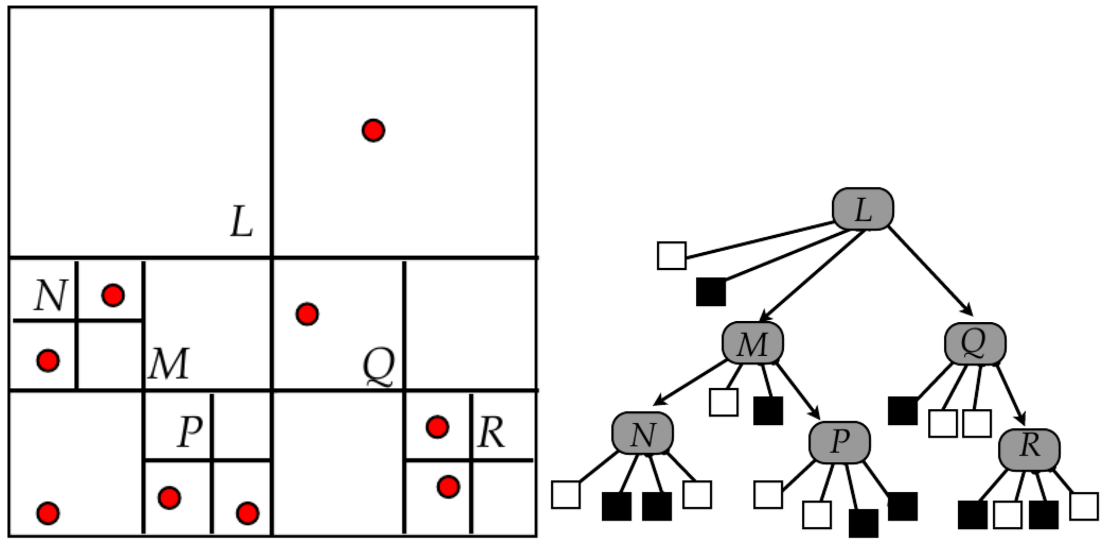


Figure 1: Equi-rectangular projection

The major advantage of equi-rectangular projection is that the resolution is uniform across the image.

Database creation:

1. Prior to damage detection and assessment, the registered and integrated data from multiple sensor is rasterized at finest resolution (1cm) and a girded database is generated using quadtree approach as shown in figure#. The grided structure is generated using equirectangular projection



(a) (b)

Figure 1 (a) spatial quad tree (b) Graphical quadtree

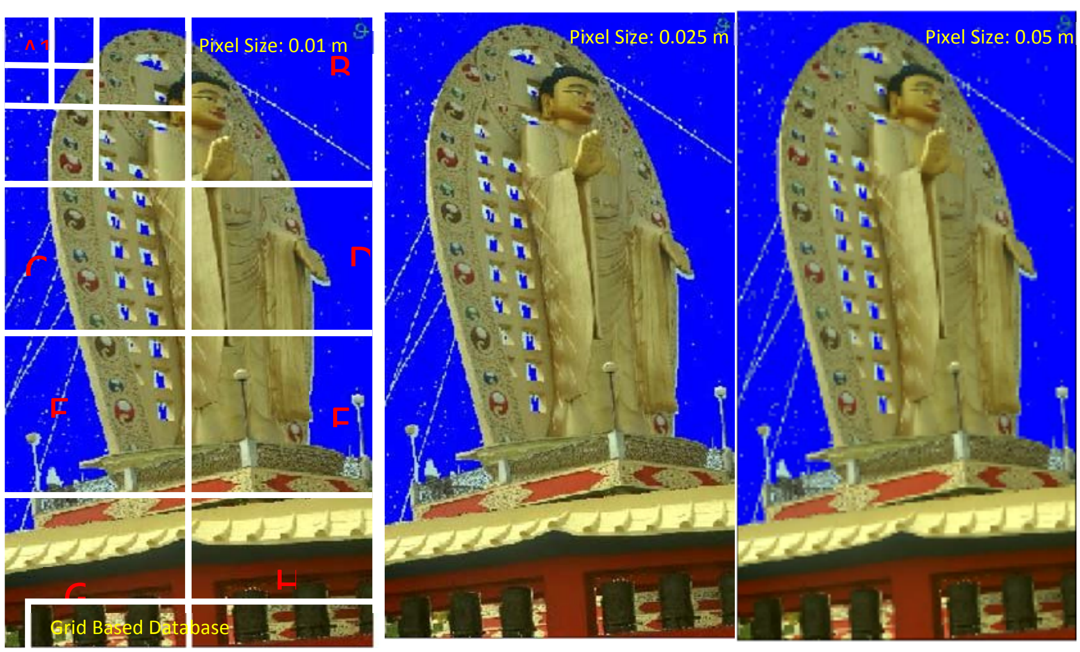


Figure 2: Quadtree based grided database of raster at different resolutions

Figure 3: Budha statue with two AOIs

The change analysis was carried out in two aspects: Geometric and radiometric variations Geometric based analysis mainly deals with changes/damages in structures e.g. cracks, peel-offs etc. whereas radiometric changes are studied using IHS (Intensity Hue Saturation) for identifying changes in colour.

Geometric based analysis:

For detection of damages and cracks, two areas were selected from the entire structure of buddha statue which are highlighted in figure 3.

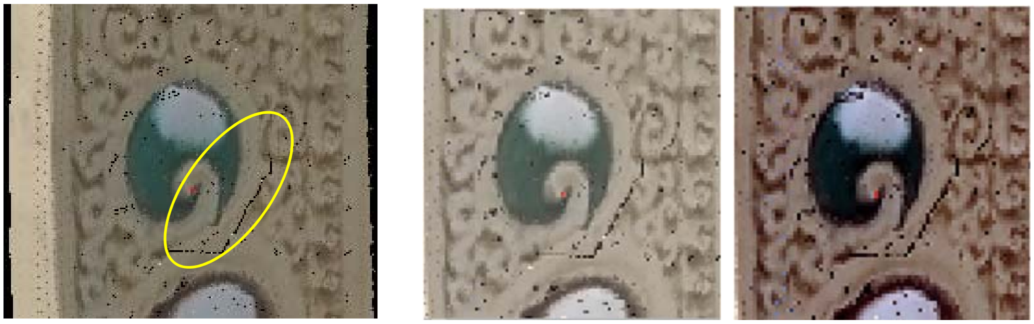
Crack identification:

For detection of crack, two data sets pre and post damage have been rasterized at same resolution. The rasterized images are shown in figure 4 and edges in the carvings which are detected using non-directional edge detecting filters (figure 4(b)).

(a) (b)

Figure 4: (a) Curvings in Budha status (b) Edges in carving

Using the dataset of carvings having crack, the raster image generated are showing in figure 5.



Figures 5 shows the raster generating using the data with crack

For identifying a crack, edges in both rasters with and without crack are extracted using a non-directional edge detecting filter. Edges in image with crack are shown in figure 6. Crack is extracted by performing edges from images with crack and without crack, further to supress the noise a thresholding is applied over the substracted image. The Identified crack is showin in figure 7.

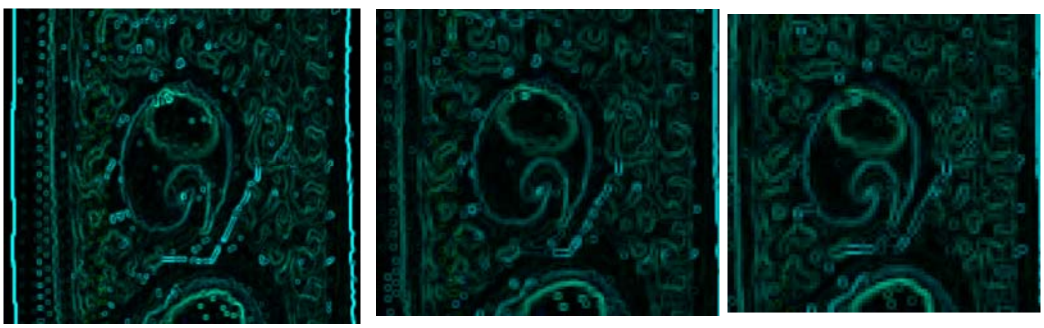
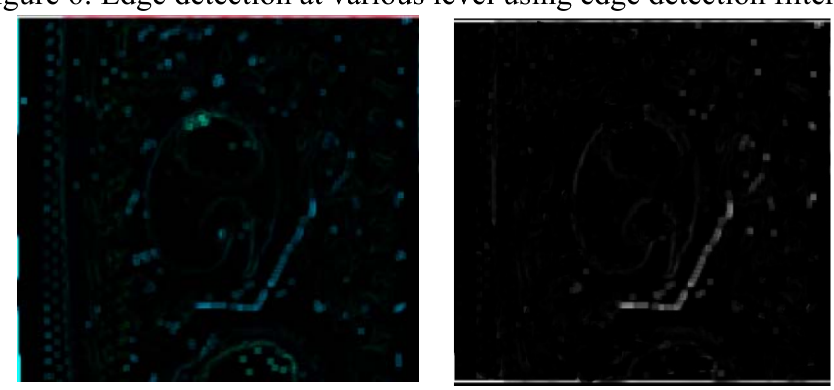


Figure 6: Edge detection at various level using edge detection filters

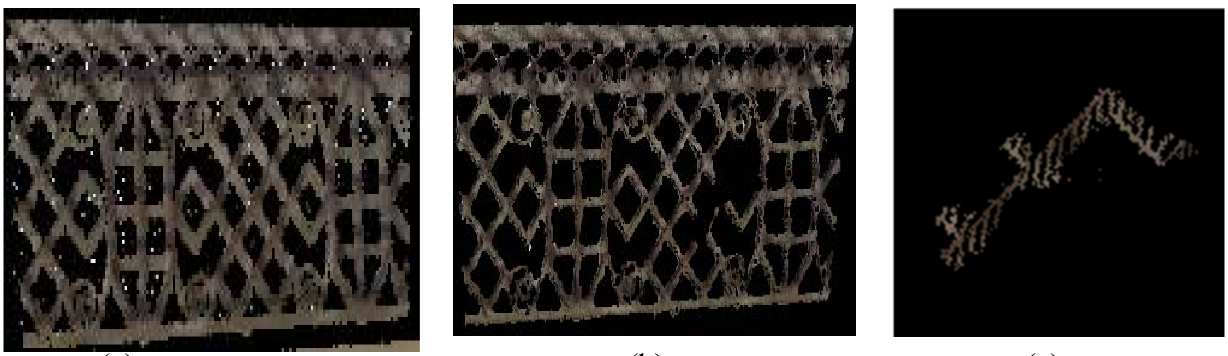


(a) (b)

Figure 7: (a) Crack detection after image subtraction (b) thresholding at finest resolution (1cm)

Damage detection:

For identifying the damages, pre and post damage image are used and change detection is perfomed to identify the damage portion within the area of interest. Pre-damage, post damage and broken portion are shown in figure 8.



(a) (b) (c)

Figure 8: (a) Pre-damage raster image (b) Post-damage image (c) broken portion

Conclusion:

Terrestrial images are of high resolution which can highlight changes in a surface in the spectral domain. However, it will not be easy to pick up these changes if there is heterogeneity in the surface. Image processing will highlight the features of interest along with the other surface characteristics. The TLS is, however, largely unaffected by these variations as long as they are on the same plane.

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