

APPLICATION OF CLOSE-RANGE PHOTOGRAMMETRY FOR 3D MAPPING OF PARKING SPACE

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ABSTRACT:

This paper explores and investigates potential of the close range terrestrial photogrammetry for urban parking space, which is occluded by trees and surrounded by buildings. The main challenge is to map boundaries of horizontal ground surface adjacent to vertical building structures. The study outlines a strategy for comprehensive mapping of such spaces at local scale. The methodology accounts for four criteria, namely, target characteristics, camera positions, overlap, and environmental conditions for planning of data acquisition. Further, target design and camera target geometry are considered to implement data acquisition with a consumer grade camera. Target design decides effective shape, orientation, and pattern of targets, and further determines the optimal distance with camera. Two-sided planar targets in vertical orientation with distinct and discriminate patterns, placed at a short distance to camera, are found appropriate. Camera target geometry designs the target and camera positions at specific distances in both longitudinal and lateral directions. Targets are placed in parallel lines, spaced at a constant distance in lateral direction on building surface and ground, and camera positions are interspaced geometrically in the same pattern. Camera positions acquire images that maintain designed overlap in lateral direction and contain minimum two layers of targets. This mechanism acquires images and generates 3D model that maps both building and horizontal ground surfaces simultaneously. A study site of 84,000 m² requires a total of 6615 images, which are processed to generate the 3D photogrammetric model. The model is geo-registered to local reference frame. Area occupied by parking spaces, open areas, and buildings are calculated. Parking space is 6.85% of the total area of the study site and can accommodate 141 car vehicles. Apart from mapping of parking area, the study also prepares a comprehensive map of site that can be used for planning of other utilities and facilities. Though the developed strategy generates and processes voluminous data of images, yet it is an attractive alternate as it demands minimum resources and logistics.

1. INTRODUCTION

1.1 Motivation

The growth of major cities led to spatially big buildings and monuments of high social importance, like shopping malls, universities, entertainment places, and other public utility services. All such locations attract a mass of people, who commute with different types of conveyance vehicles. This results to traffic congestions at most of the places in cities and sub urban areas, which also include parking spots and open areas. In the university campuses, open spaces located adjacent to roads are used as parking spaces. Lack of space availability demand excessive time for the parking of vehicles in designated places as well as open areas. This, in turn, influences and back propagates the traffic congestions. Consequently, it necessitates proper mapping of parking and open spaces in urban environment for economic, environmental, and social sustainability.

In general, the parking space refers to an area either closed or unenclosed which is sufficient in size to accommodate an automobile or any other conveyance together with a driveway for connection of the space with the street and permitting the ingress or egress of all such conveyances. On the other hand, open space refers to an integral part of the plot, which is considered as per the building bylaws. Parking spaces can be measured with visual and non-visual detection methods (Ma et al., 2021). However, currently authorities are looking towards a technology-based

solution with a lower cost and faster implementation for the 3D mapping of an urban location with parking and open spaces.

Although remotely sensed images, field inventories, LiDAR mapping, and reports from various public bodies are available for management and monitoring of parking space, they are often unavailable or costly for various locations. As an alternate, different approaches implemented for the 3D model generation have also considered mapping with close-range techniques; especially terrestrial, and UAV photogrammetry are commonly used techniques (Themistocleous et al., 2016; Ulvi et al., 2021). The photogrammetric process for construction of the 3D models involves procedure of obtaining image data at lower heights and then processing the acquired data to obtain the virtual 3D model. For example, Chandler et al. (2007) demonstrated a case of 3D mapping of a flume at a laboratory scale with drone photogrammetry using targets. However, data acquisition for the close-range UAV photogrammetry is difficult for urban spaces if the surface is occluded by tree covers. Also, the sensor utilization is dependent on the beam angle, direction, resolution and working distance. Whereas, for close range terrestrial photogrammetry, data acquisition involves lower cost and it can be successfully utilized for inaccessible regions. It can provide a platform for the direct interaction with the concerned object through the management of data acquisition strategies. On the other hand, the potential of a 3D model generated with terrestrial close-range photogrammetry for application in parking and featureless open spaces are not yet explored. The need for an accessible and interactive 3D photogrammetric model for a

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parking space requires a cost effective and reliable methodology with minimum complications and maximum precision.

1.2 Objectives

The topographic field to be mapped for the case of parking areas mostly consists of vertical boundaries of buildings and adjoining open or parking spaces. Moreover, homogenous surfaces of buildings, roads, open spaces are covered by featureless material like soil, metaled or paved surfaces, or grass. In this paper, we have proposed a cost-effective strategy to model a high-resolution 3D map for parking spaces. The paper addresses and investigates some of the relevant issues from all phases of model generation, starting from data acquisition to data processing. The objectives are as follows:

- (i) Designing targets and a strategy for placement of the artificial targets for automatic detection, recognition, and measurement of the common feature points among images. In addition, in the absence of any naturally detectable objects or surfaces, targets should also act as the distinct features for the overlapped images.
- (ii) Deciding camera locations in a network acquiring overlapped images not only to align images and determine various orientation parameters but also to achieve appropriate resolution and quality of the modeled regions, which provide a dense point cloud and mesh such that parking spaces can be demarcated from buildings surfaces visually.
- (iii) Geo-registration of multiple 3D photogrammetric models with accuracy assessment.

The 3D model generated along the building boundaries and the available parking spaces will enable the decision making for further expansion and planning of the buildings. Also, it will estimate the possible requirements of parking spaces in future. The paper is organized into four sections. After the introduction in first section, the second section contains the details of the materials and methodology. The following section deduces the probable challenges and the map generation and accuracy assessment of the generated map. Fourth section concludes the paper.

2. MATERIALS AND METHODOLOGY

2.1 Close range terrestrial photogrammetry

The generation of a 3D model by close range photogrammetry refers to the two processes in sequence: data acquisition, and determination of the interior and exterior parameters using various algorithms for the formation of a fully reconstructed model. During the former process, images are acquired with key points. The latter phase identifies correspondence pixels using common key points to join the images and determine the image orientation parameters. The next step is dependent on the type of algorithm followed by the software utilised for the combined model. The algorithm utilises camera positions and orientation parameters, which are determined with key points, to generate a sparse point cloud. Further, dense point cloud and triangular mesh from the sparse point cloud with the texture are generated from the images.

An important factor for the effectiveness of any digital data and transmission with the use of any software-aided design is the automatic detection, recognition and measurement of the artificial targets for the points of interest detection from the overlapped images (Fraser, 2001). Depending upon the requirement of the project and availability of resources, the

targets suggested so far for the aerial photogrammetry are planar, spherical or cylindrical, coded, or coloured targets (Chow et al., 2010). The artificial spherical, and hemispherical targets are popular as these are invariant to view perspective and involve simple construction. However, an alternative is required due to the high cost incurred and the difficulty in the detection of the centroids of the targets (Brazeal, 2013). In this work, the planar targets have been used to create 3D objects and the data obtained is studied to understand its reliability in context of terrestrial photogrammetric techniques. The planar targets were framed in different orientations to form a cuboid, prism with a triangular base, and double-sided planar surface to investigate the effective orientation that should lead 3D model generation. The targets not only alleviate the problem of featureless or a smaller number of key points in homogenous landscape but also are economical. The simple artificial target preparation required for the experiments, data acquisition and the processing using terrestrial cameras and the Pix4D software as a tool are discussed in next sections.

2.2 Study area and instruments

The study was conducted in the campus of the Indian Institute of Technology Guwahati, India. The region consisted of three storey buildings, open spaces, and parking spaces. The roads around the study area define the boundary. The study area, which approximately occupies 0.084 km² area, is marked as shown in Figure 1. With increased number of students and infrastructure growth, existing parking spaces do not suffice and their expansions are needed. Moreover, randomly parked bicycles also demand appropriately located parking spaces near to the academic area.

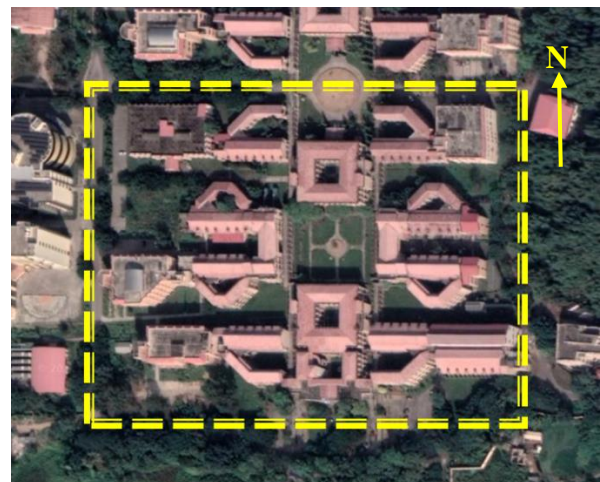


Figure 1. Google image of study area

For determining the effectiveness of a target for 3D model generation, a single target of each of the cuboid, triangular prism, and two-sided planar types is placed in ground and image data are captured using Canon SX610 HS camera, which is a consumer grade point and shoot camera. Specifications of the camera are mentioned in Table 1.

Field of view (degrees)	68.86
Focal length (mm)	4.5
Sensor size (mm x mm)	6.17 x 4.55
Resolution (pixels)	5184 x 3888

Table 1 Specifications of the camera

2.3 Methodology

Figure 2 depicts the methodology flowchart for the data acquisition and software processing to obtain the 3D model.

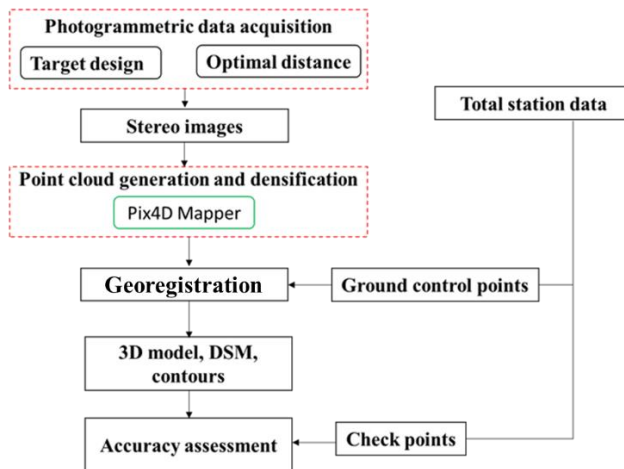


Figure 2 Flow Chart of Methodology

All steps of the methodology along with the necessary preliminary information are explained in the sections below.

2.3.1 Data acquisition: Characteristics of any photogrammetric model is dependent on the exterior and interior orientation parameters determined from the input data. The interior orientation parameters are determined from camera calibration parameters, whereas the exterior orientation parameters are determined from the key points measurements. The key or the feature points detected by the software from the input images enabled the parameterisation of the camera. Hence, several experiments were conducted to decide the optimum target design to produce dense point cloud in homogeneous surfaces. The following are some of the important aspects we considered for reliable data acquisition in the experiments.

2.3.1.1 Camera position patterns: As recommended by many studies like García-Gago et al. (2014), convergent and stereo images are preferably acquired for building corners and flat surfaces, respectively. However, due to combined coverage of the building and ground surfaces, it is found that convergent images acquire less area. Thus, contrary to a general practice, we preferred to acquire only stereo images at different tilt angles maintaining a constant distance from building and ground surfaces or their combination. For the image correspondences, proper overlap and camera network configuration are adopted.

2.3.1.2 Overlap: The overlap between the images from different positions help in reconstruction of the 3D model. The stereo photographs with an overlap of 90% was considered to determine the camera parameters with high precision. The number of photos required for the generation of the 3D model are determined using the swath of the single photo for the specified camera and overlap.

2.3.1.3 Target design: Although various networks have been established for 3D mapping of building facades with targets, there are no specific contributions towards the data acquisition of homogeneous open ground surfaces combined with buildings using terrestrial photogrammetry. Moreover, as the data acquisition is considered for a larger area, issues of pattern recognition may arise. This demands the target design for this

study. To provide an aid to the problem, different types of target patterns are considered. In addition, experiments are also conducted to identify the best 3D shape and orientation of targets.

2.3.1.4 Environmental conditions: The primary source of information for the model generation are images having uniform resolution. Thus, the images should be acquired in such a way that feature identification for key points generation is least affected. To maintain the uniform illumination and avoid glare and reflections of direct sunlight, data acquisition is planned during the day time for cloudy days, or in morning hours for clear sky. Also, on cloudy days, minimum or no winds provide a preferable environment for data acquisition.

3. EXPERIMENTS AND RESULTS

3.1 Data acquisition, data processing, and geo-registration

The data acquisition for a 3D model of an urbanised area with open green spaces and parking spaces include target placement and locating camera positions on site. Series of experiments are conducted in two phases. The first phase study the effects of shape, orientation, and design of targets. Thereafter, optimal distance between camera and object surface is determined.

Experiments reveal that among three shapes of targets, two-sided planar board is better than other two targets for obtaining optimum number of stereo images for maximum area coverage. Vertical orientation of targets is found better because a camera axis maintains stereo geometry as it needs less tilt compared to that of the horizontal target. While capturing the images, the targets are placed in vertical position in a linear pattern along a row. It is observed that for homogenous surface of object, consecutively placed targets appear to be associated with a same point in a 3D model. This is due to same pattern of the target. Thus, targets with different design patterns are used. Figure 3 depicts the designs of targets used.

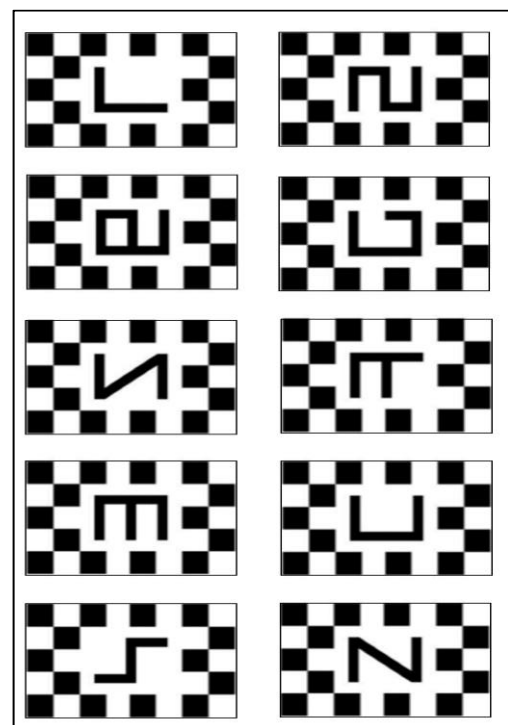


Figure 3: Different targets designed for pattern recognition

After realizing the appropriate shape, orientation, and pattern of target, the optimal distance is obtained with the analysis of the visual quality for 3D models generated by images acquired at different distances from 2m to 10m. Criterion for the visual quality are the minimum distortion and the least discontinuity in model surface. The maximum distance to create 3D models is identified as 7m because beyond this distance target resolution appears poor to distinguish different points on object surface.

In the second phase of experiments, camera network geometry and target positions are configured. Targets are placed on object surface as well as on ground parallel to object surface. Moreover, targets are placed in saw tooth or zig-zag pattern at a specific distance in two directions: (i) along the optical axis of camera or in normal direction to building surface, and (ii) parallel to building surface.

Along the object surface (wall), 3m distance is maintained between two targets. Whereas, in the normal direction, the targets are placed to fulfil two criterions. The first criterion is to maintain continuity of target features in images, which are consecutively acquired from camera positions in a row along the object surface. The second criterion places the targets stacked in two layers so that an image should fully occupy the targets of farther layer and partly occupy the targets in closer layer. Figure 4 illustrates the target locations and camera positions.

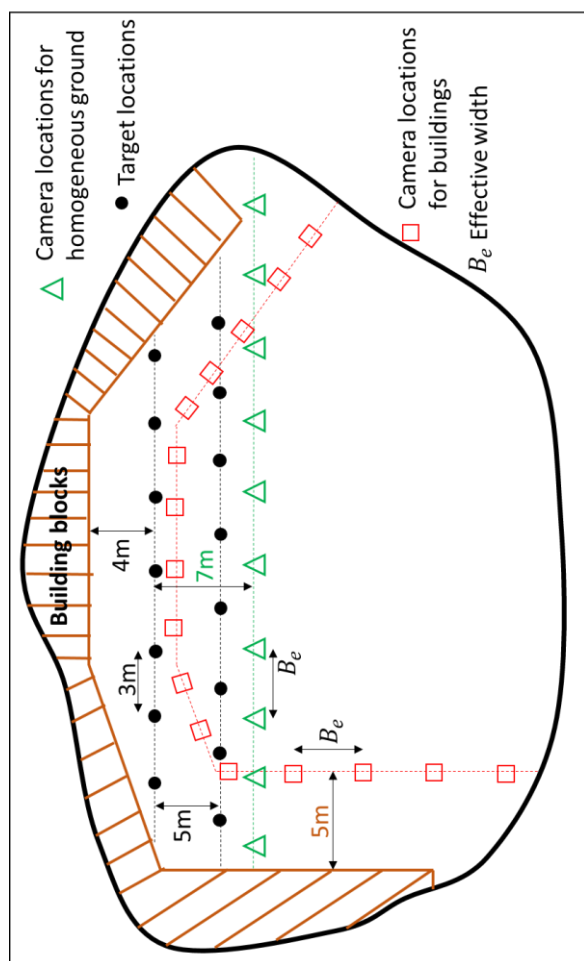


Figure 4. Schematic representation of the targets and camera positions

During data acquisition by camera positions in a row parallel to object surface, each image occupies two layers of targets in

normal direction. The first layer of targets is placed on object surface. As shown in the figure 4, the next layer of targets is placed at 4m immediately to object surface. Further layers of targets are placed at 5m from a previously placed layer. On the other hand, as mentioned earlier, the camera positions are also decided in rows parallel to object surface. The first or closest row maintained a distance of 5m from object surface. As a result, this row of camera positions maintains 1m distance from targets, which are at 4m and placed immediately to object surface. However, the remaining rows preferably acquire images occupying only two layers of targets and not the building surface. For such rows of camera positions, distances of 7m and 2m are adopted for farther layer and closer layer of targets. In a row, a camera position can occupy 9.6 m width on the object surface or target layer from 7m distance. Thus, two consecutive camera positions in a row are placed at 0.96m to obtain 90% overlap.

With the above arrangement of targets and camera positions, images are acquired. The targets are placed vertically with the help of a peg across the ground surface. With the horizontal optical axis of camera, the image data for building surface are acquired up to first floor. However, for combination of building and ground surface as well as ground surface alone are acquired with maximum tilt of 20°. Figure 5 shows an image occupied from one of the tilted camera positions.



Figure 5: A tilted image occupying targets placed on ground surface

After configuring the camera position geometry, images are captured for twelve number of individual areas that appear spatially divided and bounded due to buildings surrounding them. For each of the areas, two layers of targets are kept intact for all camera positions in a row. It means that when the survey is proceeded for the coverage of a larger area on the ground, previous layer of targets is not disturbed and targets in next layer are arranged. The intact positioning helps to act as a reference for the new targets to align distinct features of targets, which are placed on the ground surface and building. Subsequently, during the data processing, it also connects all features together in the

3D model. Moreover, the zig-zag pattern in successive layers having distinct and different target design allows for better visibility of each target and avoid pattern recognition issues.

3D models for each of the areas is generated after selecting the appropriate images by trial and error approach till the model is generated. It is observed that images with uniform illumination are better for model generation. In context of the study area, where moderate temperature and cloudy weather dominates across the year, authors experienced that the day time of cloudy days and morning hours on clear days provide uniform illumination across many months in a year. After successful model generation for each area, a total of 6615 images are selected from combined database of all images and the selected images are processed together in one attempt to generate 3D model of complete study area. Details of the data processing are explained in next sub-section.

Apart from the image data acquisition, 3D control data is also collected by a traverse survey using total station unit (Pentax R1502N model). A total of 393 distinct data points, uniformly distributed, are collected on ground as well as building surface with $\pm 2\text{cm}$ accuracy. These points can be identified and detected easily due to their shapes, texture, size etc. Such points, for example, include window corners, lid and covers of drainage boxes, road markings, intersections of concrete and bitumen surfaces of roads, and points on brick walls. Uncertainty of a control point location is estimated in field as 10cm (4 inches maximum). These control points are then used for the registration of 3D model. In South West of the study site (refer figure 1), control points are less in numbers and distributed non-uniformly. Next section explains the data processing and geo-registration processes.

3.2 Data Processing for 3D Point Cloud Generation

To generate the 3D point cloud, images are utilised as input to pix4D software that processes the data in three steps. Camera calibration is performed in the first step and next step detects common key points among overlapping images using sophisticated algorithms. In the last step, common key points are used for processes like aerial triangulation to generate sparse and dense 3D point cloud in pixel coordinate system. Specific details of the data processing by pix4D is explained by Fassi et al. (2013). The control points are used for the geo-registration of the 3D point cloud model. It is observed that the images are selectively used by automatic process for camera calibration. Also, model accuracy is found to vary with number of control points. The model accuracy is $\pm 8.6\text{ mm}$ (RMSE) with 248 control points. Even with higher number of control points, the model accuracy is less because area in South West of the study site having non-uniformly distributed control points degrade the model accuracy. Figures 6 depicts the 3D mesh model of the study area. In addition to the requirements of being distinct and detectable, the control points should also appear in more than three images and should not lie in shadow regions.

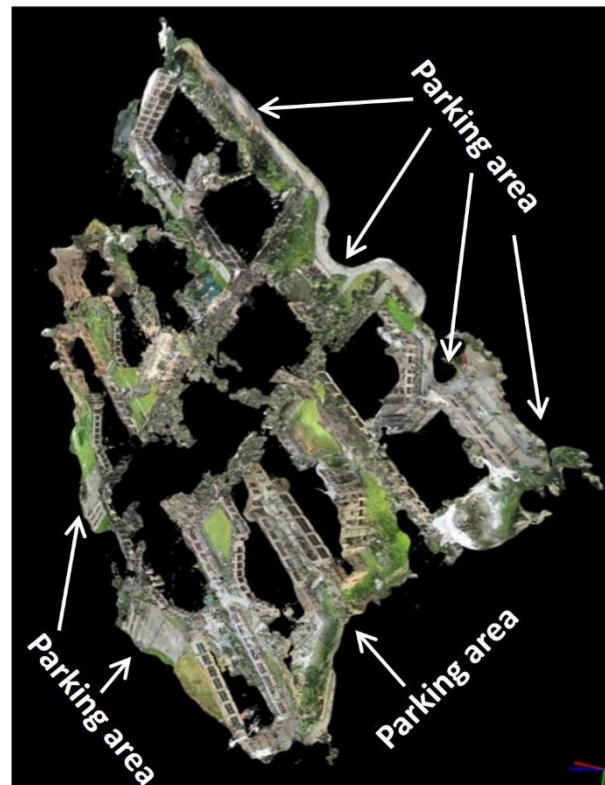


Figure 6. Low resolution 3D point cloud of study site showing parking areas

Figure 6 explicitly illustrates the parking spaces in the 3D mesh model. The boundaries of the buildings can be identified with black windows, whereas open spaces are in grass colour. As building surfaces are captured up to a height of first floor, building areas occupied inside their boundaries are appearing dark in the model. However, open spaces and parking places are appearing as planimetric features with their true colour. With these details captured in the 3D photogrammetric model of the study site, we demarcate the boundaries and measured areas occupied by the parking space, open spaces, and buildings. Values of the three areas are, respectively, 5750 m^2 , 9857 m^2 , and 68392 m^2 , which are 6.84%, 11.7% and 81.46% of the total area of the site. The parking space can accommodate 141 car vehicles.

4. CONCLUSION

The paper explores the potential of close range photogrammetry for 3D photogrammetric model generation for a considerably large and open area that cannot be acquired by UAV data because of partial or full occlusion by trees and surrounding buildings. The study consisted of three steps. The first step conducted experiments for calibration of targets for their shape, orientation, design patterns, and optimal distance with camera. The second step devises strategy and protocols for image data acquisition for the combined ground and building surfaces. The third step involves the photogrammetric point cloud generation and its geo-registration using control points.

Preliminary isolated experiments reveal that targets in the form of two-sided planar surface, in vertical position, having distinct design patterns at an optimal distance suffices for 3D photogrammetric model generation with the given camera characteristics and terrain. With these findings, the methodology considers target pattern design, camera positions, overlap, and

environmental conditions to plan the data acquisition. Certain thumb rules are followed for deciding camera positions and target placement, which are as follows:

- Geometry of camera and target network should be standardised and followed uniformly throughout the survey with a minimum 90% overlap.
- Targets should be placed on the planar and homogenous featureless vertical walls. For the planar ground surface, the targets should be placed in a linear pattern with the specific longitudinal and lateral spacing. Similarly, distance of the camera and target surface should be decided aprior. All distances mentioned here should be determined by experiments in field.
- For image acquisition, tilt of the camera should be so maintained that two layers of target should be visible from a row of camera positions.

Large number of images are acquired, and for the generation of the 3D model, the images have been selected by a regressive trial and error approach that combines the images with uniform illumination. 3D point cloud and mesh model are generated and then geo-registered with control points. The control points should be distinct, detectable, and appearing in more than three images and in illuminated regions.

The generated point cloud produced a triangular mesh that delineated the open spaces, building boundaries, and parking areas. The high-quality 3D model allowed to analyse capacity of parking area equal to 141 car vehicles and possible extensions for further developments in open spaces of the infrastructure. The suggested methodology can be utilised to influence future designs and proposals for a sustained development. Moreover, the 3D model can be classified for analysis of different objects and features.

Apart from above, authors also realized that different factors such as the complexities of terrain due to occlusion also restricts control point acquisition. Thus, decision making for location, distribution, and number of control points requires a substantial understanding of landscape. On the other hand, the data generated is voluminous. However, ease of implementation makes the methodology an attractive alternate for mapping of larger areas with minimum resources and logistics under restricted conditions, i.e. consumer grade camera, inexperienced users, and occluded areas. In prospect of future applications, the proposed method can be applied for architectural and cultural heritage studies.

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