# Integration of Photogrammetric and LIDAR Data for Realistic 3D Model Generation

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## 1. Introduction:

In the field of augmented reality, which deals with the combination of real world and computer generated data, the creation of realistic 3D models plays a vital role in overlaying the real world with one or more layers of additional information. Realistic 3D models are not only important for augmented reality, but also span that to other fields such as virtual reality, virtual tourism, city modeling, and military training. In this regard, the role of geomatics techniques has been limited to the creation of Digital Surface Models (DSM) and ortho-photos, and mostly draping the generated ortho-photos on top of the DSM for 3D visualization purposes. Such visualization was mainly sufficient for low resolution data over relatively smooth terrain. The advent of LIDAR and medium format digital imaging systems gave the geomatics research body the potential to satisfy the detail level and complexity needed by augmented realty applications. The affordability and availability of medium format digital cameras pushed towards their exploitation in photogrammetric mapping. A prerequisite step is to successfully calibrate such cameras and ensure their stability for repetitive usage. Habib et al. (2006) showed that such cameras are stable over time and can be reliably used for mapping applications. As for LIDAR systems, its accuracy is mainly dependant, beside other factors, on the availability of high-quality direct geo-referencing units in the form of an integrated GPS and INS system. Recent development in the positioning and navigation technology allowed higher levels of accuracy to be attained from LIDAR scanners leading to more accurate and realistic capture of physical surfaces. The integration of imaging and LIDAR datasets will lead to the acquisition of high resolution datasets over urban areas with a higher level of detail. Due to the nature of data acquisition of imaging and LIDAR systems, the complementary characteristics in the collected datasets can only be utilized after the successful geo-referencing of the photogrammetric data with respect to the LIDAR reference frame. Hence, the co-registration of imagery and LIDAR is a pre-requisite step for true ortho-photo and realistic 3D model generation. In the following sections, the geo-referencing and co-alignment of LIDAR and photogrammetric datasets will be discussed followed by the methodology for true ortho-photo and realistic 3D model generation.

## 2. LIDAR Data for Photogrammetric Geo-Referencing:

The position of a LIDAR-measured point is directly calculated using the LIDAR equation which involves the ground coordinate system, GPS/INS coordinate systems, together with the laser unit and the laser beam coordinate systems. The overall accuracy of a LIDAR derived surface depends on the accuracy and calibration of the different components comprising the LIDAR system. The positional nature of LIDAR data collection makes it difficult to derive semantic information from the captured surfaces (e.g., material and types of observed structures) (Wehr, 1999; Baltsavias, 1999).

Photogrammetric geo-referencing was traditionally accomplished indirectly through the establishment of a basic network of image-identifiable ground control points with known horizontal and vertical coordinates relative to a specific ground coordinate system (Kraus, 1993). Consequently, all features in the reconstructed object space will follow the reference frame in which the photogrammetric control is described. This reference frame can be a global, a local, or even an arbitrarily selected system. With the advent and availability of digital photogrammetric techniques, higher level features other than points could be efficiently used for photogrammetric geo-referencing. For example, linear features can be used in several photogrammetric activities such as resection, intersection, and self-calibration purposes (Habib et al., 2002; Schenk, 2004). Additionally, control patches can be exploited for photogrammetric resection operations (Jaw, 1999).

As it can be seen in Tables 1 and 2, the complementary nature of LIDAR and photogrammetric data continuously push towards the integration of both systems. The quality of the final synergic product unquestionably depends on the achievable quality from each individual system. Hence, a precise calibration of both systems, which is separately implemented, would guarantee that both datasets are as free of systematic errors as possible. In addition to the calibration requirement for both systems, the synergic characteristics of both systems can be fully utilized only after ensuring that both datasets are geo-referenced relative to the same common reference frame (Habib and Schenk, 1999).

| **LIDAR Pros** | **Photogrammetric Cons** |
|---|---|
| Dense information along homogeneous surfaces | Almost no positional information along homogeneous surfaces |
| Day or night data collection | Day time data collection |
| Direct acquisition of 3D coordinates | Complicated and sometimes unreliable matching procedures |
| Vertical accuracy is better than the planimetric accuracy | Vertical accuracy is worse than the planimetric accuracy |

**Table 1.** Photogrammetric weaknesses as contrasted by LIDAR strengths

| **Photogrammetric Pros** | **LIDAR Cons** |
|---|---|
| High redundancy | No inherent redundancy |
| Rich in semantic information | Positional; difficult to derive semantic information |
| Dense positional information along object space break lines | Almost no information along break lines |
| Planimetric accuracy is better than the vertical accuracy | Planimetric accuracy is worse than the vertical accuracy |

**Table 2.** LIDAR weaknesses as contrasted by Photogrammetric strengths

The first step in integrating photogrammetric and LIDAR data is to make sure that both datasets are co-aligned relative to the same reference frame. In this research, the co-alignment will be realized through the use of LIDAR data for photogrammetric geo-referencing. Utilizing LIDAR data for the photogrammetric geo-referencing can be viewed as a co-registration process. In general, a registration methodology must deal with three issues. First, a decision has to be made regarding the choice of primitives for the registration procedure. The second issue is concerned with establishing a registration transformation function that mathematically relates the reference frames of the datasets under consideration. Finally, a similarity measure should be devised to ensure the coincidence of conjugate primitives after applying the appropriate transformation function (Brown, 1992).

In his paper, straight-line features and planar patches were used in two separate methodologies as the primitives of choice for the co-registration of the photogrammetric dataset to the LIDAR coordinate system. All mathematical models and similarity measures in relation to the adopted methodologies were realized as well. It is worth noting that the devised mathematical models can be applied to imagery captured by frame and line cameras. Moreover, the inclusion of LIDAR derived features (linear and areal features), if provided in sufficient configuration, can allow for the self-calibration of the implemented camera. The experimental results from real data proved the feasibility and suitability of the proposed methodologies for the purpose of co-registering LIDAR and photogrammetric datasets, which is considered a pre-requisite step towards more fruitful applications as will be illustrated in the following section. In addition to the success of the LIDAR features for photogrammetric geo-referencing, the experimental results have shown that the geo-referencing quality from the proposed procedures is quite comparable to the traditional geo-referencing techniques (direct and/or indirect). For more technical details, interested readers can refer to Habib et al., 2004.

## 3. True Ortho-photo and Realistic 3D Model Generation:

After the photogrammetric dataset has been aligned to the reference frame of the LIDAR data, the results are ready to be used in the ortho-photo generation process. Ortho-photo production aims at the elimination of sensor tilt and terrain relief effects from captured perspective imagery. Differential rectification has been traditionally used for ortho-photo generation (Konecny, 1979; Novak, 1992). For large scale imagery over urban areas, differential rectification produces serious artifacts in the form of double mapped areas (Figure 1) at object space locations with sudden relief variations (Skarlatos, 1999). Double mapped areas constitute a severe degradation and are a major obstacle to the interpretability of the generated ortho-photo. Such artifacts are removed through true ortho-photo generation methodologies, which are based on the identification of occluded portions of the object space in the involved imagery (Catmull, 1974; Amhar et al., 1996; Amhar et al., 1998; Rau et al., 2000; Rau et al., 2002; Sheng et al., 2003; Kuzmin et al., 2004). To overcome the problems associated with current true ortho-photo generation techniques, angle based true ortho-photo generation techniques are suggested in this research. According to the proposed methodologies, the presence of occlusions can be discerned by sequentially checking the off-nadir angles to the lines of sight connecting the perspective center to the DSM points along a radial direction starting from the object space nadir point. In the remainder of this paper, the off-nadir angle to the line of sight will be denoted as the $\alpha$ angle, Figure 2.

(a) (b)

**Figure 1**. Perspective image (a) and corresponding ortho-photo (b) with double mapped areas enclosed by solid black lines

Since there is no relief displacement associated with the object space nadir point, one can assure that this point will always be visible in the acquired image. As one moves away from the object space nadir point, it is expected that the α angle will increase. As long as there is an increase in the α angle as one moves away from the nadir point while considering DSM cells along the radial direction, these cells will be visible in that image. On the other hand, occlusions will take place whenever there is an apparent decrease in the α angle while proceeding away from the nadir point. This occlusion will persist until the α angle exceeds the angle associated with the last visible point. The performance of such a methodology does not depend on the relative relationship between the DSM cell size and the Ground Sampling Distance (GSD) of the imaging sensor. The impact of the GSD of the imaging sensor, as it relates to the DSM cell size, on the quality of the derived true ortho-photo is the major disadvantage of current techniques. Two angle-based methodologies, which will be denoted as the adaptive radial sweep and spiral sweep, are introduced for occlusion detection and true ortho-photo generation. The radial sweep detects occlusions while sweeping the DSM one radial direction at a time. On the other hand, the spiral sweep detects occlusions while sweeping the DSM in a spiral mode starting from the object space nadir point.

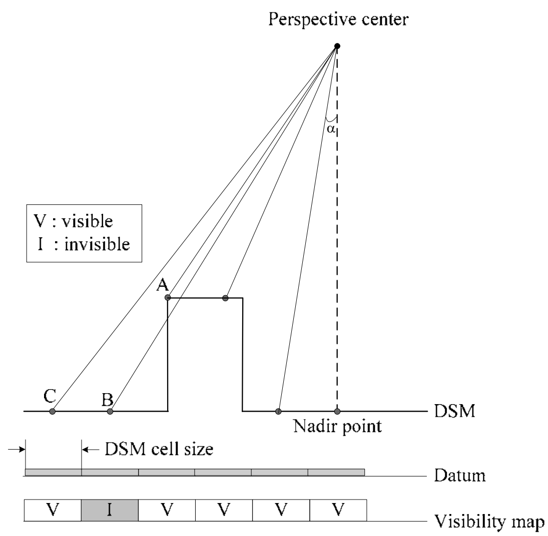
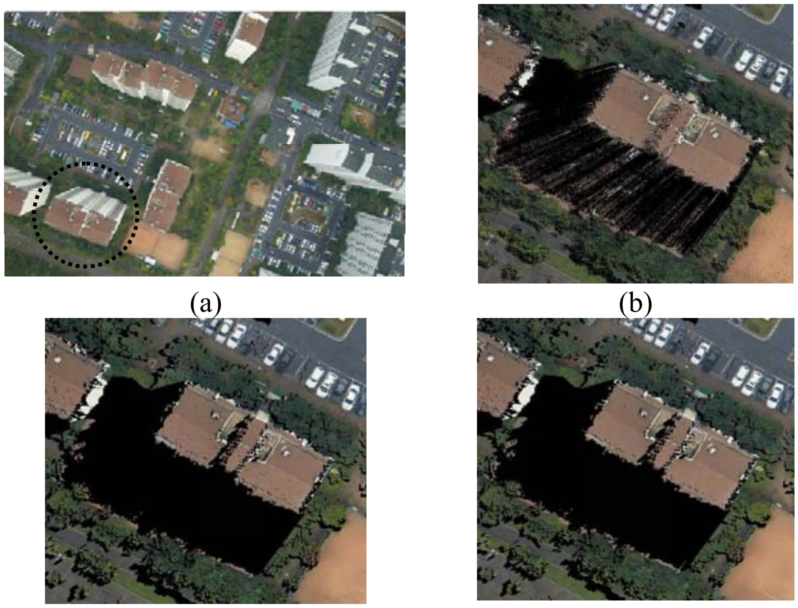



**Figure 2**. Using the off-nadir angle to the line of sight as a means of detecting occlusions

As an illustration of the performance of the suggested methodologies in comparison to that of existing technique, let's consider the building enclosed by the dashed line in Figure 3(a), which has a significant relief displacement along the radial direction. The true ortho-photos of the building by the different techniques are generated while detecting and removing the occlusions. The spiral sweep, Figure 3(c), and adaptive radial sweep method, Figure 3(d), achieved significant enhancement of the quality compared to the existing method, Figure 3(b), where false visibilities are introduced in the occlusion areas. Moreover, it is quite evident that the spiral sweep and the adaptive radial sweep methods are showing almost an identical performance (compare Figures 3-c and 3-d, respectively).

Given an image block, generated true ortho-photos from the involved images can be tiled together as shown in Figure 4(a). In that figure, occluded cells in each of the tiles are filled using those in overlapping ortho-photos. Figure 4(b) is a closer look at a realistic 3D model resulting from draping the true ortho-photo on top of the DSM.



(a) (b)

(c) (d)

**Figure 3**. Comparison of true ortho-photo generation methodologies: original imagery (a), generated true ortho-photo using existing Z-buffer method (b), spiral sweep method (c), and adaptive radial sweep method (d)

(a) (b)

**Figure 4**. True ortho-photo mosaic (a) with a 3D perspective view (b) of the portion enclosed by the white circle

### 4. Discussion

In the above short overview of the objectives of this paper, new methodologies were devised for the purpose of integrating LIDAR and photogrammetric datasets to generate true ortho-photos and realistic 3D models. The first of these were methodologies for the co-registration of the involved datasets. In this regard, LIDAR features (e.g., linear and areal primitives) are used as the source of control for photogrammetric geo-referencing. The outcome measures from the geo-referencing procedure can be analyzed for the inspection of any biases and/or discrepancies between the datasets. The subsequent methodologies dealt with new techniques for true ortho-photo generation to overcome the limitations of current methods. The derived true ortho-photos are then draped on top of the LIDAR DSM to generate a realistic 3D model. Due to the fact that most of the aerial images were taken from vertical direction, we do not have any visual information along building facades. Therefore, future research will focus on using additional data acquisition systems to add realistic texture on the sides of the building models. This can be achieved by using terrestrial cameras and other sources of available spatial databases.

Currently, the interpolation and smoothing of the DSM causes some non-straight (wavy) building boundaries. Future work will establish new techniques to enhance the appearance of the derived 3D model. More specifically, LIDAR data will be segmented to identify man-made structures. The underlying premise of such segmentation is that man-made structures are usually comprised of planar patches. Afterwards, segmented planar patches will be augmented through the integration with the available imagery to derive a Digital Building Model (DBM). The incorporation of the generated DBM within the proposed true ortho-photo generation methodologies will ensure clean boundaries in the final 3D model. Finally, future research will also focus on developing quantitative techniques to evaluate the quality of the final product; namely generated true ortho-photos and 3D models.

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