SPECULATIVE COMPARISON OF LASER-SCANNING AND 3D-PHOTOGRAMMETRY

Leberl Franz Prof.
Technische Universität Graz, Inst. für Maschinelles Shen u d Darstellen
Inffeldgasse 16
A-8010 Graz, Österreich
Tel.: +43 316 873 5011
Fax: +49 316 873 5050
E-Mail: leberl@icg.tugraz.at

Koautoren:
Gruber Dr. Michael , Wiechert, Dipl.-Ing. Alexander
Microsoft Photogrammetry
Anzengrubergasse 8
A-8010 Graz, Österreich
Tel: +43 316 849066-0

ABSTRACT

Recent years have seen an enthusiastic acceptance of airborne laser scanning as the primary source of digital terrain surface models. This has eroded the importance of Photogrammetry as a source for 3D information. We argue in this contribution that with the transition to the fully digital photogrammetric workflow that erosion should stop and Photogrammetry, in the form of "*3-dimensional vision*", should reemerge as a primary provider of 3D terrain information, particularly in the emerging application to 3D models of the mostly urban human habitat. Main advantages of photogrammetric data over laser point clouds are the cost savings by a single workflow for all 3D work, the ability of extracting much more information from photogrammetric data than the laser can provide, a higher geometric accuracy, greater density of source information, the ability to exploit redundancy and to interpret the scene from images.

The traditional laser-advantage of an "instant gratification" no longer is applicable if and when a fully automated photogrammetric workflow is in use. The often-quoted ability of a laser-system to show both the surface model and the "Bald Earth"-model is an advantage of laser technology, but this is an occasional application mostly in a forestry context that may not really justify the high expense of maintaining a separate sensor and workflow next to a fully digital 3D Photogrammetry system.

1. THE ORIGINAL APPEAL OF, AND BENEFITS FROM AERIAL LASER SCANNING

The film-based photogrammetric workflow indeed was deficient in many ways. In flight, film negatives had to be exposed. On the ground, the film had to be transported to a photo lab for development, copying to a positive, and submission to quality control. All one could at that time determine was that the image quality and the coverage of a project area were satisfactory. Any knowledge about geometric accuracy had to await the completion of an aerial triangulation. And if this was to be done efficiently, the film images had to get scanned and then submitted to the triangulation. It was not until that step was completed that anyone could think of any dense digital surface models (DSM) per patch covered by the overlap area of an individual image pair. In reality, fusion of those surface or point-cloud-patches was the final proof that the data are acceptable.

By contrast, laser scans produced an instant view of the terrain elevations per an entire flight line. No wonder that anyone in the business of terrain modeling was impressed with this simple alternative. The result has been a proliferation of technical conferences to advertize these advantages (ILMF, 2009; ISPRS, 2008), and commercial success of vendors of airborne laser scanning systems (Optech, 2008, Leica, 2008a). While it was still necessary to merge the point clouds from separate flight lines, this was considered a small effort when compared to a full 2D photogrammetry workflow.

The primary advantage of laser scanning was thus "*instant gratification*". Yet a lot of value was attached in many discussions to the penetration of the laser beams through trees to observe the bald Earth, and the ability to obtain also a reflection from the top of those trees. The delivery of a bald Earth digital elevation model (DEM) was considered to be a no-cost by-product of aerial laser scanning.

2. THE COST AND QUALITY OF LIDAR OPERATIONS

Practically all LIDAR-operators are also aerial photogrammetry operators. Therefore these operators already are supporting a full end-to-end workflow and sensors for aerial stereo photogrammetry. Investment for a mapping company was (and is) to add a second sensor system for LIDAR with high accuracy geo-positioning, and an end-to-end workflow for LIDAR processing.

We assume that this investment equals that for stereo-photogrammetry with aerial sensor and ground processing tools.

LIDAR point density may be in the range of 1 to 5 points per square meter. Aerial photogrammetry point density may at first be seen as defined by the ground sampling distance GSD, thus pixel size. At a 10 cm pixel, one would produce 100 points per square meter. But these are not 3D elevation values. These depend on the image overlap and thus the reasonable spacing of 3D matches. If 50% of the pixels were to get matched for independent 3D elevation values, one would achieve 50 points per square meter from 10 cm pixels.

The difference between LIDAR and 3D vision is more distinct when one considers swath width and flight lines:

<u>LIDAR:</u>
8 points per square meter
30 degrees FOV;
Flying height 750 meters
Aircraft speed 60 m/sec
170 scans per second (190 kHz)
Strip width 403 m
20% overlap, thus effective strip width at 322 m

<u>UltraCam Xp Multi-Ray Photogrammetry</u>
GSD 25 cm, leading to 8 points per square meter (if 50% of the pixels can be matched reasonably)
Flying height 4188 m
Aircraft speed 141 m/sec
Strip width 4328 m
Side-lap between flight lines 60%
Effective strip width 1731 m
.
A LIDAR-mission would require about 5 times more flight lines to produce the same coverage at the same point density.

3. WHAT IS “FULLY DIGITAL AERIAL 3D PHOTOGRAMMETRY”?

The instant gratification advantage of LIDAR is being paralleled by a near instant gratification from 3D digital photogrammetry. There is no film, no photo lab, and no scanning, not necessarily even any aerial triangulation if precision GPS is sufficient. Time to the desired 3D point cloud is vastly reduced. Wu (2008) even speaks about “real-time photogrammetry” and suggests that time has come to perform aerial 3D-photogrammetry while the airplane is still in the air.

LIDAR continues to offer the secondary advantage of dual echoes from the Bald Earth and the top of vegetation, but that is an exotic “value” of infrequent importance.

3D digital photogrammetry builds on automation of the photogrammetric workflow. Sensing is digital and results in radiometrically and geometrically superior imagery with at least 4 color channels in red, green, blue and near infrared. An aerial mission delivers useful digital data files ready for automated processing. An aerial triangulation is set up automatically using approximate position and attitude values from GPS and IMU sensors. The triangulation is thus applied to improve the internal geometry of an image block beyond what the GPS and IMU-observations would otherwise be capable of delivering. The high redundancy of perhaps an 80% forward overlap and a 60% side-lap will help in the robustness of the triangulation process as well as in its geometric accuracy.

Typically, such a triangulation would employ thousands of tie points, in contrast to the few tie-points used in manual triangulations. As a by-product of these tie-points, one will obtain a sparse digital surface model since there will be a 3D point computed for each tie-point (Figure 1).

Following the automated triangulation, we proceed to the creation of a dense digital surface model using perhaps 10 images per any terrain point. The high image overlaps lead one to obtain a denser surface model than classical 2-image stereo-photogrammetry would suggest. While one might suggest to match an image pair perhaps with a point posting at every 10 pixels, this could get reduced to a posting every 3 pixels, sometimes even every 2 pixels. Those dense digital surface models can be filtered so that one obtains also a bald Earth model, as seen in Figure 2.

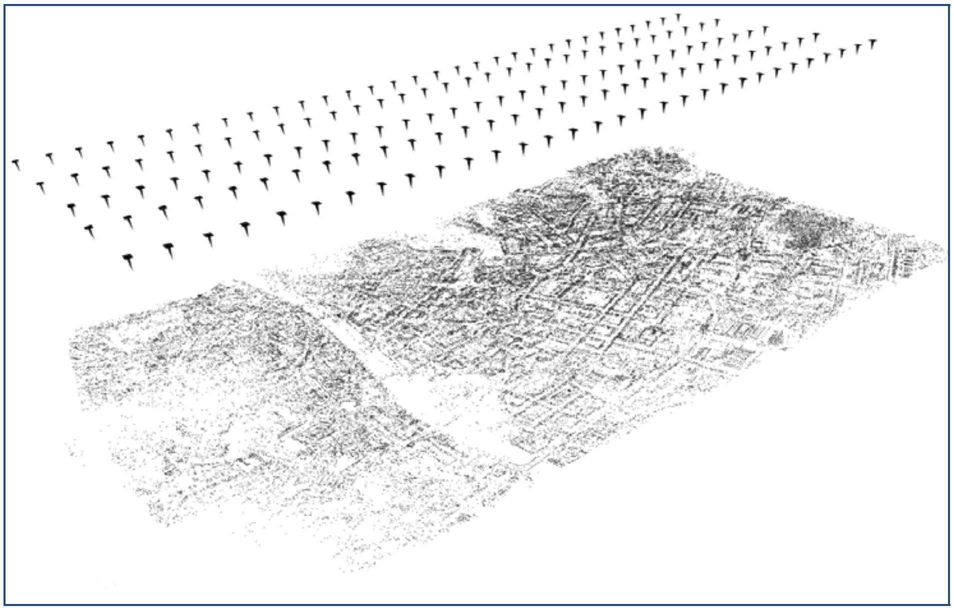

Figure 1:
The concept of a fully automated aerial triangulation results in the exterior orientation of thousands of camera stations, but also in 3D ground coordinates of a large number of tie points representing a coarse DSM. This example is from an UltraCam-coverage of a portion of Graz (Austria).

An added consideration might consist of the use of image-based edge information, separate from the pixel-based matches. This would densify the effective posting interval, if the elevation grids from images get complemented by 3D edges along elevation discontinuities, for example along roof lines of buildings.

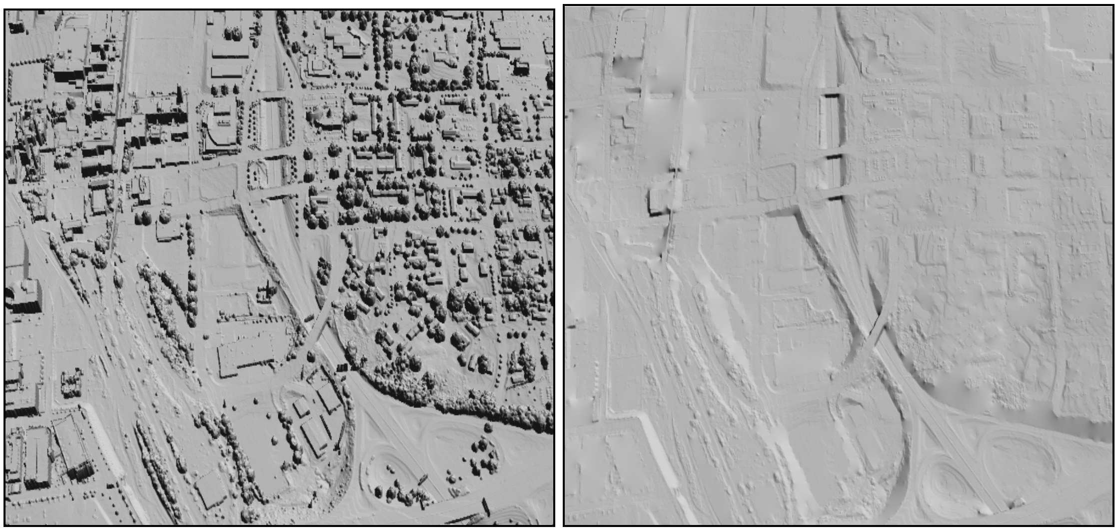

Figure 2:
A digital surface model DSM extracted automatically from a 3D vision framework using UltraCam aerial photography, and the filtered bald Earth DEM-version of the data set. The data is from Winston-Salem (USA).

These various automation steps are in need of imagery that is overlapping to a greater extent than was traditionally the case for manual photogrammetry. In lieu of 60% forward and 20% side-laps, one will prefer an 80% forward and 60% side-lap. Added overlaps lead to a higher level of redundancy and therefore to increased geometric accuracy, greater robustness, with reduced failures of the automated process, reduced occlusions and a more complete 3D result.

These developments have led to an expectation of a reemergence of 3D-photogrammetry (Grün, 2009).

4. WHY IS 3D DIGITAL PHOTOGRAMMETRY NOT WIDELY BEING RECOGNIZED AS SUPERIOR?

The end-to-end fully automated 3D-photogrammetry workflow has not yet been implemented commercially. Digital cameras exist, but the workflows are still as if film needed to get scanned. No fully automated aerial triangulation is being offered commercially. Dense matching is based on image pairs as if a human operator was in the loop. The UltraMap-offering by Microsoft is a pioneering solution, but it is yet to get completed (Reitinger, 2008).

Dense matching to create point clouds over large areas is not available; while there exists the Microsoft dense matcher (Klaus, 2008), this is reserved for internal uses and is not available commercially. Other dense matchers are for 2-image stereo only and therefore produce point clouds of questionable completeness.

Issues with 3d digital photogrammetry are being raised by some as follows:

- Obtaining complete and automated point clouds requires high overlaps along flight lines and dense flight lines, resulting in an overload of data.
- Operating with thousands of images is still painful and slow. Dragonfly/UltraMap is a pioneering approach and not easily available; and even for smaller urban areas one quickly runs into 1000s of images (Graz--- 3000).
- The aerial triangulation (AT) is needed because for stereo matching, the geo-positioning via GPS and IMU is not accurate enough; at ± 20 cm accuracy for a single camera station, the stereo differences are contaminated by uncertainties much larger than a pixel. The resulting need for an AT is painful and the workflows are not yet fully automated.
- Dense matching is very CPU-consuming and slow. At 1 hour per photo and 3000 photos for a city like Graz, computation would be 125 days on a single CPU. One would therefore need to operate with a multi-computer arrangement using 50 CPUs. An example of such solutions is that offered the Verari-blade-systems (www.verari.com). However, that approach adds costs for system management, investment, knowledge and rapid depreciation.

The "*promise of 3D digital photogrammetry*" for high quality point clouds exists but is seen by many to still be off in the future. Innovation in photogrammetry is slow-paced, the market and therefore also the funds for research and development are small, progress is not commensurate with that in other computer applications. The transition from theoretical concept to commercial availability is painful.

5. ADVANTAGES OF 3D PHOTOGRAMMETRY, ONCE AN AUTOMATED WORKFLOW IS AVAILABLE

3D computer vision offers the potential of many advantages over the airborne laser. We list the following:

- The basic measurement entity of photogrammetry is an extended image with rigid internal geometry. By contrast, the laser's basic measurement is a single data point in 3D without any rigidity connecting it to other data points.
- The surface cover can be classified by computer vision using 4 color channels and multiple images.
- Occlusions are practically eliminated given a no-cost high forward and low-cost sideways overlap.
- Error checking can be automated due to overlaps and redundant observations.
- Large areas can be defined as a single entity, rather than the strip-wise LIDAR acquisitions, and the triangulation ties all component data together into a single coordinate system at high geometric accuracy.
- In urban spaces, all facades are being imaged. The option of a fully 3D point cloud exists, unlike the 2.5-D point clouds from LIDAR (roof lines and eaves, for example).
- Superior accuracy is being achieved due to the AT, as opposed to the reliance on IMU and GPS associated with laser operations.
- Superior detail is being extracted by means of computer vision and the use of edge/texture information and the interpretation of the imaged object scenes.
- Only a single workflow for all aerial mapping projects is needed in lieu of a separate workflow for LIDAR.

- Down the road, we anticipate “*real time 3D Photogrammetry*” with processing starting during flight and point clouds obtained upon the end of the survey flight (“*supercomputer in a match box*”).
- The point density is a function of pixel size and of overlaps, to an extreme of one single 3D-point per pixel if the overlaps support the statistics of such a density.
- 3D vision produces many accuracy measures since there exists redundant observations, while the laser observations have no “second” look at the object.

Of course the advocates of laser sensing are working on methods to perform “vision” with the laser point clouds. An example may be the interpretation of windows from laser point clouds (Ali, 2009). Laser operators add camera pixels as a secondary information source to cope with some of the laser deficiencies. Again, this causes a need for a dual track workflow for both vision and laser.

Figure 4 illustrates the expectation for the future role of the fully digital 3D photogrammetry workflow vis-à-vis the LIDAR-role.

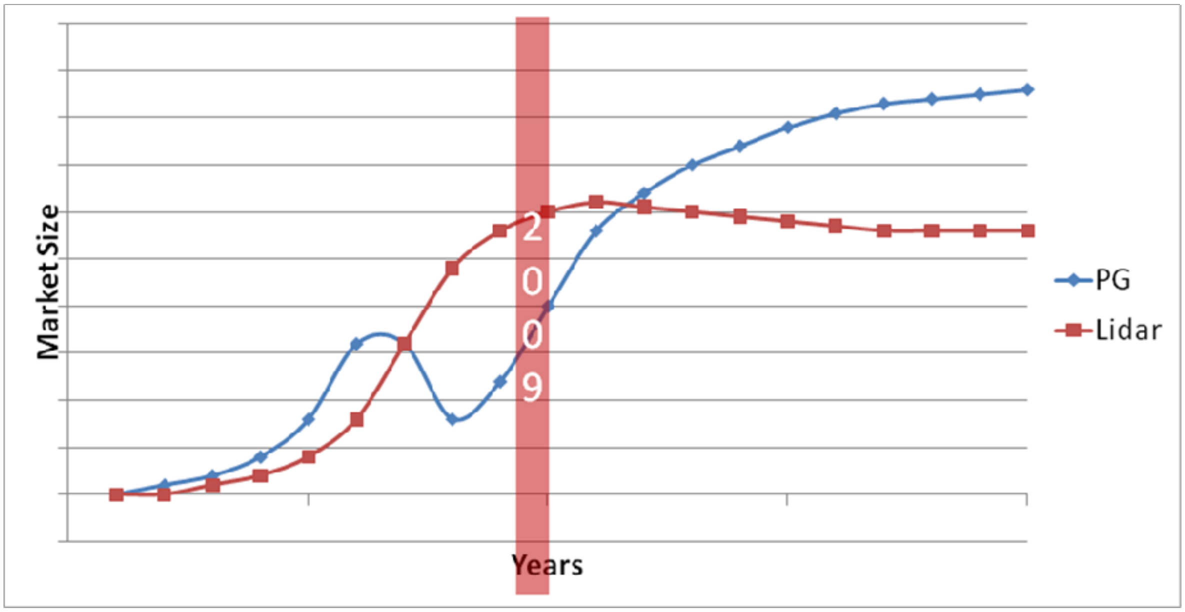

Figure 4:
A qualitative view of the evolution of airborne LIDAR and 3D photogrammetry over time (Wiechert, ILMF 2009).

6. AERIAL, STREET SIDE AND INDOOR PHOTOGRAMMETRY VERSUS LASERS

The appetite for detail justifies an augmentation of aerial mapping by street-level and indoor mapping. Commercial solutions have been developed in significant numbers to map streets (Figure 3), and indoor spaces such as tunnels (Leica, 2008b). The workflow and technology issues transfer also into these newer applications. The comparison between street-side and indoor lasers versus the use of blocks of overlapping street-level and indoor digital images may be of great interest:

- Maintaining single workflows in lieu of separate workflows will be commercially attractive also in street-side and indoor applications.

- Images document the details of street sides and indoor scenes, for example with street signs and alpha numeric information on facades.
- The interpretability of objects from imagery as a computer vision task relies on imagery. Images are therefore unavoidable, and redundancy is also unavoidable. The laser may not add much value to a redundant block of street side or indoor images when an automated workflow for 3D vision is in use.

Figure 3:
Street-Mapper laser point cloud created with a driving car. The data set is of a segment of Graz. Note the visual limitations of interpreting such data since points are superimposed on top of one another.

7. CONCLUSIONS

We are speculating on the relative advantages of airborne laser scanning over film-based and fully digital photogrammetry operations. While it seems fully understandable that laser scanning will be advantageous over film-based 3D photogrammetry, that advantage goes away as photogrammetry morphs into 3D vision based on a fully digital and automated workflow. While we focus on the aerial application to terrain mapping, we argue that the same thinking should apply to terrestrial street side mapping and even to indoor mapping.

REFERENCES

Ali H., R. Sablatnig, G. Paar (2009) *Window Detection from Terrestrial Laser Scanner Data*. Proc. VISAPP-2009 4th Int'l Conf. on Computer Vision Theory and Applications, Lisbon, pp. 393-397.

Grün A. (2009) *Photogrammetry – Revival of a Discipline*. GIS Development, Vol. Jan. 2009, pp. 30-31.

ILMF (2009) International Laser Mapping Forum 2009, New Orleans, organized by the Am. Soc. for Photogrammetry and Remote Sensing: http://www.lidarmap.org/.

ISPRS (2008) The International Archives of the Photogrammetry, Remote Sensing And Spatial Information Sciences, 31st ISPRS Congress Beijing 2008, Volume XXXVII, ISSN 1682-1750

Klaus A. (2007) *Object Reconstruction from Image Sequences*. Dissertation, TU Graz.

Leica (2008b) Leica Scan Station 2: http://www.leica-geosystems.com/hds/en/lgs_62189.htm

Leica (2008a) Leica Airborne Laser Scanner ALS60: http://www.leica-geosystems.com/us/en/lgs_57629.htm

Optech (2008) ALTM Ortion Aerial Laser Scanner: http://www.optech.ca/press_ALTM_Orion_Release.htm

Reitinger B. (2008) *Interactive Visualization of Huge Aerial Image Data Sets*. ISPRS Archive, Volume XXXVII, Beijing