Photogrammetry

Low altitude aerial photograph for use in photogrammetry. Location: Three Arch Bay, Laguna Beach, CA.

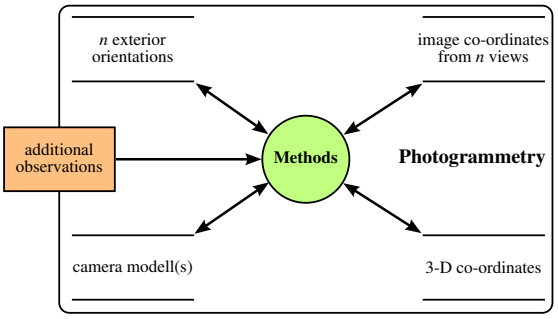
Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points. It may also be used to recover the motion pathways of designated reference points on any moving object, on its components, and in the immediately adjacent environment. Photogrammetric analysis may be applied to one photograph, or may use high-speed photography and remote sensing to detect, measure and record complex 2-D and 3-D motion fields (see also sonar, radar, lidar, etc.). Photogrammetry feeds measurements from remote sensing and the results of imagery analysis into computational models in an attempt to successively estimate, with increasing accuracy, the actual, 3-D relative motions within the researched field.

Its applications include satellite tracking of the relative positioning alterations in all Earth environments (e.g. tectonic motions etc.), research on the swimming of fish, of bird or insect flight, and other relative motion processes (International Society for Photogrammetry and Remote Sensing). The quantitative results of photogrammetry are then used to guide and match the results of computational models of the natural systems. They help to invalidate or confirm new theories, to design novel vehicles or new methods for predicting or/and controlling the consequences of earthquakes, tsunamis or other events, or to understand the flow of fluids next to solid structures and many other processes.

Photogrammetry is as old as modern photography, dating to the mid-19th century. Its detection component has been emerging from radiolocation, multilateration and radiometry. Its 3-D positioning estimative component (based on modeling) employs methods related to triangulation, trilateration and multidimensional scaling.

In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane, can be determined by measuring their distance on the image, if the scale (s) of the image is known. This is done by multiplying the measured distance by $1/s$.

1 Photogrammetric methods



Georg Wiora's data model of photogrammetry[1]

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.[2]

Photogrammetry uses methods from many disciplines, including optics and projective geometry. Digital image capturing and photogrammetric processing includes several well defined stages, which allow to generate 2D or 3D digital models of the object as an end product.[3] The data model on the right shows what type of information can go into and come out of photogrammetric methods.

The *3-D co-ordinates* define the locations of object points in the 3-D space. The *image co-ordinates* define the locations of the object points' images on the film or an electronic imaging device. The *exterior orientation*[4] of a camera defines its location in space and its view direction. The *inner orientation* defines the geometric parameters of the imaging process. This is primarily the focal length of the lens, but can also include the description of lens distortions. Further *additional observations* play an important role: With *scale bars*, basically a known distance of two points in space, or known *fix points*, the connection

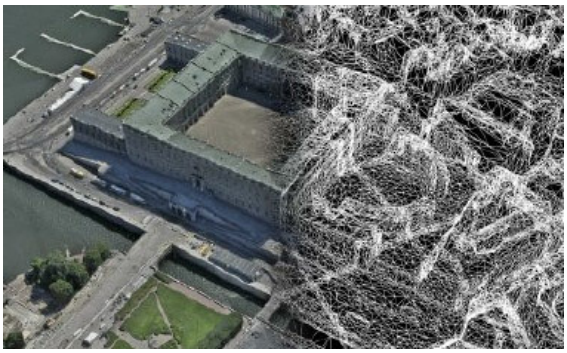
to the basic measuring units is created.

Each of the four main variables can be an *input* or an *output* of a photogrammetric method.

Algorithms for photogrammetry typically attempt to minimize the sum of the squares of errors over the coordinates and relative displacements of the reference points. This minimization is known as bundle adjustment and is often performed using the Levenberg–Marquardt algorithm.

1.1 Stereophotogrammetry

"Stereophotogrammetry" redirects here. It is not to be confused with Roentgen stereophotogrammetry.
Main category: Stereophotogrammetry
See also: Computer stereo vision
A special case, called **stereophotogrammetry**, involves



The stereophotogrammetry technology Rapid 3D Mapping applied on the Royal Castle of Sweden.

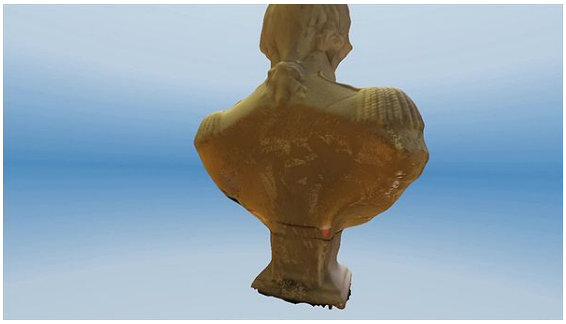
estimating the three-dimensional coordinates of points on an object employing measurements made in two or more photographic images taken from different positions (see stereoscopy). Common points are identified on each image. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays (triangulation) that determines the three-dimensional location of the point. More sophisticated algorithms can exploit other information about the scene that is known *a priori*, for example symmetries, in some cases allowing reconstructions of 3-D coordinates from only one camera position. Stereophotogrammetry is emerging as a robust non-contacting measurement technique to determine dynamic characteristics and mode shapes of non-rotating[5][6] and rotating structures.[7][8]

2 Integration

Photogrammetric data with a dense range data in which scanners complement each other. Photogrammetry is more accurate in the x and y direction while range data are generally more accurate in the z direction. This range data can be supplied by techniques like LiDAR, laser scanners (using time of flight, triangulation or interferometry), white-light digitizers and any other technique that scans an area and returns x, y, z coordinates for multiple discrete points (commonly called "point clouds"). Photos can clearly define the edges of buildings when the point cloud footprint can not. It is beneficial to incorporate the advantages of both systems and integrate them to create a better product.

A 3-D visualization can be created by georeferencing the aerial photos[9][10] and LiDAR data in the same reference frame, orthorectifying the aerial photos, and then draping the orthorectified images on top of the LiDAR grid. It is also possible to create digital terrain models and thus 3-D visualisations using pairs (or multiples) of aerial photographs or satellite (e.g. SPOT satellite imagery). Techniques such as adaptive least squares stereo matching are then used to produce a dense array of correspondences which are transformed through a camera model to produce a dense array of x, y, z data which can be used to produce digital terrain model and orthoimage products. Systems which use these techniques, e.g. the ITG system, were developed in the 1980s and 1990s but have since been supplanted by LiDAR and radar-based approaches, although these techniques may still be useful in deriving elevation models from old aerial photographs or satellite images.

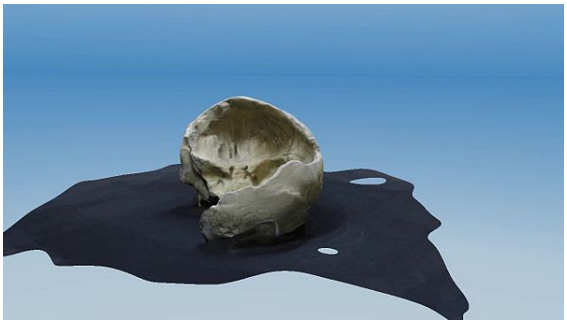
3 Applications



Video of a 3-D model of Horatio Nelson bust in Monmouth Museum, produced using photogrammetry

Photogrammetry is used in different fields, such as topographic mapping, architecture, engineering, manufacturing, quality control, police investigation, and geology, as well as by archaeologists to quickly produce plans of large or complex sites and by meteorologists as a way to determine the actual wind speed of a tornado where objective weather data cannot be obtained.

It is also used to combine live action with computer-generated imagery in movies post-production; *The Matrix* is a good example of the use of photogrammetry in film (details are given in the DVD extras). Photogrammetry was used extensively to create photorealistic environmental assets for video games including *The Vanishing*



Gibraltar 1 Neanderthal skull 3-D wireframe model, created with 123d Catch

of Ethan Carter as well as EA DICE's *Star Wars Battlefront*.[11]

A somewhat similar application is the scanning of objects to automatically make 3D models of them. Some programs like RealityCapture, Acute3D's Smart3DCapture, now part of Bentley Systems and renamed ContextCapture, Pix4Dmapper, Photoscan, 123D Catch, Bundler toolkit,[12][13] PIXDIM, and Photosketch[14] have been made to allow people to quickly make 3D models using this photogrammetry method. It should be noted though that the produced model often still contains gaps, so additional cleanup with software like MeshLab, netfabb or MeshMixer is often still necessary.[15]

Photogrammetry is also commonly employed in collision engineering, especially with automobiles. When litigation for accidents occurs and engineers need to determine the exact deformation present in the vehicle, it is common for several years to have passed and the only evidence that remains is accident scene photographs taken by the police. Photogrammetry is used to determine how much the car in question was deformed, which relates to the amount of energy required to produce that deformation. The energy can then be used to determine important information about the crash (such as the velocity at time of impact).

4 Software

There exist many software packages for photogrammetry; see comparison of photogrammetry software.

5 See also

Main category: Photogrammetry

- 3D data acquisition and object reconstruction
- 3D reconstruction from multiple images
- Aerial survey
- Computer vision
- DAT/EM Systems International
- Edouard Deville
- Epipolar geometry
- ERDAS IMAGINE
- Geofoto
- Geoinformatics
- Geomatics engineering
- Geographic information system
- Intergraph
- International Society for Photogrammetry and Remote Sensing
- Leica Photogrammetry Suite
- Mobile Mapping
- Periscope
- Photomapping
- PhotoModeler
- Rangefinder
- Rapid 3D Mapping
- Solid image
- SOCET SET
- Stereoplotter
- Simultaneous localization and mapping
- Structure from motion
- Surveying
- TopoFlight
- Videogrammetry

6 References

[1] http://www.ub.uni-heidelberg.de/archiv/1808

[2] ASPRS online Archived May 20, 2015, at the Wayback Machine.

[3] Sužiedelytė-Visockienė J, Bagdžiūnaitė R, Malys N, Maliene V (2015). "CLOSE-RANGE PHOTOGRAMMETRY ENABLES DOCUMENTATION OF ENVIRONMENT-INDUCED DEFORMATION OF ARCHITECTURAL HERITAGE" (PDF). *Environmental Engineering and Management Journal*. pp. 1371–1381.

[4] Ina Jarve, Natalja Liba. The Effect of Various Principles of External Orientation on the Overall Triangulation Accuracy. TECHNOLOGIJOS MOKSLAI. Estonia. #86, 2010, pp. 59-64.

[5] Jūratė Sužiedelytė-Visockienėa. Accuracy analysis of measuring close-range image points using manual and stereo modes. Geodesy and Cartography. V. 39, Issue 1, 2013, pp. 18-22.

[6] Baqersad, Javad; Carr, Jennifer; et al. (April 26, 2012). *Dynamic characteristics of a wind turbine blade using 3D digital image correlation*. Proceedings of SPIE. **8348**.

[7] Using Stereophotogrammetry to Measure Vibrations of a Rotating Wind Turbine

[8] Using Stereophotogrammetry on Helicopter Rotor

[9] A. Sechin. Digital Photogrammetric Systems: Trends and Developments. GeoInformatics. #4, 2014, pp. 32-34.

[10] Ahmadi, FF; Ebadi, H. "An integrated photogrammetric and spatial database management system for producing fully structured data using aerial and remote sensing images". *Sensors (Basel)*. **9**: 2320–33. doi:10.3390/s90402320. PMC 3348797. PMID 22574014.

[11] http://starwars.ea.com/starwars/battlefront/news/how-we-used-photogrammetry

[12] Bundler toolkit

[13] Building Rome in a day project

[14] PIXDIM and Photosketch

[15] MAKE:3D printing by Anna Kaziunas France

7 External links

- RSPSoc - Remote Sensing and Photogrammetry Society of UK
- History of Photogrammetry
- Photogrammetry overview on the Cultural Heritage Imaging web site
- World Photogrammetry, the spanish website of photogrammetry for everyone
- Visual Revolution of the Vanishing of Ethan Carter
- Examples of photogrammetry

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