Introduction

Photogrammetry is a surveying and mapping technique which can be used in various applications. There are many uses of Photogrammetry in the surveying industry such as topographic mapping, site planning, earthwork volumes, production of digital elevation models (DEM) and orthophotography maps. It is also useful in a vast selection of industries such as architecture, manufacturing, police investigation, and even plastic surgery.

The word “photogrammetry” is composed of the words “photo” and “meter” which means measurements from photographs. The classical definition of photogrammetry is: The art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images on photographs. (www.state.nj.us/transportation/eng/documents/survey/Chapter7.shtm)

Photogrammetry is a skilled profession for the reason that obtaining reliable measurements requires certain skills, techniques and judgments to be made by the Photogrammetrist and experience is an advantage. It is a science and technology because it takes information from an image and transforms this data into meaningful results.

Types of Photogrammetry

There are two types of Photogrammetry, Aerial Photogrammetry and Terrestrial (Close Range) Photogrammetry.

- Aerial digital photogrammetry, often used in topographical mapping, begins with digital photographs or video taken from a camera mounted on the bottom of an airplane. The plane often flies over the area in a meandering flight path so it can take overlapping photographs or video of the entire area to get complete coverage.

- Close-range, or terrestrial, digital photogrammetry often uses photographs taken from close proximity by hand held cameras or those mounted to a tripod. Close-range photographs can be used to create 3D models, but they are not usually used in topographical mapping. This type of photogrammetry is useful for the 3D modeling of many objects or areas such as buildings, automobile accident scenes, or movie sets. (www.wisegeek.com/what-is-digital-photogrammetry.htm)
Historical Background

There are four major phases in Photogrammetry which are directly related to the on-going advances in technology throughout the years especially with airplanes, electronics, computers and software.

- The first generation was the invention of photography. The commencement of this exciting new invention, followed many years of experiments and investigations, which led to the next phase.

- The second generation was the era of Analog Photogrammetry. In this phase the analogue rectification and the stereopplotting instruments were invented. Airplanes and cameras were now being used for the two World Wars. Within this time frame Aerial survey techniques were established and continue to be the fundamentals on which the Photogrammetry is based on today. Photogrammetry became a reputable and popular surveying and mapping method.

- In the 1950s the third generation was born with the invention of the computer. This phase was the Analytical photogrammetry generation. It was in this phase where serious attempts were made on applying adjustment theories to photogrammetric measurements. Block adjustment programs was developed and aerial triangulation was improved greatly. The analytical plotter was also developed in this phase but was only made available in the 1970s.

- The fourth generation in photogrammetry is actually the current phase, called digital photogrammetry. In this phase the transition from analogue to digital began. Photography is transformed to digital data and photogrammetric processes are done by specialized software on computers. Digital cameras are now used, thus the photography is already in digital format and therefore there is no need for scanning.

The main reason behind the push to extend analogue and analytical photogrammetry into the digital realm is for the expectations of huge cost savings in producing typical photogrammetric outputs and the new ability for using this digital output as input into other analysis systems.

The implementation of automated data input, compilation and output should lessen the time needed to produce a given quantity of Photogrammetric output, like planimetric and topographic maps which will in turn have direct affect on reducing the costs of that particular output. (Mahmoud Hassani and James Carswell)
Aerial Photogrammetry versus Traditional Surveying Techniques:

Advantages:

- It is a permanent pictorial record of the significant area at that specific moment in time which is recorded with a metric camera (known interior orientation).
- The pictorial record also helps in minimizing field work. If certain data is missing or the information has to be re-evaluated, it is not necessary to go back to site. The measurements can be done in the office with using the same photography. Thus this new information is acquired quicker due to the elimination of the field work.
- With aerial photogrammetry, a larger area can be mapped more resourcefully and economically than traditional survey methods.
- Photogrammetry can be used in areas that are unsafe and difficult to access. Whereas with traditional field work, it has a disadvantage in terms of time and the safety of the Survey team.
- When detail surveys of roads are required, roads don’t have to be closed or free flowing traffic disturbed. The safety of the survey team is kept to the minimum as they would not have to be physically on the road for long periods of time. Road features and important data can be obtained in the office from measurements made from the photographs.
- Intervisibility between control points and intervisibility between the area to be surveyed and control are not a requirement. This minimises excessive control surveys. Every point within the mapped area can be coordinated with no extra cost.

Disadvantages:

- Weather conditions could affect the quality of the picture and the flight plan. Conditions such as snow might give a false representation of the ground.
- The ground that is usually hidden by structures such as buildings or by tree canopies and vegetation cannot be accurately mapped.
- Accuracy of contours and cross sections depends on flight height and accuracy of ground control.
- Generally, aerial photogrammetry cannot produce the same level of accuracy as traditional survey field methods.
Photogrammetric Process: 3 Main Components

1. Image acquisition
   1.1. Flight Planning
       - The number of flight lines, their location, the spacing between them, and their orientation depends on the characteristics of the project to be mapped and on the specifications of the flight mission.
       - Specifications which outline how to take the photos, including camera and film requirements, scale, flying heights, end lap, side lap, tilt and crab tolerances, etc.

   1.2. Selecting an appropriate camera system
       - The camera is one of the most important types of equipment used in the photogrammetric process as it is the data in which all photogrammetric principles will be applied to. The camera should produce distortion free images in rapid successions in a moving aircraft.

   1.3. Aerial Films
       - The image must be recorded on stable film in order to avoid shrinkage or expansion. If the film does change it will result in measurement errors with less accuracy achieved. Aerial film size is usually 23x23 cm each.

   1.4. Image scanning
       - Photographs can be scanned into a digital format that can be imported into digital image processing software. Specialized scanners are used. These scanners preserve radiometric and geometric integrity of the scanned image.

   1.5. Digital Cameras
       - Recently digital cameras are used, therefore the data (photograph) is already in a digital format hence there is no need for the specialized scanner.
2. Image Control

This component is important because it is the control that is used to establish the position and orientation of the camera at the moment of exposure. Photo Mosaics require no control, Rectified aerial control requires partial control; Mapping and Orthophotography requires full control information. Photographs can be controlled using three different methods:

1. Ground control points which are surveyed by normal survey methods
2. Bridging control through aerial triangulation. This is done by computing on the photographs common points that appear in three successive photographs or in two adjacent strips and computing their 3 dimensional coordinate values.
3. Aerial photography control by kinematic GPS measurements, this will give the position and elevation of the camera without the use of ground control.

2.1. Locations for ground control and selecting which type of targeting to be used

- There are two main types of ground control, targeted and photo identifiable control points.
- Targeting is an integral part of photogrammetric mapping and should be carefully considered. When targets are positioned, it should not be affected by shadows. The targets should preferably be symmetrical in shape and an adequate size. Being able to easily identify the targets on a clear image enhances the accuracy and efficiency of the photogrammetric process.

2.2. Field Surveying the control points

- Photogrammetric control is usually fixed by traditional survey methods. Control should be spread out widely, thus making the GPS the most effective survey method for establishing photogrammetric control.

2.3. Aerial Triangulation

- This is the process of calculating the Y, X and Z of ground coordinates on specific point from measurements on a photograph. Aerial Triangulation can also be linked with bridging.
- Aerial Triangulation provides necessary control for the stereo model using a limited amount of surveyed control points. It also provides consistency checks for field surveyed control points.

2.4. In the future, this component could be eliminated when advanced GPS technology will be able to solve the photo orientation problem without needing ground control. Ground control is only used to recover the position and orientation of the photograph at its moment of exposure. Replacing the need for ground control reduces the number of field surveyed control points and in return minimizing time and costs in the photogrammetric process.
3. Product Compilation

3.1. The product compilation varies and is dependent on the nature of the final product.

3.2. Each of these components requires the utilization of different equipment, different measurement techniques, and different data processing.

- The most commonly used photogrammetric instrument is the stereo plotter. Its main purpose is to reconstruct the original orientation and the geometric integrity of an image at the moment of exposure and to collect three dimensional data.

3.3. The table below shows the differences between the various types of photogrammetric stereo plotter.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Analog</th>
<th>Analytic</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image</td>
<td>Film</td>
<td>Film</td>
<td>Pixels</td>
</tr>
<tr>
<td>Plotter</td>
<td>Analog</td>
<td>Analytical</td>
<td>Computer</td>
</tr>
<tr>
<td>Model Construc.</td>
<td>Mechanical</td>
<td>mechanic/computer</td>
<td>Computer</td>
</tr>
<tr>
<td>Stereo Viewing</td>
<td>Optical</td>
<td>Optical</td>
<td>Varies</td>
</tr>
<tr>
<td>Output</td>
<td>Mech./CAD</td>
<td>Mech./CAD</td>
<td>CAD</td>
</tr>
<tr>
<td>Aerotriangulation</td>
<td>Very limited</td>
<td>On/Off Line</td>
<td>Semi-automatic*</td>
</tr>
<tr>
<td>Orthophoto</td>
<td>Very limited</td>
<td>Unavailable</td>
<td>Automatic**</td>
</tr>
<tr>
<td>Limitations</td>
<td>Focal length</td>
<td>Film Format</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Film format</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>Average up to</td>
<td>Very high</td>
<td>Same as scanning accuracy</td>
</tr>
<tr>
<td></td>
<td>±15µm(microns)</td>
<td>up to ±3 µm</td>
<td>accuracy</td>
</tr>
<tr>
<td>Cost</td>
<td>Very high</td>
<td>Very high</td>
<td>Reasonable to high</td>
</tr>
</tbody>
</table>
Accuracy and Errors

Photogrammetric accuracy depends on two main factors, the desired scale of the photography and the errors that are introduced during the photogrammetric process.

The photo scale is dependent on the product specifications. The required accuracy can be met by using a small photo scale and high quality equipment or large scale photos with less accurate equipment.

The photo scale should be smaller than the map scale however the ratio between the two scales shouldn’t be greater than eight.

If one would assume that all blunders have been removed, then the remaining errors would be systematic errors and random errors.

For example when it comes to the photogrammetric product of an Orthophoto, the components that contribute errors to the product are:

1. Camera (characteristics and calibration)
2. Scanner (characteristics, calibration, resolution or image scale)
3. Ground control (accuracy, distribution, and abundance)
4. Aerial triangulation (design, measurement, and computation)
5. Digital Elevation Modeling(DEM) - (method of compilation; quality of the source material; characteristics of the terrain; sampling spacing, with or without breaklines; type of breaklines used; method of interpolation into pixel grid and availability of height information on or above surface features, such as buildings.)
6. Rectification process (method and software) When all of these errors are propagated and summed up following a valid error theory methodology, one can assess the spatial accuracy of the final product.
Orthophotography

An orthophoto is an aerial image that has been rectified. It contains the characteristics of a line map. By combining photogrammetric principles with digital elevation model (DEM) data the rectification process can be performed. An aerial photograph should not be used or mistaken for an Orthophoto. An aerial photograph does not have a constant scale throughout the photograph. The photography only has one point where the scale is correct which is usually around the centre. This is because the aerial photography has not been rectified or has not undergone the photogrammetric process.
The use and Implementation of Photogrammetry in the eThekwiní Municipality

The Photogrammetry Department
The main function of the photogrammetry department is to produce Orthophotos that is then used as a base map by the rest of the council. This data set is also published on to the eThekwiní municipality web site and made available to walk-in customers. This however is not the only function of the photogrammetry department. The photogrammetry Department also services other departments in the form of specialized surveys, queries and map production. Walk-in customers are also assisted.

Orthophoto Production – Basic overview of work flow and data input and output
Each year the photogrammetry department attempts to do an aerial survey of the whole of the eThekwiní Municipality. The project goes out to tender where upon the winning bidder is awarded the contract. The period most conducive for the aerial survey is between the months of late April and June. Typically the survey is based on 1 in 10000 scale photography. This equates to a flying height of approximately 1700m above ground level. The height above ground needs to be maintained throughout the survey to avoid scale differences (a 5-10% variance is accepted).
To create effective stereo pairs an overlap of 60% between consecutive images belonging to one strip is required. The side lap and overlap between strips, is about 30%. Cross strips are also flown with the same overlaps. The cross strips area essential for GPS assisted aerial surveys. The advantage of a GPS assisted aerial survey is that much less ground control points are required for the final block adjustment. There exist a large amount of redundant tie points between images, strips and cross strips. The redundancy of tie points is advantageous as only the best correlated points can be selected from the thousands of points per stereo pair. The stereo pairs are essential for effective aerial triangulation and 3D survey work.

Data received from the aerial survey:
- Contact prints and negatives – frame format 230mm x 230mm colour tiff.
- Flight plan – As flown.
- GPS coordinates – Projection WGS84, Lo31, Datum is Hartebeeshoek.
- Meta data – Each photo’s focal length, time, date and altitude.
- Camera calibration file.
- IMU (Inertial Measurement Unit)
Data output; Intermediate data sets and final products:

- Negative photo frames to digital tiff images – Using the Leica DSW700 digital scanner, the photos are scanned at 25 microns and stored digitally.
- Colour mosaic split into 5 Mr.Sid formats. This is used as the published image set.
- Individual 1 in 2000 sheets – geo-tiff format. This is used in the council environment. Recently these individual files where merged into one ECW file format that proved to be much more efficient to load into various computer mapping and GIS programs.
- Meta data file – Each photo’s date and time is published as a shape file.
- Updated terrain data.

Work Flow:
List of equipment and software used:

1. **Sensor** – This refers to the camera used. Several makes of cameras exist each with its unique set of camera calibrations. Typically the camera calibration contains information regarding the photo centre or principal point, fiducial marks and linear distortion across the image plain. This information is all used as input parameters to the aerial triangulation process.

2. **DSW 700 Photo Scanner** – This is a highly accurate scanner capable of a physical scan resolution of 12 microns. In reality a setting of 25 microns is used when scanning images. This is a good compromise between image size and accuracy. The scanner consists of a film feeder and a glass plate. Each photo is aligned over the plate so that the CCD (Charge-coupled device) camera is aligned over the full frame of the image. The scanner then proceeds to scan a photo in a matrix of blocks. Each block receives a red, green, and blue light exposure. The RGB composite is then stored on a hard drive. Once a photo is completely scanned the scanner’s operating software stitches the image matrix together to form one digital image.

3. **ERDAS IMAGINE** – Using this software all the preparation of the images for aerial triangulation can be done. The software can also manage your projects and all data related to a project. The software also provides a link to Microstation (CAD package) that allows the photogrammetrist to capture detail from the 3D stereo environment into a CAD or GIS environment. This is normally referred to as a detailed line mapping. The software also supports the generation of terrain data and the editing of that data. Edited terrain data can then be used to generate contours, do slope analysis, profiling and many more GIS and engineering functions.

4. **ORIMA and CAP-A** – This software is used for the triangulation process and block adjustment.

5. **CAD – Microstation (Bentley product)** – This software is used primarily for capturing data from the stereo pairs.

6. **ArcView, ArcMap** – This software is used when data needs to be attributed and stored in a GIS format. This can be in the form of a shape file or geodatabase.

7. **Custom applications** – The photogrammetry department also develop their own software. This is primarily done to automate parts of the work flow and to bridge the gap between the functionality not supplied by the licensed software and functionality needed by the photogrammetry department.
Future methodology – New technologies available to enhance the workflow and products of photogrammetry:

1. **LiDAR**, which stand for Light Detection and Ranging, is a remote sensing method that uses light in the form of pulsed laser to measure variable distances on earth. In the context of aerial surveys, the LiDAR device is fired from a plane towards earth. Terrestrial based LiDAR is also possible, but not often used in photogrammetry. The hope is to replace the existing terrain data covering the Unicity with a new LiDAR data set. The advantage is that the terrain data is very accurate and each point measured is classified. The classification will make it possible to filter between ground terrain, vegetation and manmade structures.

2. **Digital images** – In 2015 analogue photography (film and contact prints) was replaced by digital images. The photos are now replaced by image blocks. The camera, Integraph’s Digital Mapping Camera or DMC, is now used to capture digital images at various resolutions. The advantage of using digital images is obvious. With the analogue system the scanning process can take up to 3 months. This includes the scanning and colour balancing process. With the new digital system 3 months can now be cut from the total production time. Another advantage is that the IMU (Inertial Measurement Unit) data is provided for each image frame. This includes the 3 axis rotations, Kappa, Phi and Omega values. Having this information readily available cuts down on computations times and speeds up the aerial triangulation process.

3. Currently there is a tender advertised for the supply of oblique photography for the city. This will supply 3D views of all of the Unicity and provide a new analysis tool not previously used by Council. The hope is to have the oblique system installed throughout the Council by 2016.
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