Chapter 8: Photogrammetry

Introduction

Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment by recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant imagery. It plays a vital role in civil engineering applications such as topographic mapping, land surveying, urban planning, and infrastructure development.

Modern photogrammetry has evolved into a sophisticated process combining principles of optics, geometry, and computer science. With the integration of drones and digital image processing, photogrammetry now provides cost-effective and accurate spatial data, which is fundamental in the field of Geo-Informatics.

8.1 Principles of Photogrammetry

Photogrammetry is governed by principles of projective geometry. It relies on the formation of images through the perspective projection of a three-dimensional object onto a two-dimensional image plane.

8.1.1 Central Projection

- The fundamental principle involves capturing an image through a single exposure station where light rays from object points converge to a point (lens or pinhole).
- The image formed is a perspective view, leading to geometric distortions that must be corrected for accurate measurements.

8.1.2 Perspective Geometry

- Relationship between object space and image space is defined through collinearity equations.
- These equations relate coordinates of object points with image points, camera focal length, and orientation parameters.

8.2 Classification of Photogrammetry

Photogrammetry can be classified based on the nature of the platform, method of data acquisition, and geometry.

8.2.1 Based on Platform

- **Aerial Photogrammetry**: Images are captured from airborne platforms like drones, aircrafts.
- **Terrestrial (Close-range) Photogrammetry**: Images are captured from ground-based platforms or handheld cameras.

8.2.2 Based on Processing

- **Analog Photogrammetry**: Traditional technique using film and optical instruments.
- **Analytical Photogrammetry**: Combines analog images with digital computation for better accuracy.
- **Digital Photogrammetry**: Fully computer-based; employs digital images and automated algorithms for extraction of 3D information.

8.3 Geometry of Aerial Photographs

Understanding the geometry of aerial images is crucial for extracting spatial information.

8.3.1 Types of Aerial Photographs

- **Vertical Photographs**: Camera axis is vertical to the ground; used for mapping.
- **Oblique Photographs**: Camera axis inclined; further classified as low or high oblique.

8.3.2 Scale of a Photograph

$$\text{Scale} = \frac{\text{Focal Length (f)}}{\text{Flying Height (H)} - \text{Average Ground Elevation (h)}}$$

8.3.3 Relief Displacement

- Vertical displacement of objects due to elevation differences.
- Radial displacement from the principal point outward.

8.4 Photogrammetric Terminology

- **Principal Point (P)**: The intersection of the optical axis with the image plane.
- **Nadir Point**: The point directly beneath the camera at the time of exposure.

- **Isocenter**: Midpoint between principal point and nadir.
- **Flight Line**: Path followed by the aircraft; images are taken at equal intervals along it.
- **Overlap**: Required for stereoscopic vision.
  - **Forward Overlap**: 60–70%
  - **Side Overlap**: 20–30%

8.5 Stereoscopy and Stereo Vision

8.5.1 Principle of Stereoscopic Viewing

- Two overlapping images of the same area, taken from different positions, form a stereo pair.
- The human brain perceives depth by merging these two perspectives, creating a 3D impression.

8.5.2 Stereoplotters

- Instruments or software used to extract 3D coordinates from stereo images.
- Types include analog, analytical, and digital stereoplotters.

8.6 Orientation Procedures in Photogrammetry

Orientation is necessary for converting 2D photographic coordinates to 3D ground coordinates.

8.6.1 Interior Orientation

- Establishes the internal geometry of the camera system.
- Uses camera constants like focal length and principal point location.

8.6.2 Exterior Orientation

- Determines the position and orientation of the camera at the time of exposure.
- Includes 3 translational (X, Y, Z) and 3 rotational (omega, phi, kappa) parameters.

8.6.3 Relative and Absolute Orientation

- **Relative Orientation**: Aligning a stereo pair to simulate geometry of original exposure.

- **Absolute Orientation**: Scaling and transforming the relative model to ground coordinates.

8.7 Ground Control in Photogrammetry

Ground control points (GCPs) are essential to ensure accurate mapping.

8.7.1 Types of Ground Control

- **Horizontal Control**: For planimetric accuracy.
- **Vertical Control**: For elevation accuracy.

8.7.2 Methods of Establishing GCPs

- Traditional surveying (total station, GPS).
- GNSS-enabled real-time kinematic (RTK) methods.

8.8 Aerial Triangulation

Process of determining the coordinates of points by connecting overlapping images using tie points and GCPs.

8.8.1 Purpose

- To extend control over large areas.
- Facilitates block adjustment for multiple flight lines.

8.8.2 Bundle Block Adjustment

- Simultaneous adjustment of all images.
- Uses least squares estimation for minimizing error.

8.9 Digital Photogrammetry

Modern photogrammetry is almost entirely digital, increasing efficiency and accuracy.

8.9.1 Image Acquisition

- Through digital cameras, drones, satellites.

8.9.2 Image Matching Techniques

- Feature-based: SIFT, SURF, ORB
- Area-based: Normalized Cross-Correlation (NCC)

8.9.3 Digital Surface Models (DSM) and Digital Terrain Models (DTM)

- DSM includes all surface features (buildings, trees).
- DTM represents bare earth surface.

8.10 Applications of Photogrammetry in Civil Engineering

- **Topographic Mapping**: Creation of contour maps and elevation models.
- **Urban Planning**: Land use analysis, building footprint extraction.
- **Highway and Railway Engineering**: Corridor mapping and terrain assessment.
- **Hydrology and Watershed Management**: Basin mapping, flood modeling.
- **Mining and Geology**: Volume estimation, pit monitoring.
- **Construction Monitoring**: Progress tracking, volumetric computations.
- **Disaster Management**: Damage assessment, relief planning.

8.11 Photogrammetry vs. Remote Sensing

Parameter	Photogrammetry	Remote Sensing
Data Type	Photographic (optical)	Multispectral / Hyperspectral
Data Acquisition	Close range / Aerial / Satellite	Mostly Satellite / Airborne Sensors
Output	Metric Measurements (3D)	Thematic / Spectral Information
Use	Mapping, Measurements	Classification, Change Detection

8.12 Recent Advances in Photogrammetry

- **Unmanned Aerial Vehicles (UAVs)**: Provide low-cost, high-resolution data.
- **Structure from Motion (SfM)**: A computer vision technique to generate 3D models from unordered images.

- **AI and Deep Learning**: For automatic feature extraction and classification.
- **Cloud-Based Photogrammetry Platforms**: E.g., DroneDeploy, Pix4D, Agisoft Metashape.

8.13 Structure from Motion (SfM) in Photogrammetry

Structure from Motion (SfM) is a photogrammetric technique that reconstructs 3D structures from a series of overlapping 2D images taken from different viewpoints. It has revolutionized modern photogrammetry due to its simplicity, cost-effectiveness, and automation.

8.13.1 Workflow of SfM

1. **Image Acquisition** Multiple overlapping photos are captured from various angles—often using UAVs or handheld cameras.
2. **Feature Detection and Matching** Algorithms such as SIFT (Scale-Invariant Feature Transform) and SURF (Speeded-Up Robust Features) detect unique points (keypoints) in images and match them across multiple views.
3. **Camera Pose Estimation** Intrinsic (focal length, sensor size) and extrinsic (position and orientation) parameters of the camera are estimated using bundle adjustment.
4. **Sparse Point Cloud Generation** 3D coordinates of matched features are triangulated to create a sparse model.
5. **Dense Reconstruction** Multi-view stereo (MVS) algorithms convert sparse clouds into dense 3D point clouds.
6. **Mesh and Texture Mapping** The point cloud is converted into a mesh and textured using original images.

8.13.2 Advantages of SfM

- Does not require a calibrated camera.
- Highly automated and user-friendly software.
- Applicable to complex, irregular terrains and structures.

8.13.3 Limitations

- Accuracy depends on image quality and overlap.
- Poor performance in homogeneous areas (e.g., water surfaces, grass).

8.14 UAV-Based Photogrammetry

Unmanned Aerial Vehicles (UAVs), also known as drones, have become powerful tools in aerial photogrammetry due to their affordability, flexibility, and ability to capture high-resolution data.

8.14.1 Components of a UAV System

- **Drone Platform**: Multirotor or fixed-wing.
- **Onboard Sensors**: RGB cameras, multispectral, thermal, or LiDAR.
- **Ground Control Station (GCS)**: For flight planning and real-time monitoring.
- **GNSS/IMU Systems**: For accurate georeferencing.

8.14.2 Advantages in Civil Engineering

- High spatial and temporal resolution.
- Easy access to difficult or hazardous areas (steep slopes, construction sites).
- Real-time monitoring of project progress.

8.14.3 Flight Planning Essentials

- Ensuring optimal **forward and side overlaps**.
- Choosing **flight altitude** for desired GSD (Ground Sampling Distance).
- Considering weather, wind, lighting, and legal regulations (DGCA in India).

8.15 Accuracy and Error Sources in Photogrammetry

Accuracy is a critical consideration in photogrammetric outputs. Understanding and mitigating errors ensures the reliability of results in civil engineering applications.

8.15.1 Types of Errors

- **Systematic Errors**: Due to lens distortion, Earth curvature, tilt.
- **Random Errors**: Due to vibration, atmospheric effects, or human error.
- **Blunder Errors**: Gross mistakes like incorrect GCP location.

8.15.2 Factors Affecting Accuracy

- Camera resolution and calibration.
- Number and distribution of GCPs.
- Image overlap and coverage.
- Environmental conditions during image acquisition.

8.15.3 Accuracy Assessment Techniques

- Comparing with **ground truth data** obtained via total stations or GNSS surveys.
- Use of **Root Mean Square Error (RMSE)** to quantify error.
- Visual inspection of orthomosaics and elevation models.

8.16 Integration with GIS and Remote Sensing

Photogrammetric data can be seamlessly integrated with Geographic Information Systems (GIS) and remote sensing for enhanced spatial analysis.

8.16.1 Use of Photogrammetry in GIS

- Orthophotos as base maps.
- 3D models for city planning, terrain modeling, and simulation.
- Generating thematic layers (e.g., building heights, land cover).

8.16.2 Combined Applications

- Change detection using time-series orthomosaics.
- Slope analysis from photogrammetric DEMs in watershed management.
- Precision agriculture using multispectral drone photogrammetry.

8.17 Software Tools for Photogrammetry

A range of commercial and open-source software is available for photogrammetric processing.

8.17.1 Commercial Software

- **Agisoft Metashape**: SfM, dense reconstruction, and DSM generation.
- **Pix4Dmapper**: UAV photogrammetry and GIS integration.
- **DroneDeploy**: Cloud-based mapping and modeling platform.

8.17.2 Open-Source Software

- **OpenDroneMap (ODM)**: Full-featured UAV photogrammetry suite.
- **MicMac (IGN France)**: Advanced photogrammetric engine for research use.
- **COLMAP**: SfM and MVS pipeline for high-quality 3D reconstruction.

8.18 Ethical and Legal Considerations

With the growing use of photogrammetry, especially UAV-based, legal compliance and ethical use are important.

8.18.1 UAV Regulation in India (DGCA Guidelines)

- Mandatory drone registration.
- Restrictions on flying in **no-fly zones** (near airports, military bases).
- Need for permissions in **controlled airspaces**.

8.18.2 Data Privacy and Ethics

- Avoid unauthorized imaging of private property.
- Secure storage and responsible sharing of geospatial data.
- Awareness of implications in surveillance and data misuse.
