1 INTRODUCTION

Through discussions, it has become apparent that there is the need for a basic overview of the available data collection techniques to be made available.

This guidance material presents a high-level description of three basic approaches, namely:

- Conventional terrestrial survey;
- Airborne laser scanning;
- Aerial Photogrammetry.

For each approach, an overview of the technique is provided, along with a description of the factors which influence how the technique is applied to order to achieve the necessary data collection requirements (e.g. data quality). The workflow necessary to perform the data collection is also described.

This guidance material is not intended to be used by data collection experts. It is intended to provide those with little or no knowledge of data collection with a basic understanding of it.

2 REFERENCES

ICAO Annex 14

ICAO Annex 15, Aeronautical Information Services

Doc 8168 – ICAO Procedures for Air Navigation Services – Aircraft Operations (PANS-OPS)

Doc 9137 - ICAO Airport Services Manual

Eurocontrol: Airborne Laser Scanning for Airport Terrain and Obstacle Mapping

Aeronautical Information Exchange Model (AIXM) - Obstacle Model Proposal

EUROCAE: User Requirements for Terrain and Obstacle Data, ED-98

EUROCAE: Standards for processing aeronautical data, ED-76

ISO 19113: Quality Principles

ISO 19114: Quality Evaluation Procedures

3 Foundation

The following section describes the different surveying methods for obstacle and terrain data acquisition. In addition, the preconditions for the surveyor for each method are described. The survey of TOD shall be performed in accordance with EUROCONTROL's 'Integrity of Aeronautical Information – Aeronautical Data Origination'. It is assumed that the reader of this document is already familiar with different surveying methods.

3.1 Data Quality – Preliminary Notes

To establish a good understanding of the influences on data quality, it must be understood that the quality of geodata is not only affected by the spatial accuracy. The term quality is more comprehensive. It includes:

a) Accuracy:
- Positional accuracy (x, y, z);
- Thematic accuracy (correct attributes).

b) Resolution of data:
- The smallest difference between two adjacent values, which can be represented in a data storage, display or transfer system.

c) Assurance level:
- The degree of confidence that a data element is not corrupted while stored or in transit.

d) Traceability:
- The ability to determine the origin of the data.

e) Timeliness or temporal accuracy:
- The degree of confidence that the data is applicable to the period of its intended use.

f) Completeness:
- Commission: excess data present in a dataset;
- Omission: data absent from a dataset.

g) Logical consistency:
- Format;
- Conceptual consistency;
- Domain consistency;
- Topological consistency.

Note: Examples for the different numerical values should illustrate the range of values for the different surveying methods (e.g. spatial accuracy). The technical development for some of the described surveying techniques is ongoing and especially the enhancements with respect to sensor resolution and therefore also spatial accuracy are very significant, the values given are to be taken as snapshots. The actual values depend on the deployed sensor and should be validated carefully before the survey.

The formulae given are rules of thumb, which allow the surveyor to perform a course check of the given information. The rules of thumb can vary depending on the specific instrument (for example, due to calibration effects)

3.2 Preliminary Notes on Technical Specifications

Surveyors are specialists in data acquisition, using different sensors and software tools for data processing which are aligned with the intended use of the resulting data. They have long-term experience of using their technical instruments, alongside 'best practise', to achieve the required results. So, for the surveyors it is most important to know in detail in what kind of application the data will be used and what level of data quality is required. Therefore, it is essential that detailed technical specifications are available before starting the data acquisition. Based on the technical specifications, the most appropriate survey technique can be selected. This will save money and resources for all the parties involved.

In addition, it is recommended that the surveyor and the commissioning organisation agree on the methods / specifications that the surveyor should use to prove the conformance of the data with the required quality. If these specifications exist, the surveyors can perform tests on the data to verify and subsequently document the conformance of the data quality with the specifications. Such tests shall be reported according to the International Organisation for Standardisation (ISO) standard 19114. The advantage for the commissioning organisation is that the delivered data can be checked and verified in a shorter timeframe, which is therefore more economical.

For all the survey techniques discussed in this paper, the spatial accuracy requirements as published in the International Civil Aviation Organisation's (ICAO) Annex 15 (Aeronautical Information Services) are not difficult to achieve. Achieving completeness, thematic accuracy and logical consistency are more challenging.

4 Conventional Terrestrial Survey

Terrestrial Survey is still the most wide-spread technique for data acquisition. Compared to other surveying technologies, the investment in sensors and processing software for conventional terrestrial surveying is quite low. On the other hand, the human resources needed to perform the survey in the field are higher when compared with any other techniques. So, this method of survey, although not limited to, is usually used for localised tasks. For the data capture of extended areas, it is often more economical to use aerial Photogrammetry or Airborne Laser Scanning (ALS). Nevertheless, the two airborne survey techniques mentioned are not completely independent from terrestrial survey, e.g. benchmark surveying - the survey of highly accurate ground control points.

Conventional terrestrial survey uses the following instruments:

- GPS (Global Positioning System) receiver;
- Theodolites;
- Total stations (theodolites combined with a GPS receiver), with automated target recognition.

In regard to TOD, conventional terrestrial survey methods would be suitable for the following tasks:

- Obstacle acquisition;

- Terrain acquisition;
- Surveying of benchmarks for airborne mapping techniques;
- Validation of data acquired by an airborne sensor system

4.1 Workflow

Figure 1 describes the workflow for conventional terrestrial survey

Figure 1: Workflow of Conventional Terrestrial Survey (processes in italics indicate data in local coordinate system)

4.2 Preconditions

The following preconditions have to be fulfilled:

- Reference station;
- Local network, monumented survey control stations:
- Monument control stations, which build a local network and which are well-defined, build the base for the terrestrial survey.
- Local coordinate system:
- Measurements with a theodolite are performed in a local rectangular network (e.g. UTM). The heights are measured above the geoid, based on the published heights of the reference points.
- Transformation parameters from local to WGS84 coordinate system:
- For the transformation of the surveyed points between the local coordinate system and WGS84, transformation parameters are needed. In order to obtain ellipsoidal heights (or heights above EGM-96), the local geoid must be known to a high accuracy.

For GPS:

- Reference station(s) for differential GPS (DGPS):
- The definition of measured GPS Points is based on well-defined reference stations. For the resolution of the ambiguities, at least one additional GPS Station will be used in differential GPS. To improve the precision of the resulting coordinates, measurements with short baselines are preferred. National and international reference stations, which are usually supported by the government, allow the surveyors to use more than just one additional station to define the reference stations with higher precision. Having solved the ambiguities, modern GPS sensor operated in the Real-Time Kinematic (RTK) mode allow the measurement of points in high frequency.

4.3 Influences on Data Quality

The data quality of terrestrial survey is influenced by the following:

In General:

- Manual interpretation of what is considered to be an obstacle:
- The operator will have to define the objects in the field, which are considered to be obstacles. To locate and survey all obstacles, experienced operators have to be used to perform the survey. The distance to the airport reference point/runways must be known as it is virtually impossible to visualise data collection surfaces in the field. Therefore, obstacles may be missed.

Theodolite:

- Measured distance:
- The accuracy of distance measurements for total stations is defined as a base value [mm] + a distance dependent value [mm per km, also called ppm], e.g. 5mm + 5ppm.
- Horizontal and vertical angle of measurement:
- The accuracy of angle measurements is defined as [mgon] or [arcseconds], e.g. 0.3 mgon / 1''.

- Automated target recognition:
- The background of the target defines the feedback to the instrument. Ideally this is a white area which is orthogonal to the beam of the instrument. Therefore, small antennas are very difficult to be measured with automated target recognition (at the required accuracy). They have to be measured in an indirect way: first the distance to the obstacle is measured and afterwards the height will be defined through a measurement of the angle.

GPS:

- The accuracy of GPS Measurements is influenced by the position and arrangement of satellites (PDOP = positional dilution of precision, GDOP = geometric dilution of precision), by the length of the baseline and by the quality of the sensor (and its processing algorithms).
- GPS Receivers, which are used nowadays for RTK measurements, inform the surveyors if the quality is below defined values.

5 Airborne Laser Scanning

Within the last few years, Airborne Laser Scanning (ALS or Lidar) has progressed significantly and become a more established technique. One of the biggest advantages of ALS compared to conventional surveying methods is the high level of automation offered thanks to the completely digital data chain. Although ALS is a mature technique with respect to the quality of data collection it offers room for improvements with respect to data post processing (i.e. feature detection and extraction). The more automated the processes become, the more economical the data extraction will become. One other significant advantage compared to conventional surveying methods is the homogenous data acquisition over the whole area. The main drawbacks of the technique are the high investment costs and the low number of operators that have sensors capable of obstacle mapping.

As for Photogrammetry, the minimum size of the obstacle which shall be captured is the predominant factor for the flight planning. If all small antennae on top of buildings have to be captured, the flight and laser parameters have to be adjusted accordingly, to fulfil the technical requirements.

Airborne laser scanning includes the following:

- Laser scanner (measures scan angle and time of flight for each laser pulse).
- Positioning and Orientation system consisting of:
- GPS Receiver on the airplane and reference station on the ground (dGPS);
- Inertial Measurement Unit (IMU) to measure roll, pitch and heading of the scanner system.

In regard to terrain and obstacle data, ALS methods can be used for the following tasks:

- Terrain mapping;
- Obstacle mapping.

5.1 Workflow

Figure 2 describes the workflow for ALS:

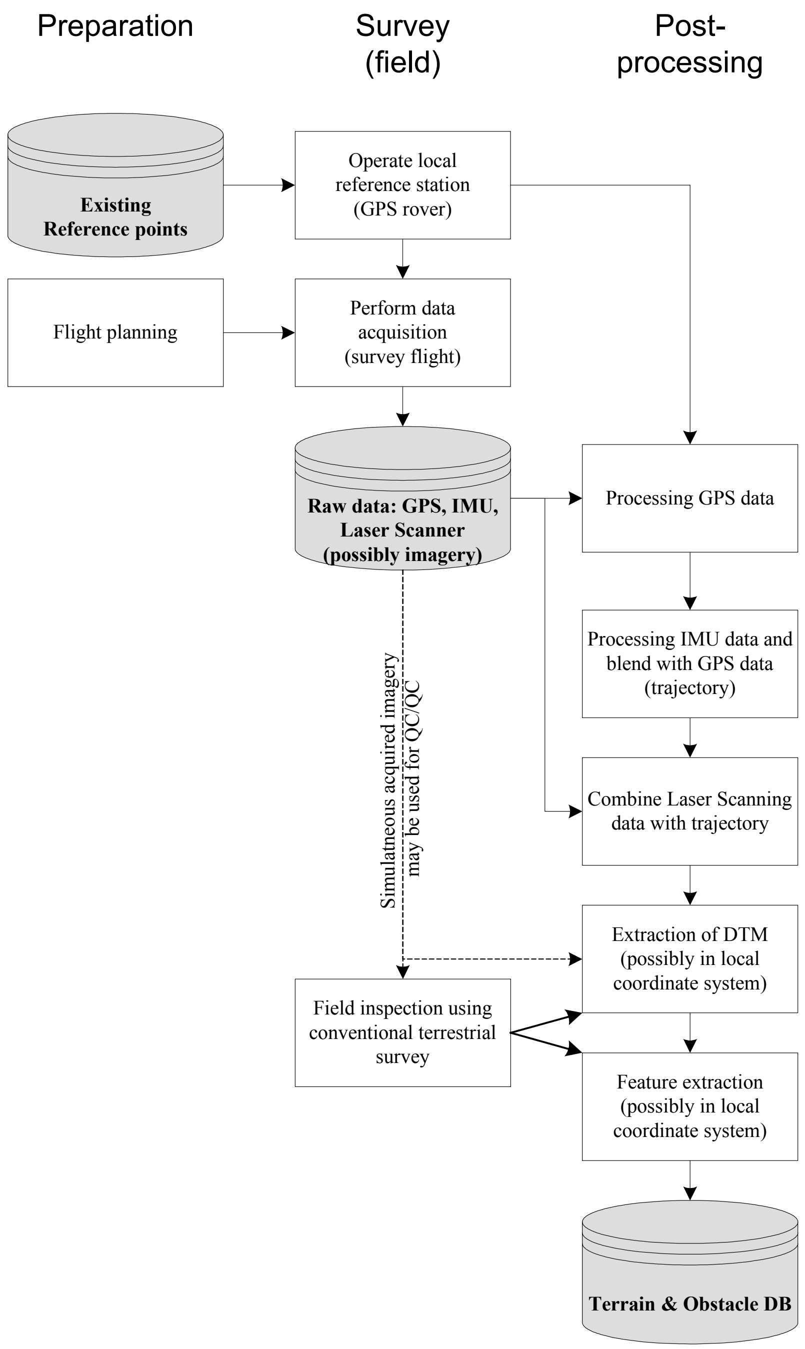

Figure 2: Workflow of Airborne Laser Scanning

5.2 Preconditions

The following preconditions have to be fulfilled:

- Flight plan with:
- scan angle;
- scan rate; and
- pulse repetition frequency.
- These parameters influence the flight height, but also the flight restrictions or topography. The system settings are defined based on the terrain and the technical specifications.
- Calibration flight: a calibration flight is performed after the mounting of the system.

Periodical re-calibration is recommended to compensate for drifts and changes of climate.

- Well-defined and monument reference station for GPS Master.

The above mentioned preconditions have to be fulfilled before the ALS Surveying flight is performed.

As with any airborne survey technique, it is recommended to perform terrestrial survey to measure specific points which are used as control points for data validation. These measurements can be performed before, during or after the flight is carried out. To improve the quality, it is recommended that the field survey is performed after the post-processing. In this way, open issues, which are detected during the post-processing, can be checked in the field. This will finally result in higher data quality.

5.3 Influences on Data Quality

The data quality of ALS is influenced by the following:

- The tilt mount for the ALS:
- To increase the probability that a thin object like an antenna is captured, it is recommended that the laser is tilted and the radiometric resolution of the sensor is calibrated.
- Flight height:
- As an example, the product information for the Laser-System ALTM Gemini of Optech states:
- positional accuracy: 1/5000 of flight height;
- vertical accuracy:
    - flight height 1’200 m: < 5 cm;
    - flight height 2’000 m: < 15 cm; and
    - Flight height 3’000 m: < 25 cm.
- Weather conditions during flight: humidity, winds;
- Point density:
- For the detection of thin objects, the point density has to be selected accordingly.
- Homogenous data acquisition:

- Compared to conventional terrestrial surveying and Photogrammetry, no human interpretation defines the completeness of the obstacle and terrain data. The completeness is influenced by the aforementioned technical issues. The limited feasibility study showed that ALS, in combination with field inspection and control measurements, delivers more complete and accurate data.
- GPS Measurements and IMU (Inertial Measurement Unit):

For the influences on GPS quality see Chapter 4.3

6 Aerial Photogrammetry

Aerial Photogrammetry is a surveying technique which has been used for a number of years. The latest development in this field is mainly in regard to digital cameras and scanners. So, the pixel size (either of the digital camera or the scanner) dominates the flight parameters which will have to be defined to fulfil the technical requirements.

The most restrictive requirement for obstacle acquisition by Photogrammetry is the minimum size of the obstacles which have to be captured. To capture very thin objects (e.g. antennas, street lamps), the image scale has to be bigger. This requires a lower flight height. With a lower flight height, it is obvious that the resulting spatial accuracy (x, y, z) will be much higher than requested.

Today analogue and digital cameras are used for Photogrammetry. The only difference within the process for analogue and digital cameras is that the film of the analogue camera has to be scanned. As soon as the images are digitally available, the process is the same for both cameras.

In regard to terrain and obstacle data, Photogrammetry can be used for the following tasks:

- Terrain mapping;
- Obstacle mapping;
- Validation of ALS Data

6.1 Workflow

Figure 3 describes the workflow of aerial Photogrammetry

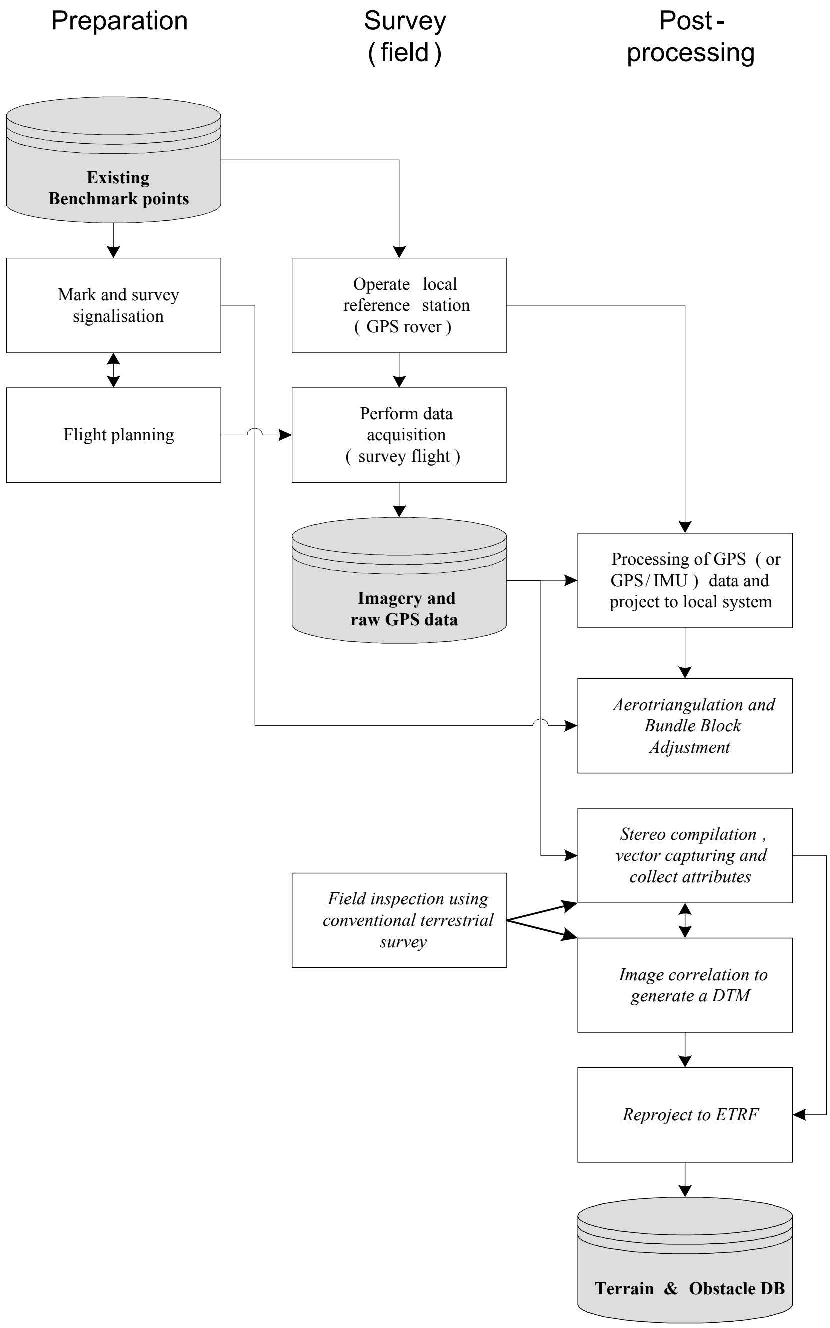

Figure 3: Workflow of Digital Photogrammetry

6.2 Preconditions

The following preconditions have to be fulfilled:

- Benchmarks have to be marked and defined with terrestrial survey:
- Flight plan based on:
- Focal length;
- Spatial accuracy requirements;
- Flight restrictions.

6.3 Influences on Data Quality

The data quality for photogrammetric survey is influenced by the following;

- Flight height of photo flight;
- Visibility/shadowing;
- Vegetation coverage;
- Focal length;
- Resolution of scanning;
- Benchmark marking;
- Overlap longitudinal and lateral;
- Algorithms for processing bundle block adjustment;
- Manual interpretation of what is considered to be an obstacle:
    - As the operator has to define which objects are to considered obstacles, human interpretation is needed;
    - Systems are available which support the operator by showing the Obstacle Data Collection Surface (ODCS).
- Algorithms for DTM generation and automated feature extraction (if applicable)

7 List of Abbreviations

Abbreviation	Meaning
ALS	Airborne Laser Scanning
DGPS	Differential GPS
GIS	Geographical Information System
GPS	Global Positioning System
ICAO	International Civil Aviation Organisation
IMU	Inertial Measurement Unit
ISO	International Organisation for Standardisation
LIDAR	Light Detection and Ranging
ODCS	Obstacle Data Collection Surface
RTK	Real-Time Kinematic
TOD	Terrain and Obstacle Data
TOD WG	Terrain and Obstacle Data Working Group
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984

Table 1: Abbreviations Used