6. Positioning

Positioning is a crucial step in using information collected by Unmanned Aerial Vehicles (UAVs), as it enables the accurate location of the drone and its collected data. For this, GNSS (*Global Navigation Satellite System*) combines satellite systems such as GPS, GLOSNASS, BEIDOU, and GALILEO, developed and maintained by different countries. Generally, the accuracy of geopositioning technology used on UAVs remains within the range of 2–5 m, similar to smartphones. Such accuracy is usually not enough for (repeated) mapping, which requires aligning orthophotos taken at different points in time with the precision of one pixel – typically < 10 cm.

The most common way to achieve and later check the necessary accuracy is by using reference points on the ground. Reference points are divided into tie- and checkpoints, and their coordinates are calculated with devices allowing necessary accuracy, generally with a high-accuracy GNSS receiver. Tie points are used for a more precise georeferencing of the data, E.g. orthophotos, and checkpoints for error characterisation. Reference points need to be marked on the terrain so that they are clearly recognisable – for example, for photos, colour marking is used; for LiDAR work markers with a specific shape; for thermal work, aluminium markers that reflect the sky, etc. To get a good result, such points need to be located evenly throughout the area to be mapped, and their number depends on the degree of accuracy of the concrete task. It must be kept in mind that in addition to the horizontal coverage, we must consider the even vertical distribution of reference points. In the case of orthophotos, it is advisable to mark one reference point per 1– 10 million pixels (Singh and Frazier, 2018). Often the marking and measuring of checkpoints is the most time-consuming part of UAV mapping.

More accurate GNSS devices for drones are available on the market since 2018. These have accuracy (1–5 cm horizontally, <10 cm vertically) that is already enough in most cases for the *direct georeferencing* of data, allowing accurate georeferencing of single photos taken by the drone or data points in case of laser scanners, and the number of ground tie points drops significantly or the necessity disappears altogether. Independent check points are still necessary for the accuracy check, but as accuracy evaluation goes now already along with every photo, a couple of checkpoints should suffice.

Mostly two precision GNSS solutions are used: **PPK** (*Post Processed Kinematic*) and **RTK** (*Real Time Kinematic*). In both cases two simultaneous GNSS sensors are needed, whereby one is attached to the drone and the other is an immobile or static base station located somewhere nearby. The two devices must be located as close as possible to each other for them to receive signals from the same satellites, and for the atmosphere conditions to be the same. The *baseline* of the two GNSS devices determines the absolute accuracy of georeferencing: for example, in RTK module accuracy is characterised by „1.5 cm + 1 ppm“. In which case „1.5 cm“ is an error anyway, but „+1 ppm“ means that for each ten kilometres of distance between the drone and the base station, the error margin increases one centimetre.

The static base station on the ground can be another GNSS receiver, or data from a more distant fixed reference station is used, from which a GNSS correction is received over mobile data transmission, or the data are available for a later download from the network. Networks have been created from fixed reference stations (CORS - *Continuously Operating Reference Station*) in most of the European countries. Such a network provides an opportunity to set up virtual reference stations (VRS) between the base stations to decrease the distance between the UAV and the base station in comparison to the actual base station. Estonia has a network comprised of 27 fixed base stations offering GNSS correction sharing services (ESTPOS). In addition, there are several privately owned and managed networks of fixed stations in Estonia (E.g. Trimble, Hades, etc.).

In case of PPK solution, the calculation of accurate coordinates takes place after the flight, in case of RTK, however, in real time. Thus, when using RTK, a constant bilateral communication between the UAV and ground controller and the network of fixed stations is inevitable. The communication between the UAV and the controller is conducted via a communication channel meant for telemetry. However, guaranteeing constant communication during the flight can be complicated in some cases. In case of PPK solutions, both GNSS's data is saved simultaneously and the correction of coordinates takes place later in the computer. This enables the user to choose the calculation schemas more flexibly and analyse the errors more accurately. PPK systems are thus considered to be more reliable, but in comparison with RTK they are more labour intensive. However, one does not exclude the other: RTK by default allows recording GNSS data and, if necessary, conduct PPK processing later.
Both PPK and RTK solutions have been compared to the method of ground referencing points. Experiments show, that the more accurate location of photos (Stöcker *et al.* 2017; Turner *et al.* 2014) along with the calibration of the camera (Carbonneau and Dietrich, 2017) allow achieving the necessary accuracy (almost) without the time consuming marking of reference points. By 2022, virtually all the UAVs for professional use possess either RTK and/or PPK capabilities; what is more, PPK additional modules can be added to older UAVs (E.g. Emlid Reach or Topodrone products). Both high precision GNSS solutions the precise moment of taking the photo must be recorded – for that, an accessory fitted to the *hotshoe* is generally used.

6.1. Terrestrial reference points and learning/training data

Data used in earth sciences must/could be georeferenced i.e. tied to an absolute system of coordinates. One way to fulfil this goal is to use reference points or markers on the ground. Terrestrial reference points can be grouped in two: tie points and control points. The former is used for georeferencing and specifying internal parameters of the data. We use control points for independent error characterisation.

It is very important that terrestrial reference points are clearly visible from the photos and their centre unambiguously identifiable. The markers/points can be placed in a different manner, what is important is that they are clearly recognisable from the rest of the environment (Image 21).

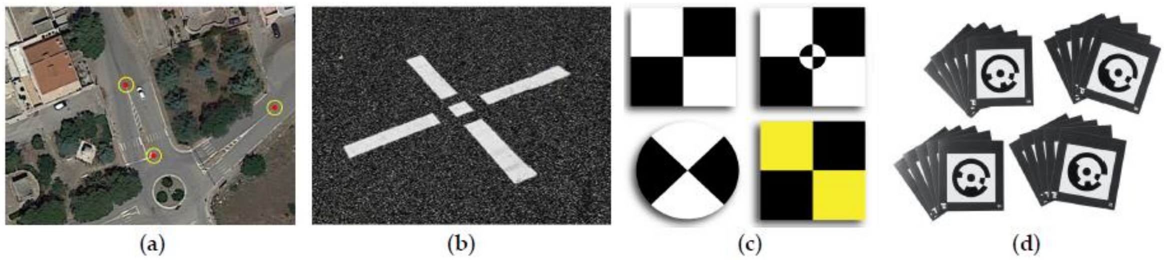

Image 1. Some examples of the terrestrial reference points or markers (Pepe *et al.*, 2022): a) using existing real objects as markers b) reference point marked by colour c) high-contrast markers d) machine readable markers.

The sign used as a marker must not be too reflective, especially when we fly the UAV and take pictures in direct sunlight. For example, the reflection of a white marker might be so strong in sunlight that in the sensor it is dispersed to the adjacent pixels. This way, a bright white square might affect the adjacent black square and identifying the centre of the marker becomes difficult on the picture. In order to ensure the unambiguous identification of the centre, it needs to be large enough. If the reference point marker only covers an area of 6x6 pixels, identifying the centre of this marker on the image becomes difficult. The size of the terrestrial reference point with chess square configuration needs to be more than 10 pixels.

Marking and measuring terrestrial reference points is one of the most time-consuming procedures in UAV survey. Therefore, we need to get by with the least number of markers. If the UAV is equipped with a precise differential GNSS, direct georeferencing of images helps, since it decreases the number of reference points significantly.

Often the inhibiting factor for marking reference points on the ground is the inaccessibility of the area. This makes each survey area unique, but some universal guidelines for placing the markers are as follows:

1. Reference points should be located at the corners (edges) and at the centre of the surveillance area – with such layout it is important that we cover as large an x and y directional area as possible. We also need to remember that the accuracy of a 3D model based on UAV photogrammetry decreases considerably in the areas outside the terrestrial reference points (extra polarisation), if this is the only way of georeferencing.
2. If at all possible, we need to cover the survey area also vertically, i.e. place the markers on different levels, E.g. at the bottom of a valley, on top of a hill, etc.
3. Flight trajectory has to be taken into consideration – the bigger the number of photos with one and the same reference point, the more efficient the marker is. Therefore, it is not advisable to place reference points to the margins of the survey area where these will feature only in a couple of photos. Placement of reference points should be planned alongside flight trajectory planning.
4. It is useful to think about the size and complexity of the survey area. With a rectangle shaped area and a network of regular flight lines, a minimum of four markers at the corners and one in the centre of the research area should suffice. When the area is not that regular-shaped, the location of markers should be carefully considered. Furthermore, a part of the surveillance area might need greater precision, and such parts take more reference points.

A draft outline on paper is recommended for terrestrial reference points, to see the location of markers in relation to each other. This becomes especially important when there are more markers and the survey area is quite uniform. The reason why we need to work at reference points is that an initial mistake has a cumulative tendency and errors made in direct georeferencing of reference points and/or photos will inevitably be transferred to the results of photogrammetry. Most photogrammetry software allows defining measuring accuracy that enables adjusting other modelling parameters within the given error margin and the end result might therefore be of above average accuracy.

It is advisable to collect **reference data** at the same time or as close as possible with UAV surveillance. Reference data is terrestrial controlled data that allows us to interpret the data collected by the drone. Much like reference points, reference data is divided into two categories: learning/training data for the training of classification algorithms and validation data used for classification accuracy assessment.

For example, if we were to map the spread of Sosnowsky's hogweed, areas covered by this weed could be the reference points. Several methods of marking exist that can be differentiated by their credibility and labour-intensiveness. For instance, a field worker might record an outline by a manual GNSS, covering the area of hogweeds' spread. However, without metadata, the person handling such data does not know the location accuracy of the outline (1-5m?), neither does he know the georeferencing accuracy of the UAV surveillance and this orthophoto mosaic. Thus, it is impossible to assume by default that the entire 'content' of this outline is actually usable as reference data.

Similarly, to reference points, it is also good to mark reference areas before the flight in a way that the markers be visible from drone photos. Coming back to the hogweed example, marking the reference area is a very time-consuming part of fieldwork and the vegetation, depending on the local

growth area, tends to vary already within one species. As mentioned before, for reference, a phenologically suitable time needs to be determined in order for the object to contrast with the surroundings. On the other hand, it is good if the object of interest is as homogeneous within the species as possible at the chosen moment in time, since reference areas should be able to cover the entire variety within the area of research.
One of the most attractive opportunities for UAV surveillance is to increase the spatial/spectral/radiometric resolution (more data and work!) in a way that the hogweed be more recognisable from the orthophotos and the expert can digitalise the training areas directly from the UAV orthophotos. This needs to be tested before large scale mapping. From personal experience, it is difficult even for a top expert to conduct classification immediately, even on the basis of areas with simple structure and a few species of plants, because, as a rule, traditional terrestrial survey methods are not compatible with UAV surveillance methods. Terrestrial methods thus need to be adjusted (E.g. group the species, etc.) for the surveillance methods to be mutually compatible (Sun *et al*., 2021). The process of collecting data from terrestrial referencing needs to be planned carefully: how to document locations and the schema of designating data points, which classes need data collection and how to align it with post-production later. Metadata come very handy if we need to specify something later. Also, georeferenced photos taken on the ground will prove to be very efficient.

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