ABSTRACT

At the Jurong Island Westward Extension (JIWE) project in Singapore, a large stockpile of rock was accumulated. The stockpile was built with steep slopes that did not allow safe access. For a proper follow up of the production, regular progress surveys and matching volume calculations are required. Completing the biweekly surveys in such tight areas safely and in a timely manner was a challenge for the team. After having studied various options, aerial surveying techniques by using drones with cameras were considered the best option for the project.

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INTRODUCTION

The Joint Venture of DIAP (Dredging International Asia Pacific) and SHAP (Star High Asia Pacific) was awarded the Jurong Island Westward Extension (JIWE) Contract on Jurong Island in Singapore. The project consists of dredging works, design and build of reclamation sites, soil improvement works, and civil construction of roads, drains and sewers, and the supply of aggregate materials.

Part of the contract involves the removal of a 60-metre high stockpile of materials – measuring about 450 metres by 250 metres at its base and containing about four million cubic metres of rock, the transport of the material to a rock sorting area, the screening of the material into various gradings and the storage of the sorted rock in numerous smaller stockpiles. The stockpiles have been built with steep slopes that do not allow safe access during times of operation. Only the bottom and top contours of the stockpiles were safely accessible at the start of the project. As a result of the limitation in space in the rock sorting and storage area, the stockpiles had been placed with minimal space in between.

For a proper follow up of the production, regular progress surveys and matching volume calculations are required. Completing the biweekly surveys in such tight areas safely and in a timely manner was a challenge for the team. After having studied various options, aerial surveying techniques by using drones with cameras were considered the best option for the project.

GENERAL GUIDELINES

Progress in technology of working with radio-controlled planes and multicopters carrying camera platforms that are gyroscopically stabilised, have made it possible to conduct low altitude aerial photography. The use of radio-controlled aircraft provided easier access to previously inaccessible or dangerous areas. Mobilisation of the aircraft is quick and take-off and landing can take place in virtually any area. The use of Wi-Fi allows live streaming of the aircraft camera’s data through the operator’s control unit. Surveying with radio-controlled aircraft is filling the gap between traditional topographic surveys and manned aircraft surveys (Figure 1).

Surveys are being done at a fraction of the cost compared to surveys by manned aircrafts. Nowadays, aerial surveys provide levels of accuracy and detail that were never possible before; they also complement topographic surveys. Large areas can be surveyed in a fraction of the time compared to traditional
mainly camera and drone
3. Pre-aerial flight preparation
4. Actual aerial survey
5. Post-flight quality check of the data
6. Post-processing of the data, which involves the compilation of photos to create a 3D digital surface. This surface will be used for volumetric calculations for generating reports and/or for preparation of presentations.

ESTABLISHMENT OF BENCHMARKS AND BASE SURFACE AND DRAWING

Aerial surveying starts with the installation and topographic survey of permanent and temporary benchmarks known as GCPs (Ground Control Points).
- Permanent reference points can be parts of existing structures such as culverts, bridges, and manholes.
- Temporary GCPs can be square plates of 50 by 50 cm that are divided into four equal parts and are painted alternately black and white for easy recognition (Figure 2).

The GCPs preferably need to be evenly distributed around the working area to be surveyed. Within the actual working area, temporary GCPs need to be placed to create a denser grid of reference points. The more reference points, the higher the accuracy. GCPs need to be measured by RTK GPS backpack.

Aerial survey mapping is based on photogrammetry, whereby photographs are used to extract measurements from the compiled ground surface. Overlapping photos show objects from a different perspective, allowing calculation of measurements. By flying at low altitudes (60-100 metres), high resolution overlapping photos can be taken. These are processed into accurate georeferenced models. An overlap of pictures needs to be taken into account, both in the direction of flight as well as sideways to guarantee overlap with the next flight path. The level of overlap is determined by the required accuracy and terrain variation. Results are more accurate with more overlaps. That means that more pictures need to be taken, making the flight path denser and the flight time longer. GPS is used to control the flight path and the image capturing. Camera movements are compensated for by a gyroscope.

As a general guideline, the whole process consists of the following steps:
1. Establishment of benchmarks and base surface and drawing
2. Preparation of the aerial survey equipment,
RTK GPS measurements around the boundary of its base. The surveyed boundary (closed loop) will be used as base surface. If the area is one upon which stockpiles will be placed, a surface bigger than the limits of the actual future stockpiles needs to be surveyed. The points gathered can be processed and converted into a TIN (Triangulated Irregular Network) or mesh for future processing.

Based on the initial topographic survey a drawing can be compiled, containing the boundaries, GCPs and other essential information. The drawing will be used as a base reference and will be updated during each consecutive progress measurement (Figure 3).

**PREPARATION OF THE AERIAL SURVEY EQUIPMENT**

The aerial survey equipment comprises the camera and the drone which need to meet certain criteria and be properly installed.

**Camera**

The camera should fulfill certain criteria such as the use of a fixed lens, maximum camera resolution and sensor size. Using a fixed lens camera will assist in eliminating any problem with the focus depth. Also, the higher the resolution of the camera, the larger and more detailed the photos. This will help reduce the number of photos to be taken and help cover the subject area with the required overlap. In addition, better image quality can be obtained with the right-sized sensor, since larger pixels can collect more light than smaller pixels.

Ideal camera settings are: Use TIFF files, setting the resolution as high as possible and apply low ISO values. Raw data converted to TIFF files is better since JPG compression might induce unwanted ‘noise’ to the images. Pictures should be taken at maximum possible resolution. ISO values should be low to minimise additional ‘noise’ to the images. Blurry photos can be avoided by setting a high aperture value and by applying a shutter speed that is not too slow.

**Drone**

To decide on a good flying platform, important points to examine are:  
- good stability,
- a high lifting capacity,
- maximum flight time,
- minimal vibration, and
- a gimbal attachment.

A flying drone should be stable enough to fly and manoeuvre through windy conditions. In principle, more rotors should provide more stability but this still depends on other factors like stabilising algorithms (flight controllers). For aerial survey purposes, a hexacopter drone is standard but an octocopter would be more stable. A higher lifting capacity is ideal so that the drone can focus more of its power on stability while lifting a load.

Furthermore, good quality batteries are important since they allow an increase in flight time, reducing unproductive take-offs and landings that would result in a shorter time frame to finish the job. Good quality drones should have minimal vibration so that this will not affect the quality of the images taken by the camera unit. A decent 3-axis gimbal is a must so that the camera unit will stay on the desired relative angle from the ground regardless of the movement of the drone.

**PRE-AERIAL FLIGHT PREPARATION**

Pre-aerial flight preparation consists of the topographic survey of the permanent, semi-permanent and temporary benchmarks, the survey of the base surface and the processing of the data into a base drawing (Figure 4). The survey of the benchmarks can be done one day ahead of the planned aerial survey. In addition, a last minute survey of temporary added benchmarks can be done in the case of disturbed benchmarks or in order to increase the density of the GCP network. The more evenly distributed the GCP network, the higher the accuracy of the results. The survey of the stockpile boundary can preferably be done just prior to the aerial survey to get the most up-to-date boundary of the described working area.

**ACTUAL AERIAL SURVEY**

Preflight preparation

- **Safety:** Special care should be taken so that
FRANK SMOLDERS has worked overseas for more than twenty years for DEME (Dredging, Environmental & Marine Engineering) in various survey and operational roles and has spent numerous years primarily in the Far East, Africa, the Middle East and the Indian subcontinent. After having created land for the future in Abu Dhabi waters, he is currently employed as Survey Manager for DIAP-SHAPJV on JIWE project in Singapore.

the drone can take off and land in a secured area, which is off-limits to all personnel. Reports indicate that when an accident happens with a drone, it will most likely occur during take-off or landing – at the moment when the drone is hovering just above the ground, a sudden gust of wind might bring the drone out of balance whereby the propellers might touch the ground resulting in the drone getting into an unwanted spin (Figure 5).

- **Flight height calculation**: Depending on the camera specifications, the flight height should be calculated for optimal Ground Sampling Distance (GSD). The GSD is the distance between pixel centres that are measured on the ground. The bigger the value of the GSD image, the lower the spatial resolution of the image and the fewer details visible. The GSD is related to the flight height. The higher the altitude of the images, the bigger the GSD value. To calculate the GSD, following camera specifications are needed: sensor width (in mm), focal length (in mm) and image width in pixels. Using a GSD calculator, the flight height will be calculated and adjusted to result in a preferred value of GSD, being 2cm/pixel or less. (Figure 6).

- **Flight path preparation**: Depending on the location where the drone will be doing a survey, a flight plan should be prepared. The flight plan should be based on various factors including the calculated flight height (while taking into consideration local legislation with regards to flight ceiling, timing and availability of necessary permits) and overlap requirements. Enough overlap needs to be predicted in both forward as well as lateral directions. Flight plans should be revised depending on the actual requirements and progress within the working areas. The preparation of the flight path should be done by the pilot, based on map of GCPs, flying altitude and overlap requirements. Corrections to the flight path will be done, based on a test run (Figure 7).

- **Battery level check**: Before the flight, all batteries including drone battery, camera battery and remote control unit battery, need to be checked if they are fully charged. If a battery is going to get drained during flight, the operator gets a warning and the drone will return to its base location.

- **Camera and gimbal check**: Test shots need to be taken prior to take off to ensure that the drone can take off and land in a secured area, which is off-limits to all personnel. Reports indicate that when an accident happens with a drone, it will most likely occur during take-off or landing – at the moment when the drone is hovering just above the ground, a sudden gust of wind might bring the drone out of balance whereby the propellers might touch the ground resulting in the drone getting into an unwanted spin (Figure 5).

Figure 5. Special care must be taken during take-off and landing of a multicopter, preferably in a secured area off-limits to personnel.

Figure 6. Sample Ground Sampling Distance (GSD) calculator for determining the flight height of a multicopter.
All settings are correct. Gimbal movements and controls should be checked to see if the roll and pitch are always compensated.

- **Test flight**: A short test flight should be done to double check if all parameters are set correctly and if all systems are working as needed.

**The flight**
- As per the flight plan, the drone should carry the camera and follow the flight path till the whole area is covered. During this flight, the camera must remain orthogonal to the subject area. To improve the quality and accuracy of the data, a second flight following the same flight path but with the camera in an oblique angle horizontal to the subject area, should be conducted.
- Although the drone is fully automated, the telemetry needs to be monitored closely (especially the battery level) during the flight. Currently, the average flying time of the drones used on the project is about twenty to twenty-five minutes. If a First-Person-View (FPV) device is available, it should be monitored so that deviations in camera angles can be detected and adjusted right away.
- The team should always be on the look-out for sudden weather changes, especially on large areas where the drone will take more time to return to its base location.
- Flight paths can be repeated for consecutive surveys. However, changes in the size of the working area must be taken into account, potentially leading to an adjusted flight plan.

**POST FLIGHT QUALITY CHECK OF DATA**

After completing the flight, a quick field quality check is required to ensure all gathered data is of suitable quality. During the check, the following points should be addressed:
- Are the photos orthogonal and gimbal compensated on the first flight?
- Are the photos properly tilted as per desired angle on the second flight?
- Is the whole subject area covered?
- Is the number of photos sufficient?
- Are the photos sharp enough and not overexposed or blurry?
- Are the GCPs clearly visible?
- Do the photos show enough overlap?
- Are the photos in the correct format (TIFF)?

**POST-PROCESSING THE DATA**

After the field check has shown that all data is sound, one can start the post-processing. This consists of updating the boundary drawing in a CAD programme of choice, analysing and processing the data into output files with specialised software, and finally, exporting the results in a desired format for further processing into volumes, a report or presentation.

- **Update the boundary drawing**: Newly measured data should be used to update older data, new boundaries will replace old boundaries. Based on the new drawing, updated GCP data should be extracted and exported in a P, E, N, Z format. This data will be used in the specialised software to ultimately create a TIN of the surveyed area.
- **Specialised software will create a TIN or mesh out of the pictures taken during the flights.** The procedure comprises:
  - Inspection and selection of suitable photos for further processing. Working with the optimal amount of photos is the most efficient. There should be enough photos with sufficient area coverage and overlap but not excess. Excessive photos will only cause the processing time to become longer without a noticeable increase in the quality of the results. Low quality pictures (overexposed, blurred) are to be excluded. Pictures taken during take-off and landing are also to be removed from the data set.
  - Uploading of the photos in the software.
  - Aligning of the photos in the software. While aligning the photos, a sparse point cloud will be generated and displayed. Passing through a sparse point cloud first is recommended to allow removal of unwanted ambiguities prior generating a dense point cloud.
  - Cleaning of the sparse point cloud. In
case of outliers and bad points, these points will be deleted during this part of the process. Additional unwanted points can also be removed in this stage prior to final processing.

- Creating of a rough mesh, based on the sparse point cloud. This mesh is being used for placement of the markers.
- Detection of the markers.
- Renaming of the markers.
- Importing of the ground control point text file to assign coordinates to each GCP in the model.
- Marking and adjusting of the markers in case needed.
- Optimisation of cameras. In this phase, all photos are aligned properly, matching with the GCP assigned coordinates. All pictures are georeferenced by now.
- Building of a dense point cloud. After georeferencing of the photos, the final dense point cloud can be generated.
- Rebuilding of the mesh, based on the dense point cloud.
- Building of texture. The building of texture assists in showing the mesh with an enhanced 3D view, by allocating heights to all the pixels of the orthogonal photo. This view is preferred for presentation purposes (Figure 8).

- Exporting of the processed files: The last step in the processing is the exporting of the files required to perform volume calculations and to prepare the final reports. The three files currently exported are the model, the points file and the orthogonal photo.

The model file would be used in specialised software, e.g., to calculate volumes of the subject surveyed area. Similar to the model file, a points file is exported, which would also be used to carry out, e.g., volume calculations in any CAD or modelling software of choice.

The orthogonal photo is extracted as a TIFF format. Currently, the orthogonal photo is used as a quality check on the accuracy of the surveyed areas boundaries. While not all of the above files are necessarily needed, the files can be used to verify calculations through different software with a different approach, thus increasing reliability and quality of the results.

Any of the formerly proposed exported files can be used to generate reports for follow-up of progress, future operational planning or for promotional purposes.

To allow optimum results, it is recommended to follow the step by step process given above. However, the process can be shortened by automating some steps once one is confident with the various software parameters.

**DEVELOPMENTS**

At the time of writing, further developments have been taking place in the field of aerial surveying. One of the developments involves incorporating RTK accuracy into the drone’s GPS.

By doing an aerial survey with a RTK-GPS drone, one can more confidently omit the topographic survey of the area boundaries during the preparation stage and reduce the number of GCPs, resulting in less preparation time.

**CONCLUSIONS**

The application of aerial survey techniques has given the JIWE survey team a big advantage in terms of speed of data acquisition. Requests to survey the progress of the excavation of the stockpiles and the progress of the build-up of new stockpiles can be accommodated more easily and faster.

The fact that people working at the site are exposed less often to risky conditions has been a big step forward in terms of HSE (Health-Safety-Environmental) recommendations.

Any surveyor using this technology will soon be convinced that aerial survey is a revolutionary improvement to the traditional topography and brings the surveying of difficult-to-reach or potentially dangerous areas within reach.