MAPPING KUWAIT OIL FIELDS WITH LEICA LIDAR AND IMAGING SENSOR SYSTEM

Majeed Al-Muwail, Faisal Al-Bous, Nasir Osman, Ramesh Mahishi Murthy
Operations Technical Services (South & East Kuwait), Kuwait Oil Company, Kuwait

Introduction

The Infrastructure Master Plan (IMP) section of the Operations Support Group in Kuwait Oil Company (KOC) is responsible for developing a Master Plan to manage all the oil field's surface footprint. Recently, KOC made an important decision that would impact the quality and accuracy of the data used for planning, operations and Health Safety & Environment (HSE) activities. In order to achieve the purpose of supporting automation, coordination and management of the company's geographic information and resources, IMP completed its first ever, aerial acquisition of high resolution digital images of 10 cm and LiDAR (Light Detection and Ranging) of 4 ppm. Orthophotos and LiDAR bare-earth Digital Elevation Model (DEM) will be produced at two different resolutions (10cm) and (20cm) using cutting-edge technologies.

Project Approach

Project planning involved numerous coincident activities. KOC selected the Area of Interest (AOI) based on the geographic distribution of KOC services/ facilities all over the State of Kuwait. KOC fully understands that the AOI includes some military areas and Kuwait international border lines that require special consideration. Coordination was exercised to obtain necessary permits from the Directorate General of Civil Aviation, Ministry of Defense and Air Force.

Distribution of ground control points (GCP) was planned and signalization was performed to support the accuracy requirements of the project.

Aerial Data Acquisition

The option of using Unmanned Aerial System (UAS) over a manned aircraft was first evaluated. Factors considered for the evaluation included:

1. Area of Interest: Spread over 8000² Km. It was not feasible to use a UAS.
2. Security: The AOI is close to international borders and includes vital defense installations and air bases, making it impossible to fly a UAS over them.
3. Permissions: Obtaining permissions from Directorate General of Civil Aviation (DGCA) to fly a UAS across half the country is next to impossible.
4. Safety: If there were a failure in the UAS like disconnection of GPS lock or a mechanical failure, the UAS could go rogue and cause safety concerns to KOC assets or violate the geo-fence.
5. Endurance: The endurance of a UAS is dependent on the weather, headwinds, etc. The maximum flight time for the UAS could be about an hour making it difficult to complete acquisition in one flying season.
6. Payload: Although the scope included acquiring both aerial images and LiDAR data, getting a UAS to support simultaneous collection was not possible.

Keeping above factors in mind, the choice of sensor was the second step towards aerial data acquisition. Since the aim was to acquire digital images and LiDAR data over the same area, flying two sorties was impractical. Therefore, Leica RCD 30 Digital Imagery Sensor integrated with Leica-70-HP-MPIA LiDAR platform with simultaneous collect facility was selected. RCD30 is the first medium format, single head camera which collects perfectly co-registered 80 MP RGBN multispectral imagery. Its innovative features and configuration flexibility support photogrammetric and remote sensing applications, offering performance otherwise only available from large format airborne sensors. Leica-70-HP LiDAR sensor has a unique, sophisticated, optical beam-splitting system that bifurcates the laser beam, resulting in an effective scan rate of 500,000 points per second. This gives the ALS-70-HP the ability to achieve the highest point density at a given altitude of any system currently in the market, resulting in exceptional acquisition efficiency (www.leica-geosystems.com).

The contractor was entrusted to choose an aircraft that could accommodate the sensor system, be able to fly steady and make tear-drop turns within short distances. Rockwell International 690A was an ideal choice for this. Pictures in Figure 1 are of the aircraft and equipment used for acquisition.

Area of Interest

Aerial acquisition was planned at 10 cm resolution digital images and 4 points per square meter of LiDAR data for highly developed areas, and 20 cm resolution digital images and 0.5 points per square meter of LiDAR data for the other areas. Area of interest towards North Kuwait had to be restricted to three (3) nautical miles from the Iraq International border.

Photogrammetric Engineering & Remote Sensing
Vol. 87, No. 5, May 2021, pp. 313–317.
0099-1112/21/313–317

doi: 10.14358/PERS.87.5.313

Challenges during Aerial Acquisition

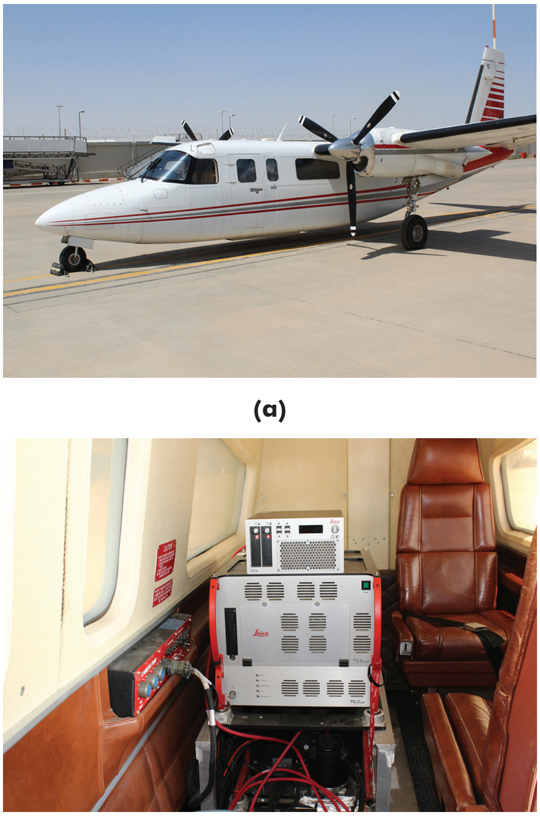
The industry experts would agree that aerial acquisition, though sounds easy, is quite a tedious task and influenced by various external factors. The experience of IMP was no exception. Some of the challenges faced during acquisition and mitigation steps taken were:

1. Weather: Kuwait experienced abrupt weather changes during 2019. Although the acquisition was planned to commence during the best season for aerial survey in Kuwait, i.e. November to February, the planned 19 days of acquisition actually took slightly over four (4) months due to unexpected strong winds making it difficult to stick to the planned flight path. Other challenges faced during acquisition were unexpected rains, haze, clouds, dust, and fog. This was overcome by extending the schedule and permissions assigned for aerial acquisition.
2. Smoke: Although the Production and Operations teams were informed prior to aerial acquisition to keep the flaring activity to minimum on the days of aerial photography, it was not always feasible due to operation and production constraints. Re-flights over the same areas were performed to get images with minimum smoke around production facilities.
3. Turbulence: One of the activities during production of oil is to burn gases that usually accompany oil through a smoke stack. This process is called as flaring. As part of production process, another activity is to burn out oil during asset maintenance. The air in the atmosphere heats up around the flare stacks or burn pits causing temperature and pressure variance. This makes the aircraft lose altitude around these areas. The air-crew were prepared well to control the aircraft around these areas, yet maintain the course and altitude manually. In order to maintain good quality data, the affected areas were re-flown.
4. Flying close to international borders: The area of interest for aerial acquisition included areas close to international borders that consist of crucial KOC assets. These areas thus involved close coordination with the Aviation and Defense authorities on both sides of the border and due care was taken not to violate any aviation laws. Experienced air crew were specially identified for the process who carefully piloted the aircraft through tight boundaries, yet covering a maximum AOI.

Image Data Processing

Data processing is a vital step for interpreting the results and drawing meaningful conclusions. Digital Aerial Triangulation (AT) was performed immediately upon the completion of aerial acquisition. The purpose of AT is to densify horizontal and vertical control from relatively few ground control points (GCPs). Since obtaining GCPs is a relatively significant expenses in any mapping project, AT procedures were used to reduce the amount of field survey required by extending control to all stereo models.

The surveyed control, along with the reduced image coordinates, served as input into a combined block adjustment.



(a)

(b)

Figure 1. The aircraft – Rockwell International 690A (top) and the Integrated Sensor System – Leica RCD 30 with ALS70-HP (bottom).

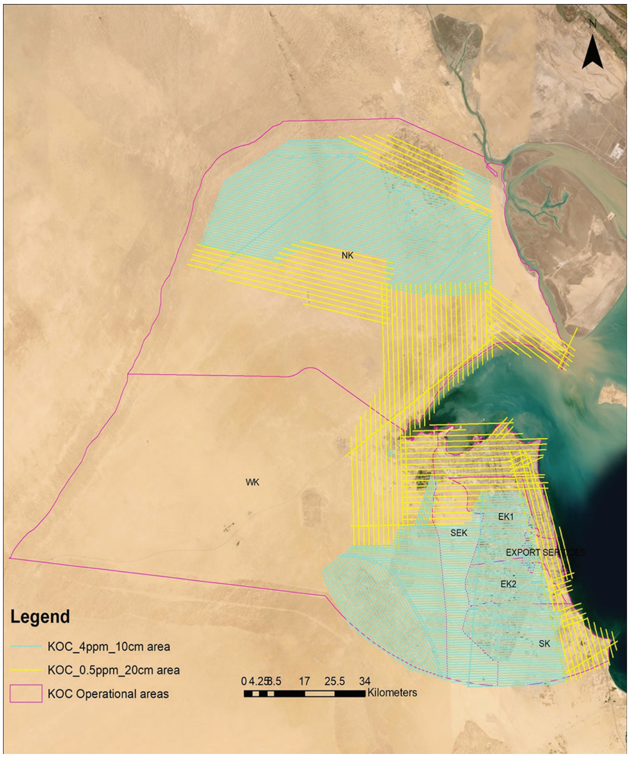


Figure 2. Area of Interest covering South & East Kuwait (SEK), North Kuwait (NK) and West Kuwait (WK) areas.

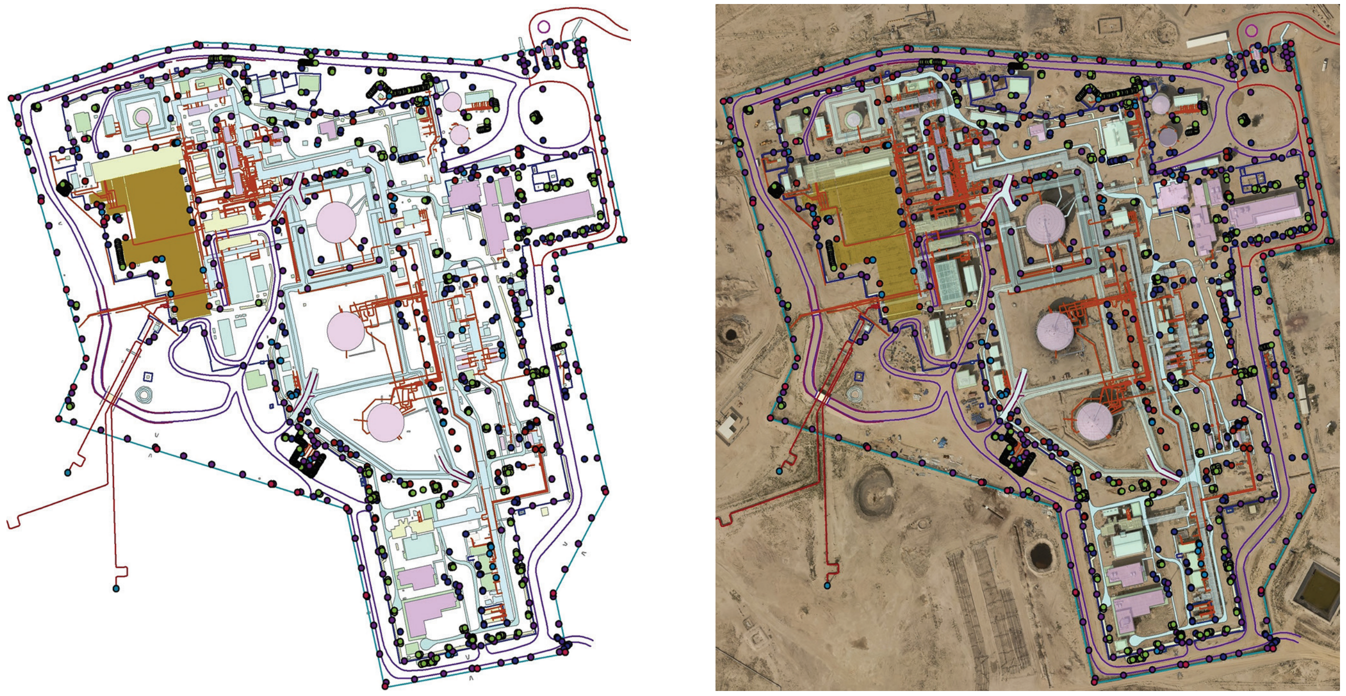


Figure 3. 3D Data Compilation of a Gathering Center.

Three dimensional, simultaneous least squares adjustment by bundles, commonly referred to as "bundle adjustment", was undertaken using Inpho Match-AT GPS adjustment software. A series of AT solutions were completed. The final adjustment and the optimal solution to be used for mapping, included all control points as constraints.

The AT results are being used for topographic data compilation and creation of Digital Terrain Model (DTM) by compiling breaklines photogrammetrically.

LiDAR Data Processing

Post processing of all LiDAR data flight, strips were completed to perform calibration and verify quality and coverage. In order to ensure a homogenous surface, adjustments were made to the orientation and/or linear deviation of individual and overlapping swaths to obtain the best fit relative accuracy. Project-wide calibration was evaluated using advanced vector matching analysis; and trajectory based solutions were applied. This procedure was repeated interactively until the residual errors of overlapping swatch was reduced. A visual and statistical analysis was completed using elevation difference intensity raster and vector based accuracy reporting.

LiDAR data was then filtered and classified to separate terrain data from other data on land cover and manmade features. Only a ground/non-ground classification was performed for this project. A variety of commercial and proprietary software were used to build macros for automated classification. The macros were specific for the landscape of the project taking into consideration terrain relief, ground cover and natural and manmade features. The routines were used to classify points based upon the laser attributes including intensity, elevation and the numeric value of the returns.

Orthophoto Creation

Aerial images were ortho-rectified using the AT results and LiDAR DEM. Color balancing and mosaicking were performed to ensure the final imagery is both radiometrically and geometrically seamless. The orthophotos were partitioned and written out in compliance with the desired naming convention in GeoTIFF and MrSID format. The resulting orthophoto tiles were seamless with no overlaps or gaps between them.

On completion of data processing, KOC produced the following outputs to support planning, operations and HSE activities:

1. Digital Orthophotos: Images that are rectified to accurately represent the ground and could be used as photo maps.
2. Bare Earth DEM: Accurate representation of ground features or hypsography which could be used for generating contours depicting slopes.
3. 3-dimensional Vector Maps: Compiled photogrammetrically to represent the above ground features such as buildings, pipelines, utilities, etc., in 3 dimensions (X, Y, Z) accurately.
4. Digital Terrain Model: Created by adding supplementary breaklines to the LiDAR DEM, where necessary to depict the sudden changes in slopes. The above derivatives shall be tested based on the industry accepted accuracy standards set by the American Society for Photogrammetry and Remote Sensing (ASPRS), ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, version 1.0. – November, 2014). <https://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf>

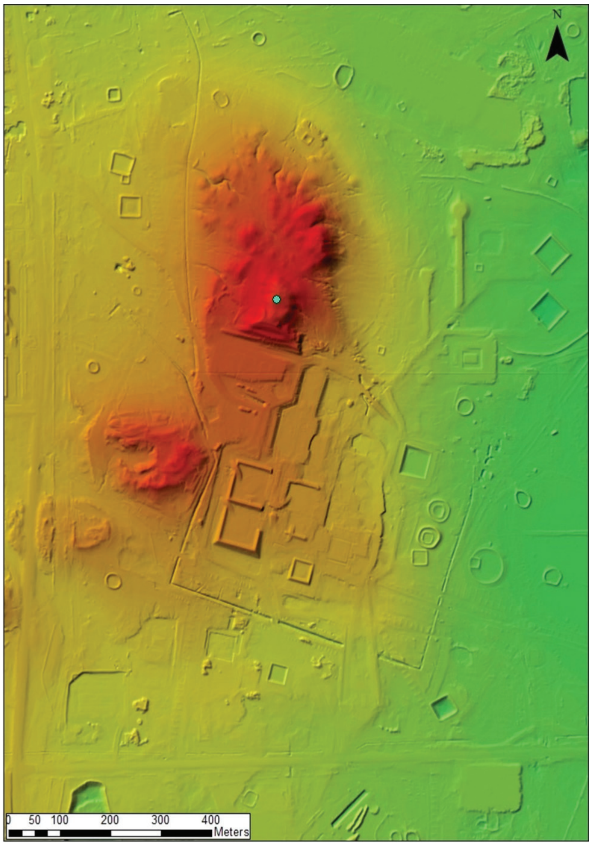


Figure 4. LiDAR generated terrain model after point classification.

Figure 5. Ortho-image at a resolution of 10 cm.

Quality Assurance and Quality Control

QA/QC is a process used to ensure the highest probability of creating quality products to predefined standards. KOC prepared a detailed measurable Acceptance Criteria to guide the production activities. It provides the basis for developing the supporting necessary tools to check the final deliverables and to confirm the all the delivered products have passed the established listed Acceptance Criteria. This includes in-house developed scripts to automate the checking (file naming convention, format, projection parameters etc.) as well as visual checks to confirm the adherence of the data to the predefined acceptance criteria.

Statistical and testing accuracy assessment has been implemented to verify conformance with accuracy requirements of the project. The positional accuracy is calculated statistically from well-known Ground Control and resulted in 10 cm for 10 cm orthophotos and 20 cm for that of 20 cm.

Conclusion

The anticipated challenges creating setbacks to the project as mentioned earlier were used to create and update the risk register and lessons learnt for future projects.

1. Although, using the imaging and LiDAR sensors for simultaneous data collection reduced the collection time, mobilizing two sets of aircraft and equipment would make the collection process faster, resulting in faster data output. Also, the re-flights of some areas could be avoided. It is understood that the process would be expensive, but the benefits reaped in getting the data faster far outweighs the costs incurred.
2. KOC field assets changes continuously. The data thus collected could be processed much faster resulting in usable information available to the field teams at a faster pace.
3. Periodic updates need be performed so that the information available to the field teams are up-to-date.

The initiative of KOC in creating high resolution orthophoto maps, LiDAR DEM, DTM and 3-D topographic maps shall yield the following benefits to the company:

1. Creation of orthophotos to serve as a base map supports in daily planning, operations and HSE functions. The challenges faced by the field survey team in day-to-day operations, such as route planning in terms of safest route, and avoiding hazardous areas, etc. are eliminated.
2. Visual reference for infrastructure planning provides a suitable platform to study the impact of KOC operations. One of the main functions of IMP is effective land management. With the use of high resolution orthophotos and LiDAR DEM, activities such as pipelines routes, land reservation, asset demarcation, removal of abandoned assets, etc. have become efficient.
3. Enhanced data collection in inaccessible and geo-hazard areas through 3D compilation.
4. Producing LiDAR data (Elevation Data, Terrain Datasets) to support:
   a. Orthophoto rectification.
   b. 3D simulations and spatial analysis.
   c. Hydrological modeling.
   d. Better representation of the terrain.