**International Journal of Innovation Scientific Research and Review**
*Vol. 06, Issue, 05, pp.6348-6357, May 2024*
*Available online at http://www.journalijisr.com*
*SJIF Impact Factor 2023: 6.599*

ISSN: 2582-6131

**Research Article**

# CONCEPTUAL APPROACH FOR ELECTRONIC TERRAIN OBSTACLE DATA PROVISION FOR SUDAN AIRPORTS

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**Received 09th March 2024; Accepted 10th April 2024; Published online 25th May 2024**

**ABSTRACT**

The Electronic Terrain Obstacle Data (eTOD) is required to develop terrain and obstacles data to support the ICAO Communications, Navigation, and Surveillance (CNS), air traffic management systems, and safety of conducting airport services. The eTOD datasets are to provide the pilots with reliable information in their decision-making process, concerning terrain or obstacle hazards. eTOD can be used for Aeronautical Information Management and services, development, and ground-based applications. The Electronic Terrain Obstacle Data will be required for the Sudan Civil Aviation Authority(SCAA) to achieve ICAO eTOD compliance for its airports and to develop the Aeronautical Information Management (AIM) in Sudan. Aeronautical surveying is a highly specialized type of surveying, in which aeronautical survey provides critical information about airport features, obstructions, and navigational aids. This data is needed for safe aircraft operation and airport safety services. Airport surveying needs extensive knowledge of ICAO documents related to aerodromes and their environs concerning the operational areas, obstacle limitation surfaces, navigational facilities, etc. The data collection methodology by using relevant and reliable means and technologies to achieve Annex 15 ICAO requirements will be described, including terrestrial, photogrammetric, Lidar, Drone, and Satellite imagery measurements.

***Keywords:*** AIS: Aeronautical Information Service; ARP: Aerodrome Reference Point; ATM: Air Traffic Management; DEM: Digital Elevation Model; DORI: Digital Ortho-Rectified Imagery; DSM: Digital Surface Model; DTM: Digital Terrain Model; FMC: Forward Motion Compensation; FAA: Federal Aviation Administration; ICAO: International Civil Aviation Organization; CNS: Communication, Navigation, and Surveillance.

## INTRODUCTION

The Electronic Terrain Obstacle Data (eTOD) is required for the development of terrain and obstacles data to support the ICAO Communications, Navigation, and Surveillance (CNS), air traffic management systems, and other systems as appropriate [1, 2, 5, 7]. The eTOD is to make additional relevant information available for the pilots to assist them in their decision-making process, such as knowledge of one's location concerning terrain or obstacle hazards. eTOD can be used for Aeronautical Information Management (AIM), development, and ground-based applications. The targeted AIM applications may include the following: Terrain Awareness and Warning System (TAWS); Off-airway "drift-down" protection; contingency procedures (emergency at take-off or missed approach); synthetic vision system; aircraft operating limitation analysis. The ground-based applications may include the following: Minimum Safe Altitude Warning (MSAW); databases for use by the instrument procedure designer; air carrier engine-out procedure analysis; simulation and flight crew familiarization in terminal airspace. The Electronic Terrain Obstacle Data will be required for the Sudan Civil Aviation Authority (SCAA) to achieve ICAO eTOD compliance for its airports and to develop the AIM in Sudan.

Aeronautical surveying is a highly specialized type of surveying, in which aeronautical survey provides critical information about airport features, obstructions, and navigational aids. This data is needed for safe aircraft operation and airport safety services. Airport surveying needs extensive knowledge of ICAO documents related to aerodromes and their environs concerning the operational areas, obstacle limitation surfaces, navigational facilities, etc. The authors are well acquainted and have knowledge of the ICAO survey requirements, eTOD surfaces, accuracy and integrity of the eTOD datasets, and the adopted World Geodetic System—1984 as the standard geodetic reference system for international civil aviation and global reference systems realization.

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The Sudan airports data acquisition approach, aimed to cover Sudan airports in terms of Aeronautical Data and Obstacle Surveys. The authors realize that ICAO Standards and specifications are to be met, to secure safe aircraft operation. It should be stressed that the Obstacle Data Survey should be carried out with specifications as set by ICAO Annex 15 areas, 2, 3, and 4 [2] and outlined in its DPS document [7, 12]. To meet ICAO specifications, Geographical Data namely, Digital Terrain Model (DTM) and Vector data should be carried, processed and data quality controlled. The aeronautical data survey provides critical information about airport features, obstructions, and navigational aids, as well as man-made obstacles surrounding airports. Obstacle data should also cover all man-made obstacles such as buildings, towers, antennas, high tension towers, pole light antennas, windmills, poles, walls, lighthouses, bridges, and cranes. The data collection methodology by using relevant and reliable means and technologies to achieve Annex 15 ICAO requirements will be described, including terrestrial, photogrammetric, Lidar, drone, and satellite imagery measurements. The authors understand that the data collection means is not fixed, it varies based on the requirements and the quality of the final products, which shall be provided in fixed format models given by ICAO. The provided templates contain all relevant information to comply with Annex 15 and Procedures for Air Navigation Services — Aeronautical Information Management (PANS-AIM) regulation [8, 9, 12]. The contents will include at least: surveyed data and its geometric (Altitudes, heights, and coordinates) and semantic attributes (Id, Type, lighted, start date, end date, …); associated metadata fields;

accuracy (vertical + horizontal), resolution; associated process steps metadata: orientation means, verification and validation steps; data integrity protection values: Cyclic Redundancy Check (CRC).; validation and verification reports.

## ICAO AREAS OF COVERAGE AND NUMERICAL REQUIREMENTS

It is well understood that the coverage of different ICAO areas will include the terrain data and obstacles, and the spatial coverage requirement is shown in Figure 1.

The terrain data requirements for area 1 (table 1) cover the world and hence the entire country. Area 2 is a buffer around the airport runways + 90 m of 10 km that is overlaid with the Terminal Maneuvering Area (TMA) Zone (Figures 1, 2, and 3) and has the following categories [3]:

I. Area 2a: It covers a rectangular area around the runway strip plus any clear way that exists.
II. Area 2b: It extends from the ends of area 2a in the direction of landing and departure, with a length of 10 km a splay of 15% to each side, and a slope of 1.2% at each runway, Figure 4.
III. Area 2c: An area (ellipsoid shape) extending from the boundary outside area 2a and area 2b at a distance of not more than 10 km from area 2a (see Figure 5), the required eTOD surface for handling obstacles will be with a slope of 1.2 percent. Area 2d: An area outside areas 2a, 2b, and 2c up to a distance, of 45 km from the Accelerated Recovery Performance (ARP) or an existing terminal control area (TMA), Figure 6.

**Table 1:** eTOD areas definitions [3]

| Area | Definition | Slope |
|---|---|---|
| Area 1 | It covers the whole country | Nil |
| Area 2a | A rectangular area around a runway that comprises the runway strip plus any clearway that exists. | 3 m above the nearest runway elevation measured along the runway center line. |
| Area 2b | An area extending from the ends of Area 2a in the direction of departure, with a length of 10 km and a splay of 15 percent to each side. | 1.2% slope extending from the ends of Area 2a at the elevation of the runway end in the direction of departure.<br>Note: Obstacles less than 3 m in height above ground need not be collected. |
| Area 2c | An area extending outside Area 2a and Area 2b at a distance of not more than 10 km from the boundary of Area 2a. | 1.2% slope extending outside Area 2a and Area 2b at a distance of not more than 10 km from the boundary of Area 2a. Obstacles less than 15 m in height above ground are not to be collected. |
| Area 2d | An area outside Areas 2a, 2b, and 2c up to a distance of 45 km from the aerodrome reference point, or to an existing TMA boundar; | 100 m above ground. |
| Area 3 | Area at 50m from TWY PKG and 90m from RCL. | nil |
| Area 4 | extends 900 m before the runway threshold and 60 m on each side of the extended runway center line. | nil |

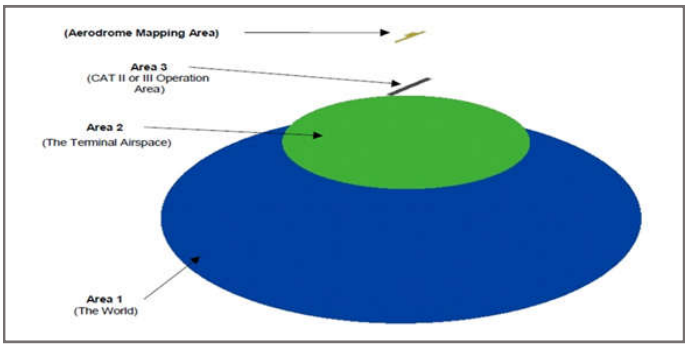


**Figure 1:** Areas of coverage of the whole country [3].

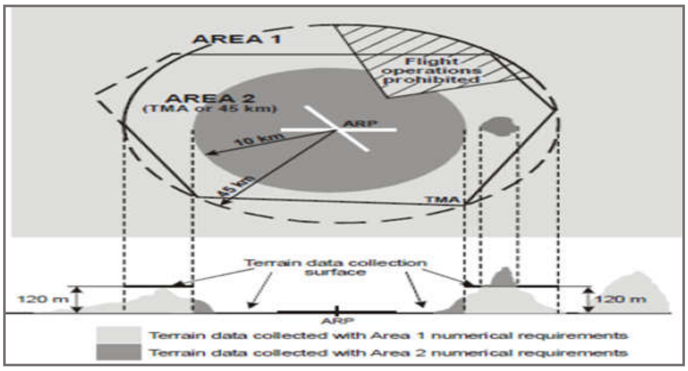


**Figure 2:** Obstacle data [2] for areas 1 and 2.

**Table 2:** The terrain data requirements [3] for Areas 1 and 2.

| Areas/Attributes | Area 1 – Continuous (The country) | Area 2 - Terminal Airspace |
|---|---|---|
| Horizontal Accuracy | 50.0m | 5.0m |
| Data Integrity Routine | (10-3) | (10-5) |
| Vertical Accuracy | 30.0m | 3.0m |
| Vertical Resolution | 1.0m | 0.1m |
| Confidence Level | 90% | 90% |
| Terrain Database Post Spacing | 3 arc-second (100m) | 1.0 arc-second (30m) |

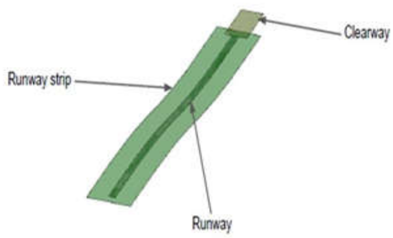


**Figure 3:** Area 2a

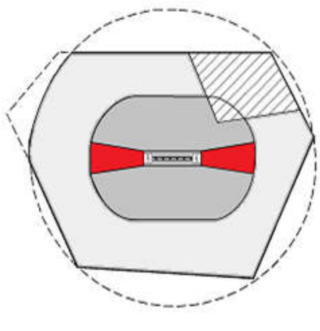

**Figure 4:** Area 2b

Area 3 (Figure 1) is defined as the Radar Altimeter Area for CAT II/III Precision Approach procedures. The area extends from the runway threshold to 900m from the threshold. It is 120m wide and centered on an extension of the runway center line. For the estimation one may take the entire airport area to cover, together with the definition of the aerodrome area - this may be adjusted. This is the area bordering an aerodrome movement area that extends horizontally from the edge of a runway 90 m from the runway center line and 50 m from the edge of all other parts of the aerodrome movement area [2].

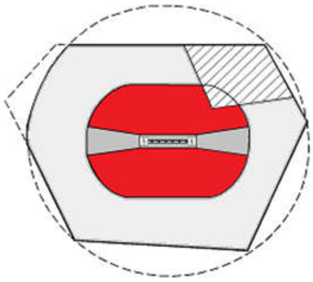

**Figure 5:** Area 2c

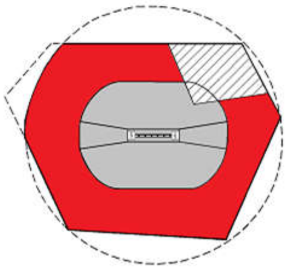

**Figure 6:** Area 2d

Area 4 extends 900 m before the runway threshold and 60 m on each side of the extended runway center line in the direction of the approach on a precision approach runway, Figure 8.

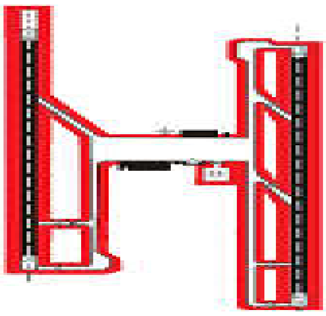

**Figure 7:** Area 3

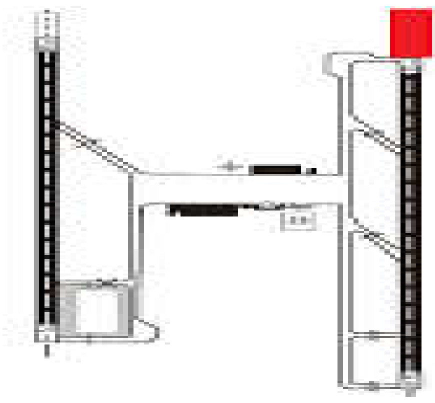

**Figure 8:** Area 4

**eTOD Obstacles Data Acquisition and Processing**

The ICAO data models and attributes for the obstacle shall be considered and follow the ICAO enforcement rules in terms of mandatory/optional. Several data sources shall be outlined to develop the terrain and obstacles databases, these include but are not limited to: -

a. Vertical Reference or Datum: In general, the vertical reference in Sudan is the mean sea level (MSL) to account for the topographic undulation of the Earth's surface, which is physically realized by a set of adjusted leveling benchmarks. Typically, the height information from precise GNSS measurements will be related to the Benchmarks to account for the Geoid height at every GNSS measurement. The vertical datum shall be defined for GNSS measurements and be obtained by the use of global Earth Gravity Models, such as EGM-2008. Indeed, accuracy tests will be carried out to validate the quality of EGM-2008 in terms of its prediction capability as well as compliance with the stated accuracy pertained to different areas (2, 3, & 4).
b. Horizontal Datum: The horizontal datum will be defined by WGS-84 epoch G1150). All existing reference data will be transformed to the adopted WGS84 epoch.
c. Resolutions: Horizontal and vertical resolutions have two components: The unit used in the measurements; and the number of decimal places for the recording of the measurement (elevation or 2D coordinates). Although this definition is dictated by the given references, we do believe that the concept of the resolution to a great extent is controlled by the spatial resolution (vertical and horizontal) and the sub-unit prediction of the measurement system; the integrity of data is the degree of assurance that the data and its value have not been altered nor lost since the data origination or authorized amendment.
d. Generation of Digital Surface Model: eTOD Digital Surface Model will be obtained, checked, quality controlled, verified, and validated, followed by inserting its metadata and attributes.
e. Generation of Digital Terrain Model: Terrain eTOD data will be generated by extracting the terrain elevations along the streets and open areas for the whole area under consideration. The DTM can be generated using one of the GIS software for 3D surfaces. The obtained DTM should be checked, quality controlled, verified, and validated, followed by inserting its metadata and attributes.

**Table 3: Obstacles data ICAO requirements**

| Areas/Attributes | Area 1 | Area 2 | Area 3 | Area 4 |
|---|---|---|---|---|
| Vertical Accuracy | 30 m | 3 m | 0.5 m | 1 m |
| Vertical Resolution | 1 m | 0.1 m | 0.01 m | 0.1 m |
| Horizontal Accuracy | 50 m | 5 m | 0.5 m | 2.5 m |
| Confidence level | 90% | 90% | 90% | 90% |
| Integrity Classification | Routine | Essential | Essential | Essential |
| Maintenance Period | As required | As required | As required | As required |

**Table 4: Terrain data numerical requirements**

| Areas/Attributes | Area 1 | Area 2 | Area 3 | Area 4 |
|---|---|---|---|---|
| Post Spacing | 3arc seconds | 1arc seconds | 0.6arc seconds | 0.3arc seconds |
| Vertical Accuracy | 30m | 3m | 0.5m | 1m |
| Vertical Resolution | 1m | 0.1m | 0.01m | 0.1m |
| Horizontal Accuracy | 50m | 5m | 0.5m | 2.5m |

## SUDAN AIRPORTS

Sudan's main airports for which eTOD datasets Areas 2a,2b, 2c, 2d, and 3; have to be collected are shown in Figure 9, while figure 10, can be considered as a sample illustrating Khartoum airport area.

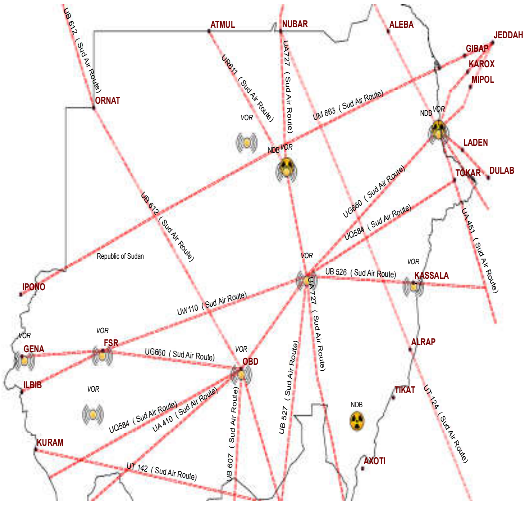


**Figure 9:** Sudan Airports

**Figure 10:** Khartoum Airport Obstacles Areas Distribution

## TECHNICAL APPROACH AND METHODOLOGY

Figure 11, illustrates the technical approach steps to be followed, and the methodology to perform eTOD datasets provision for the Sudan airports. The data-set provision (Figure 13) management requires a plan that proves an excellent ability to manage the required multi-disciplinary tasks.

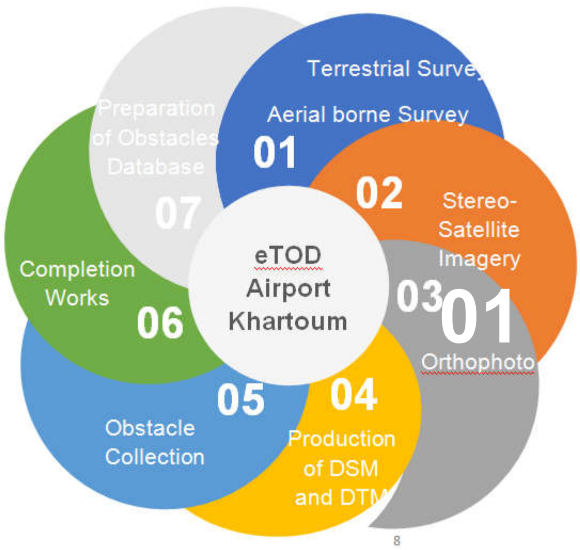


**Figure 11:** Airport eTOD Datasets Production Activities

eTOD Dataset provision (Figure 9) and management require an outstanding professional skill for:

- **(i)** Terrestrial Surveys: Recent geodetic techniques (GNSS: Static, RTK, CORS, static scanners, mobile Lidar), can be used for position determination of the required Ground Control Points. Proper investigations should be conducted for datum transformation, EGM2008 generation, and terrestrial quality control. Existing obstacles database for Sudan airports can be obtained from SCAA and Sudan National Digital Base-map. Land Survey observations should also be carried out to obtain antenna heights and tower data collected by SCAA and its relevant stakeholders.
- **(ii)** Airborne Photogrammetry and Lidar: Aerial photography or Lidar mapping, and processing, for the generation of vector maps, orthophotos, DSM, and DTM, associated with their quality control, verification, and validation of all products.
- **(iii)** Stereo Satellite Image provision: The stereo satellite data can also be used for eTOD provision. It has to be checked for accuracy, geo-referenced, and compliance with ICAO and DPS-Sudan documents. The area coverage and uses, depend on the availability of the satellite image. But certainly, the high-resolution satellite imagery can be used for the generation of orthoimages, DSM, and DTM for all eTOD areas.
- **(iv)** Quality control, verification, and validation of collected eTOD datasets.

### Terrestrial survey

The terrestrial survey includes all field survey observations and processing, distribution, and determination of ground control points that shall be used as base stations (figure 12), tie points, checkpoints and those to be used for quality control, verification, and antenna height determination. These GCPs should be distributed and placed homogeneously in the area of interest. Also, other ground control points will be measured in the same area to be used as checkpoints, further GPCs can be observed for quality control and verification purposes.

In Sudan, the ICAO requirements can be adopted by using the horizontal reference system (WGS 84- G1150), the vertical global geoid surface (EGM2008), and the projected coordinate system (UTM WGS 84- G1150, with the zones covering the entire territory i.e. zones 34, 35, 36 and 37.

Consequently, the horizontal reference for all position terrain, obstacle, and aerodrome mapping data must be the WGS-84 ellipsoid. In all those cases where data sets already exist and are based on a different reference system, they must be transformed to the WGS-84. All-terrain, obstacles, or aerodrome mapping data that includes horizontal position information must be described in units of latitude/longitude for data interchange. For all-terrain, obstacle or aerodrome mapping data that require a vertical component, the vertical reference must be the orthometric height (referenced to MSL) for data interchange. Orthometric height can be derived using WGS-84 ellipsoidal heights and an appropriate geoid undulation. Geoid undulation must be derived using the Earth Gravitational Model of 2008 (EGM2008) or its later realizations. When a different temporal reference system is used for some applications, the feature catalog or the metadata associated with the application schema or a data set, as appropriate, must include either a description of the temporal system used or a citation for a document that describes that temporal reference system [2].

Positional accuracy should be applied as relative accuracy and absolute accuracy. Relative or internal accuracy is the closeness of the relative positions of features within a dataset. Positional relative accuracy is defined as the measure of how objects are positioned relative to each other. The Relative accuracy standard is an indicator or a measure of the allowable deviation in distance between two spatial objects on the ground. While the absolute or external accuracy is the closeness of reported coordinate values to values referred to the globally accepted reference.

**Figure 12:** GNSS base stations

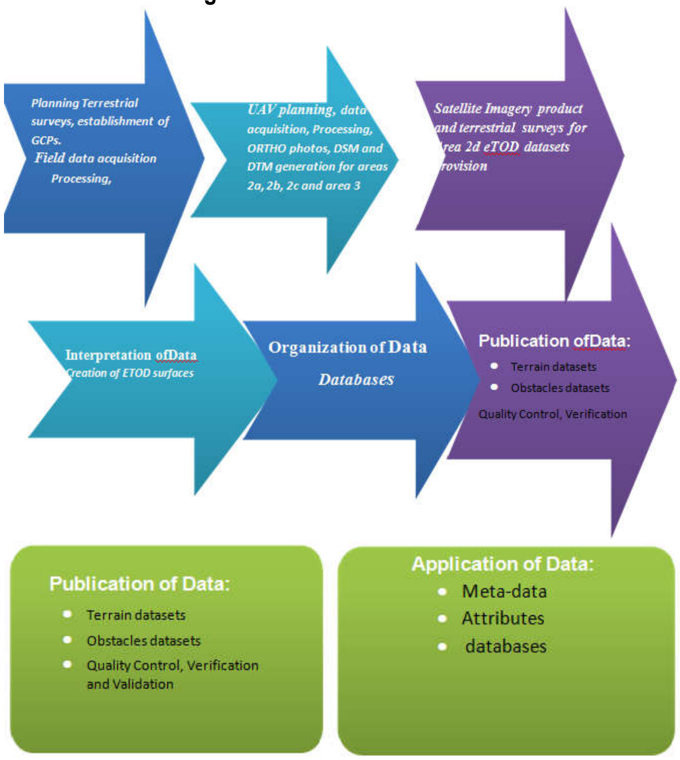


**Figure 13:** eTOD Dataset Provision processes

## Aerial Photogrammetry Imaging.

### Airborne Digital Mapping

Airborne photography can be used as the best means to provide the photogrammetric data for a variety of eTODs areas mapping and applications. Airborne images are defined as images acquired by specialized photographic equipment generally from fixed-wing aircraft or UAVs as a means of remotely recording ground-level events and scenes. Currently, airborne digital images are taken by airborne multispectral camera systems usually based on Charge Coupled Device (CCD) arrays as shown in [4, 5]. Airborne digital cameras generally fall into two categories: Frame sensors, as shown in ***Error! Reference source not found.***, which use square or rectangular CCD arrays (and have geometric characteristics similar to those of a film camera). Line sensors (push-broom) or scanners, as shown in ***Error! Reference source not found.***, use linear CCD arrays and therefore have geometrics similar to satellite sensors.

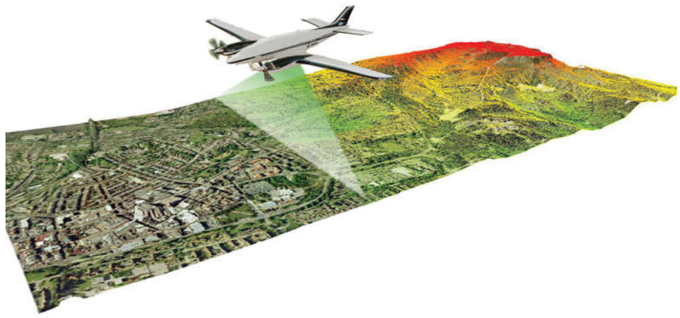

**Figure 14:** illustrates airborne photography

UAV (Unmanned Aerial Vehicles) technology has been crucial in developing modern photogrammetric and GIS applications and maintaining up-to-date eTOD datasets Remote-controlled UAVs have played an important role in lowering the cost of collecting geospatial data and making it easier to collect spatial data in a level of details and speed that unachievable using conventional surveying and photogrammetric methods. Airborne camera systems are divided into 3 main formats: Large, Medium, and small format systems, all of these formats can be used for the provision of eTOD datasets.

### UAV Aerial Photography

Figure 18, illustrates a Drone picture, or unmanned aerial vehicles (UAVs), which are a rapidly evolving and highly adaptable form of disruptive technology. The technology has multiple potential applications within numerous surveying-related sectors, which range from geospatial surveying and mapping to scanning, building surveys, environmental monitoring, and eTOD dataset capture, to name just a few.

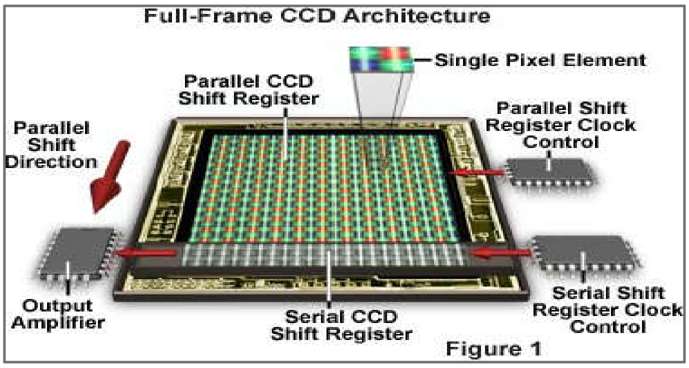


**Figure 15:** Charge Coupled Device - Courtesy of QwickStep.com

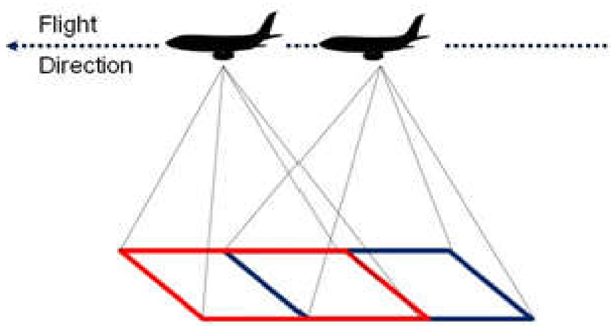


**Figure 16:** Airborne Frame Imagery

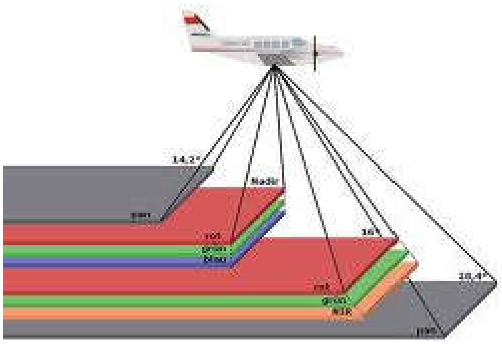

**Figure 17:** Airborne Line Scanning Imagery - Courtesy of Leica

**Figure 18:** CW-007 FIXED WING UAV SYSTEM

As with most of the aerial photogrammetric methods, the accuracy obtained with UAV-processed aerial photography products will be higher than the accuracy required for the provision of eTOD datasets (i.e. better than the required accuracy for Area 2, and Area 3). The required eTOD dataset provision works by using UAV can be outlined as given in Figure 19, and the product specifications as given in Table 5.

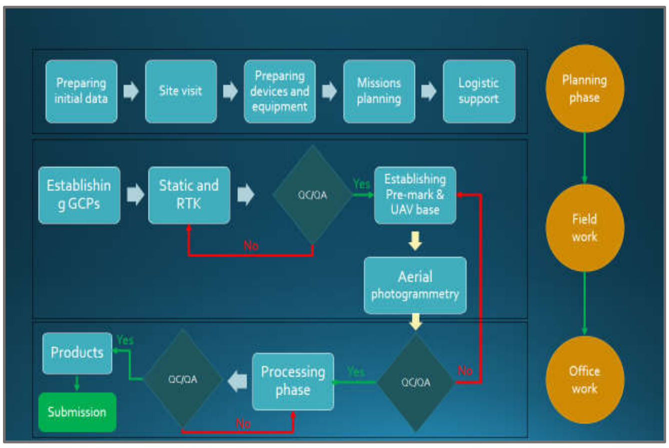


**Figure 19:** planning Phases of eTOD Data Provision:

The entire Areas, 2 and 3 are irregular in shape and the drone's short strips may require several small blocks. Further, to ensure that the desired accuracy standards are met, the points in the periphery of each block are to be in pairs and a few well-distributed control points at appropriate locations as per requirements of Block adjustment are to be provided. Thus, to ensure that the control points are beyond doubt, it is proposed to carry out signalization of about 5 GPCs tie points and three checkpoints for each UAV mission. There are many factors to be considered in airborne photography depending on the ground sample distance required, such as type of terrain; Ground Sample Distance (GSD); and flight height.

**Table 5:** UAV product specifications in areas 2 and 3

| Areas /Attributes | Area 2 Terminal Airspace | Area 3 CAT II/III Operation Area |
|---|---|---|
| Horizontal Accuracy | 3cm | 3 cm |
| Vertical Accuracy | 0.1m | 5 cm |
| Vertical Resolution | 0.1m | 5 cm |
| Confidence Level | 90% | 90% |

Aerial images will be processed using the appropriate software, to generate the vector data, Digital Surface Model (DSM), and Digital Terrain model (DTM) for the eTOD areas. The following QC/QA should be undertaken as the image should be free from "Step over" and aberrations problems, the complete frame of the Image is acquired without loss of edges, and the positioning accuracy shall be checked dimensionally by comparing the 3D coordinates of the checkpoints generated from the images with their corresponding values obtained from terrestrial survey, applying statistical measures (Root Mean Square Error, mean, median, absolute mean, max/min). Another check will be performed by comparing the feature coordinates obtained from ground field surveying with those obtained from the processed aerial images, including obstacles and antenna heights.

## Stereo Satellite Imagery and Processing

A satellite image can be thought of as an image formed by a successive integration of image lines. An array of light-sensitive devices captures the information (i.e., electromagnetic waves) coming from the ground. The captured light is converted to an electrical pulse that is transformed to a digital number and stored for transmission to a ground antenna. Although a satellite image is exposed line by line in a continuous mode while the platform is moving in its orbit, a set of exterior orientation parameters is valid only for one line at a time. The main geometrical difference between an aerial photograph and a satellite image lies in the fact that a satellite image does not have constant values for its exterior orientation parameters. They are approximately constant for one line (perpendicular to the instantaneous orbit direction), but vary from line to line. All points of an aerial photograph have the same exterior orientation parameters.

Aspects to be taken into consideration whenever satellite images are used for mapping purposes are the strong effects of earth curvature and atmospheric refraction. The distortion of the satellite image caused by the earth's curvature and its variation is more significant than the effect of atmospheric refraction. The product of stereo satellite imageries is to be used, subject to field checking for better interpretability of the processed eTOD data such as DTM and obstacles datasets. Appropriate methods of terrestrial surveys shall be used for checking, quality control, verification, and for collecting missed obstacles. It can be concluded that the eTOD datasets DTM, DSM, and GCP for eTOD areas shall be obtained from the satellite imagery product and terrestrial survey work.

The Obstacles data generation process based on satellite imagery are as follows:

***(a)*** **Step 1: RAW data processing:**

- Acquisition of recent satellite imagery over the validated eTOD area.
- Acquisition of Ground Control Point (GCP) for image processing and rectification. To comply with ICAO accuracy requirements, very accurate GCPs are mandatory to improve the image absolute location accuracy
- Creation of an ortho-rectified image: The ortho-image will represent a perfect background layer to overlay the obstacle features and to see ground details, especially for very high resolution. At this step, quality control will be made for strip adjustments, elevation adjustments, aerial triangulation computation, and the final product verification.
- Creation of an initial obstacle and terrain dataset based on satellite imagery: The product will be compliant with the provided data Product Specification [4]. Obstacles are represented by points, lines, and polygons. They are organized in three (3) feature classes (Z enabled) as defined in EUROCAE ED-119B / RTCA DO-291B Interchange Standards for Terrain [11, 12], Obstacle, and Aerodrome mapping data [12]. The attribute list for each obstacle will comply with ICAO DOC 9881 [14]. All objects that penetrate the identified obstacle assessment surfaces and whose height above ground level exceeds a defined minimum will be captured. The Obstacle capture is accurately done in 3D which should be used as a main source of the imagery stereo pair. The selection of Obstacles that must be captured will be assessed by a specifically developing a tool which implemented in real time for the operator of the Obstacle Collection Surfaces.

Within the limited Area 2a & 2b, all objects higher than 3m above the ground and intersecting the Obstacle Collection Surface (or located above) will be captured as Obstacles. Only relevant features (natural or man-made) for eTOD are captured. Regarding the completeness of obstacle collection, DS experience has demonstrated that some very thin obstacles are not detectable on satellite imagery. These obstacles are mainly located in Area 2a and the beginning of Area 2b (3m minimum height) or in Area 2c (15m minimum height) close to the limits of Area 2a. The typologies of the non-visible obstacles are small lamp posts, small antennas, some masts, and other very thin obstacles. Among those are also the small objects located on top of buildings (like thin antennas) which cannot be detected using satellite imagery.

For this particular case, since the eTOD area is limited to areas 2 and 3, the authors recommend the use of high-resolution satellite stereo imagery. This will allow for cost-effective and time-reduction processes while the quality of terrain products will remain guaranteed and compliant with ICAO requirements.

***(b) Step 2: Ground Control point collection: Customer to ensure cooperation with the Airport's authorities for security access inside and outside the airport.***

- *Ground land survey mission to collect GCP: Based on the first dataset provided ground survey measurement will be performed to obtain tie, and check Points (CP) on each airport and to validate the dataset. GCP will be collected with a regular distribution inside the overall area and taking into account, the number of GCPs should not be less than:*
  - *25 points for horizontal accuracy validation in area 2c with a vertical accuracy better than 20cm.*
  - *20 points for horizontal accuracy validation in areas 2a & 2b with a vertical accuracy better than 20cm.*
  - *30 points for vertical accuracy validation in area 2c with a vertical accuracy better than 20cm.*
  - *25 points for vertical accuracy validation in areas 2a & 2b with a vertical accuracy better than 20cm.*

**(c) Step 3: Obstacles Dataset completion:to ensure cooperation with the Airport's authorities for security access inside and outside the airport.**

- *Ground survey team to perform a land survey mission to complete the dataset with thin obstacles.*
- *Ground survey team to perform a land survey mission to collect missing metadata attributes.*

***(d)*** **Step 4: Obstacles Dataset packaging**

- Data processing to compile all information: Based on the previous steps, Data processing operators will compile all the information into a final eTOD dataset package for each airport. Satellite and ground survey results will be merged into a single and final package with all the necessary attributes and metadata. The dataset will comply with ICAO Annex 15, ICAO Doc 9881, and ICAO DOC 9674 (WGS84)
- Data processing to prepare documentation: Out of the dataset, data processing operators will prepare the associated documentation to support the evidence requested by data Product Specification in terms of quality check, mission reporting, and working methodology description.
- Data Processing to compare the collected data and to create the associated documentation: Out of the dataset, the processed data will be compared with the existing published obstacle in the AIP and assessed against the ICAO Annex 15 area [2]. A dedicated assessment report will be produced for this purpose.
- Data Processing operators to prepare AIXM 5.1 snapshot: Data Processing will provide the customer with AIXM 5.1 compliant digital file with all the data to be delivered.

## GENERATION OF DTM AND DSM:

The terrain data, DTMs shall be generated from the processed airborne or stereo-satellite data for areas 2a, 2b, 2c, and area 3 by extracting the DTM along the streets and open areas and regenerating the DTM for the area (as if all buildings have been removed). The vertical accuracy of RTK-GNSS is within a few cm, which will exceed the required tolerances [6, 10] for the three ICAO areas (2, 3). The table below shows the terrain data requirements. The control points that will be established for each airport, will be used for DTM control. RTK-GPS survey work will be conducted near the airport and at the built-up area along the center line of the road network. The figure below shows an example of UAV-produced data for DTM generation at the north Omdurman area using UAV. DTM has to meet the requirements of orthophoto production.

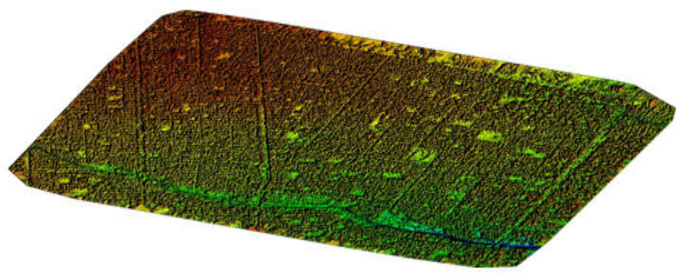

**Figure 20:** orthoimages and DTM for North Omdurman-Sudan using UAV processed data.

Two examples of geospatial databases are terrain and obstacle databases. Depending on the source of information, a terrain database may describe something between "bare earth" and "bare earth with cultural features and/or obstacles" (canopy, buildings, etc.). However, for this paper, terrain and obstacle are used according to the following definitions:

**Terrain:** The surface of the Earth contains naturally occurring features such as mountains, hills, ridges, valleys, bodies of water, permanent ice, and snow, excluding obstacles, Figure 21.

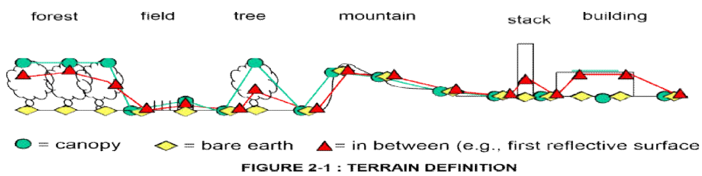


**Figure 21:** eTOD Terrain definition[6]

**Obstacle**: All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that are located on an area intended for the surface movement of aircraft or that extend above a defined surface intended to protect aircraft in flight (see Figure 22).

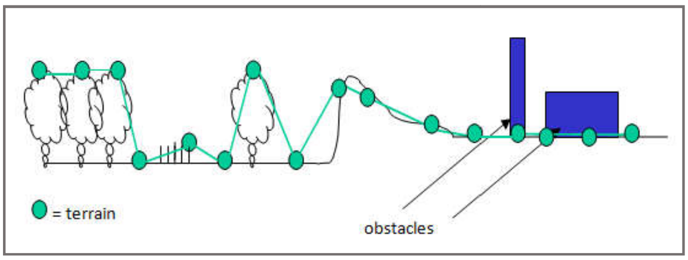


**Figure 22:** eTOD Obstacle definition[6]

## FIELD DATA VERIFICATION AND COMPLETION

DSM, DTM, and obstacles derived in eTOD areas shall be verified by independent terrestrial survey measurements, using RTK-GNSS, static scanners, mobile Lidar, or reflector-less total station. The coordinate's values obtained by airborne or satellite images will be compared with their corresponding values determined by terrestrial surveys [10, 11]. The result of the comparison should comply with the horizontal and vertical accuracy mentioned in [2]. Generated digital elevation models can also be verified by running terrestrial longitudinal profiles. Data for longitudinal profiles can be collected by using RTK-GNSS or mobile Lidar or by using a reflector less total station. Then a comparison will be carried out and statistical measures such as 90% confidence levels shall be applied. The results of the comparison should comply with the vertical accuracy mentioned in [2, 5].

Obstacles (antennas; buildings and towers) around the airports will be verified by ground survey methods, such as Reflector-less Total Station, and a close-range photogrammetric system to obtain the height information of each obstacle. This height will be transformed into an elevation value by adding the ground height from the DTM. The results obtained must follow the specifications stated in Annex 15.

## QUALITY CONTROL AND QUALITY ASSURANCE PLANS

Annex 15 [2] Quality Control and Quality Assurance procedures are to be adopted. The authors recommend the preparation of a Quality Plan (QP) specific to the eTOD requirements according to ICAOISO10005:2005 Quality Management Systems.

The Relative vertical accuracy as a measure of eTOD point-to-point vertical accuracy or vertical precision within a specific eTOD data set (FGDC, 1999) can also be made together with the Root Mean Square Error (RMSE). The Horizontal accuracy is computed as (FGDC 1998):

$$RMSE_x = \sqrt{\frac{\sum_1^n [xdata_i - xcheck_i]^2}{n}}$$

$$RMSE_y = \sqrt{\frac{\sum_1^n [ydata_i - ycheck_i]^2}{n}}$$

Where: $xdata_i$, $ydata_i$: are the coordinates of the $i_{th}$ check point in the dataset, $xcheck_i$, $ycheck_i$: are the coordinates of the $i_{th}$ check point in the independent source of higher accuracy, n: is the number of check points tested, i: is an integer ranging from 1 to n. The Vertical accuracy is computed as [8]:

$$RMSE_z = \sqrt{\frac{\sum_1^n [zdata_i - zcheck_i]^2}{n}}$$

Where: $zdata_i$: is the vertical coordinate of the $i_{th}$ check point in the dataset; $zcheck_i$: is the vertical coordinate of the $i_{th}$ checkpoint in the independent source of higher accuracy; n: is the number of points being checked; i: is an integer from 1 to n.

Guidance material relating to the validation of data is provided, such that the basic principle is that if less attribute information is available from the early stages, then more effort to demonstrate validity will be needed at the validation stage. Various types of errors that can affect the quality of a database [8] are to be described below:

- Traceability is the ability to track the history, application or location of an entity by means of recorded identifications [2]. More specifically, it is the degree to which a system or data product can provide a record of the changes made to that system or product and thereby enable an audit trail to be followed from the end user to the data originator.
- The data originator, integrator, and/or provider shall produce adequate information such that the traceability of a terrain or obstacle database can be maintained according to the above definition and in accordance with EUROCAE ED-76/RTCA DO-200A. Typically, this can be accomplished with the provision of an appropriate data record or attribute for each database element as described in Section 3.
- As given in EUROCAE ED-76/RTCA DO-200A [7], for the quality assurance of terrain and obstacle data. When originators, integrators, and system designers are unable to demonstrate

compliance with the requirements, the related data shall require testing by using validation, logical consistency, or other means to be agreed upon by the organization that approves the application. When multiple databases are employed for validation, the available meta-data shall be used to demonstrate the independence of each data set. Two sets of measurements provided by the same company, using the same data collection technology may induce a bias, either in the initial collection or in the post-processing techniques used for acquisition and sampling. Furthermore, differences between the data should be identified and compared to the requirements specified for the application.

- Errors in terrain and obstacle databases can be classified into three types: Random Errors, Blunders, and Systematic Errors. Concerning data acquisition for terrain and obstacle databases, statistical methods should be applied to assess the random errors. Digital filters, based on statistical principles should be used to locate and eliminate blunders.
- Deterministic procedures should be adopted to correct systematic errors, or the systematic errors should be taken into consideration in the derived statistics. Each data acquisition method introduces its own systematic effect or bias. To eliminate this effect or bias there are two recommended approaches: The use of an appropriate mathematical model that describes the systematic effect (e.g. Earth curvature, refraction, etc.) and the use of extended models to account for a combination of systematic effects of known sources and quasi-random effects. A typical example is the auto calibration used in photogrammetric aero-triangulation [12].
- Errors that affect the Confidence Level of a Database Point estimation is the estimation of the mean, variance, and covariance of a random variable from sample data. It is only possible to estimate a probability that the true value of the parameter in question is within a certain interval around its estimated value. This probability is referred to as the Confidence Level. The confidence level of a terrain and obstacle database is directly related to the lowest confidence level for any existing random variable in the database. Any type of error may affect the confidence level of the database, but systematic and blunder errors will have a larger impact. Therefore, to achieve high confidence levels, it is critical to locate and eliminate these systematic and blunder-type errors.
- Resolution: Errors may be introduced as a result of using multiple databases where differences exist in any of the following: spatial resolution, spectral resolution, radiometric resolution, and temporal resolution.
- An attribute of a database is its currency, which informs the user of the date of its latest update or the effective date of the data. This information should be available to the user. In the absence of continuously updating databases, changes that occur between updates will not be available as part of the database until the subsequent update.
- For some applications, aerodrome, terrain, and obstacle databases will be integrated. This integration of data is typically accomplished by layering the various information sources into an information hierarchy that supports the application and associated display processing. The data that contribute to these layers are subject to varying levels of change, which in turn suggests that the data will be updated at different times, or in cycles of differing lengths. This inconsistency may result in database errors that can be difficult to detect by the system or the end user.
- Semantic Errors are generally considered blunder errors. Examples include errors due to the misidentification of an object (e.g. a tower for a mast, a tree for a pole, a road for a railroad); errors due to misclassification of a theme (e.g. sand for clay); and errors due to incorrect attachment of attributes (e.g. length for width). These blunder errors will affect the consistency and the reliability of the terrain and obstacle database.
- System Integrity is determined using Functional Hazard Assessment (FHA). This process identifies hazards and associated failure modes for the system. The assessment identifies the mitigation required to retain the required system integrity. The system design should mitigate failure modes including those associated with database errors. Typical techniques used to mitigate system failure modes are: Architectural techniques such as system redundancy perhaps using dissimilar implementations. monitoring and built-in test equipment (BITE) functions allow the detection of system failures. The effect of monitoring or using BITE is to lower the probability of undetected failures or errors.

## TERRAIN AND OBSTACLE DATABASE

The use of terrain and obstacle databases in flight-related systems presents new equipment design certification considerations for manufacturers and certification authorities. The overall integrity of the database is dependent upon the safety assessment of the function.
Once the measurements have been collected, mathematical and spatial transformations may be required to generate an elevation model. Transformation shall be made to achieve a common reference system.

The purpose of the mathematical transformations may be one or more of the following:

- Transformation of measurement points to the appropriate post spacing: Spatial interpolation of the measurement points may not coincide with the desired reference position. Moving the horizontal location of measurements requires interpolation of the vertical elevation data.
- Transformation of the vertical and horizontal reference systems (datum). Data sets from multiple sources such as different countries or various measurement methods may use different reference systems. The production of complete set of terrain data over a given area may require the combination of several databases and the identification of any gaps that remain.
- Data sets that are to be merged shall be pre-processed to have common attributes. The data sets may contain invalid measurements that can be identified by inspections or mathematical tests. Some of these methods may allow for correcting the errors. The following are principles to note:
- For each of these transformations, the supplier shall justify and demonstrate the validity of any assumptions that have been made. In particular, the effect of each of the transformations on the errors in the measurements needs to be understood and documented to provide a clear audit trail. Without this complete understanding, the overall quality of the database can't be determined. Validation of the data should begin as early as possible in the database generation processes. This can be achieved by validating data after each transformation step.

## CONCLUSION

The paper outlined the Electronic Terrain Obstacle Data, which is required to develop terrain and obstacles data to support the ICAO Communications, Navigation, and Surveillance, air traffic management systems. The eTOD dataset and information will be used to assist the pilots in their decision-making process and to know the locations concerning terrain or obstacle hazards. eTOD as well can be used for Aeronautical Information Management, development, and ground-based applications.

The Sudan airports data acquisition methodology approach, aimed to cover Sudan airports in terms of Aeronautical, terrain, and obstacle surveys and data sets provision. The aeronautical data survey provides critical information about airport features, obstructions, and navigation aids, as well as man-made obstacles surrounding airports. Obstacle data should also cover all man-made obstacles such as buildings, towers, antennas, high-tension towers, pole light antennas, windmills, poles, walls, lighthouses, bridges, and cranes. Terrestrial Survey methodology is described together with the horizontal and vertical reference systems, establishment of Ground Control points (GCPs), Ties and checkpoints, and Quality control points. Aerial borne imaging is well described together with the stereo Satellite Image provision for the Generation of the Digital Surface Model, Generation of Digital Terrain Model; and Generation of ICAO Obstacle data. The obtained eTOD datasets will be checked, quality controlled, verified, and validated, followed by inserting their metadata and attributes. By combining the DSM and the eTOD-created surface at each airport area, the boundary of the obstacle features can be determined.

**ACKNOWLEDGMENTS**

The authors acknowledged the directions, follow-up, and information given by Engineer Al Amin Mohammed Banaga, the Director General of the Sudan Survey Authority, the technical staff of the Sudan Civil Aviation Authority, and the support given by Eng. Mohamed Nur of Karrari Engineering and the technical UAV staff of the HI Qu companies.

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