Drone-borne magnetic measurements in India

Magnetic surveys are carried out for several applications like mineral exploration, geological structure delineation, mapping of basement topography, etc. In recent times, heli-borne or airborne magnetic surveys are frequently conducted using a magnetometer aboard or towed behind an aircraft or a helicopter. In these surveys, a magnetic system on ground is required to record variations of magnetic field with time for diurnal correction to the airborne magnetic data. In heli-borne or airborne surveys, the cost increases exponentially with decrease in survey area and required logistics often becomes cumbersome and time-consuming. Drone – the unmanned aerial vehicle (UAV)-based magnetic exploration system can provide an effective, fast and economical alternative to overcome the limitations described above. UAVs are operationally more versatile and economical compared to other aerial methods, such as manned aircraft and helicopter. Conducting geophysical exploration studies in remote locations is an application where the use of small, lightweight UAVs is particularly beneficial. In fact, the reduced size, weight and power needs of these flying platforms, along with the reduced cost of the platforms and instrumentation, make them highly suitable for these operations. Development of sensitive miniature magnetic sensors using optical pumping method and related electronics makes it possible to conduct aerial magnetic geophysical explorations using UAVs. In the present experiment we used lightweight, sensitive magnetometer towed behind an indigenously developed UAV for the acquisition of high-resolution magnetic data.

Table 1. Technical details of UAV system

Geometry of the UAV	
Configuration	Hex Copter
Dimensions	Propeller tip to tip 2 m diameter
Height	500 mm
Propellers	Two-blade 24 in propeller
Battery	LiPo 6 cell 16,000 Mah
Performance details	
Weight	15 kg (max)
Payload	~4 kg (magnetometer)
Endurance	20–25 min
Range	5 km

In this study, a UAV GEM Airbird magnetometer system was used, which consists of lightweight potassium magnetic sensor with a sensitivity ~0.001 nT/Hz, GPS, laser altimeter, EMU sensor and data acquisition and control unit. In addition, real-time data transfer through a radio link was set up to receive data from the UAV magnetometer for dynamic data-logging and tracking. A ground magnetometer was used as the base station for diurnal corrections, which had time synchronization with GPS.

Unmanned aircraft encompasses a wide range of platforms depending on their physical size and power, and differ in terms of their capability and simplicity of operation. These factors impact the payload carrying capacity, speed, altitude and range of flight, which determines different applications that can be performed by different types of UAVs. Notable among

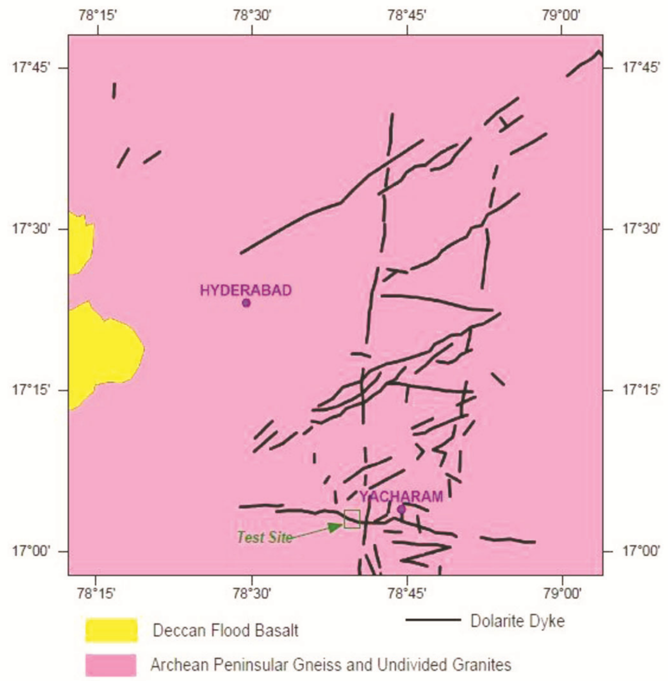

Figure 1. Geology of the area around the test site near Hyderabad, India.

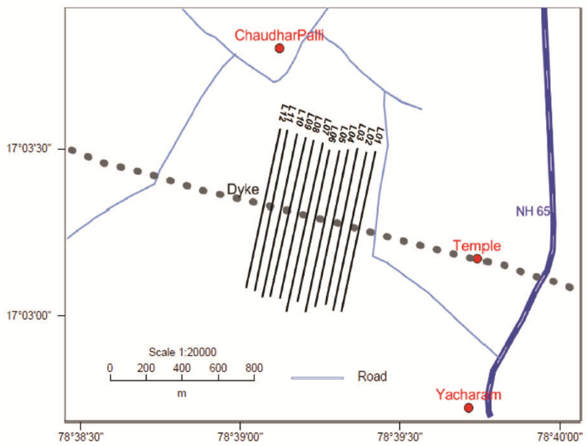

Figure 2. Study area showing magnetic profile (solid black lines) orthogonal to the dyke (black dotted line).

them are fixed-wing UAVs, multi-copter UAVs and unmanned helicopters. The present study used an indigenously developed Hex Copter. The Hex Copter configuration was chosen for this application based on a literature survey performed on the existing designs of similar class. The following design points were considered while designing the frame:

- X-Configuration Hex Copter, for its higher stability during the flight.
- Minimum safety factor of 1.2 for the structure at maximum thrust loads from the motors, keeping the structural weight within limits.
- A minimum gap of 0.2*D* between the rotor tips, where *D* is the diameter of the propeller[1].
- Payload weight of 5 kg.

With inherently unstable design, all the multi-rotor vehicles require to be stabilized artificially by a flight control system. For this vehicle, an open-source software and firmware (Pixhawk Autopilot) was used for both stabilization and autonomous flight. The autopilot is integrated with telemetry module for long-range data communication with the ground control station. For autonomous waypoint navigation, the autopilot is also integrated with a commercially available GPS receiver unit.

The desired mission of this UAV was to carry an under-slung payload of 4–5 kg (Table 1). The stability and tracking performance of the system are affected by the dynamics of the slung load. Some flight manoeuvres or conditions (e.g. changing direction of flight path, sudden gust, etc.) result in large load oscillations and can cause instability. Therefore, the autopilot gains were initially tuned to specific application needs by simulation using MATLAB Simulink. In the next stage, pseudo flights or constraint flights with and without under-slung load were conducted for tuning of the autopilot gains. This ensured vehicle stability during the course of the mission.

The rotors and other components of the UAV may cause interference in the magnetic sensor. Hence, the magnetic sensor was kept at a suitable level below the UAV during data acquisition to avoid magnetic interference. The magnetic interference test (MIT) was conducted initially to estimate the minimum separation distance required between the magnetometer and UAV, so that there is no

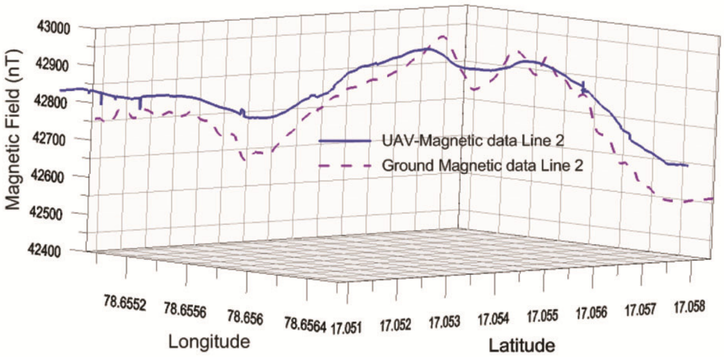

Figure 3. Ground and UAV magnetic data along Line 02.

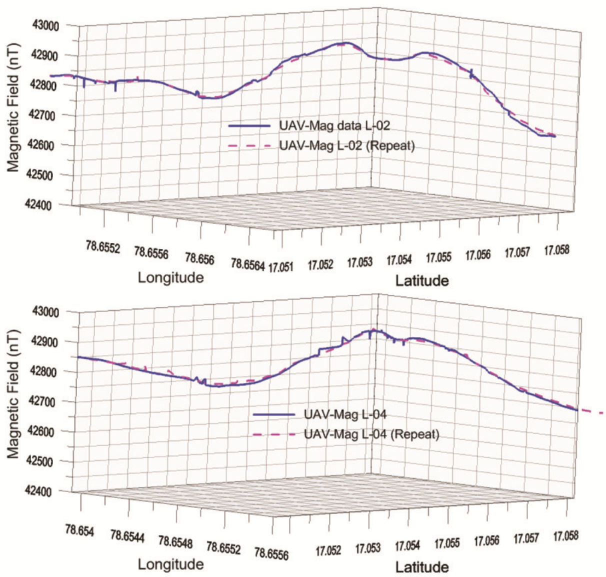

Figure 4. Repeatability of UAV magnetic data along lines 02 and 04.

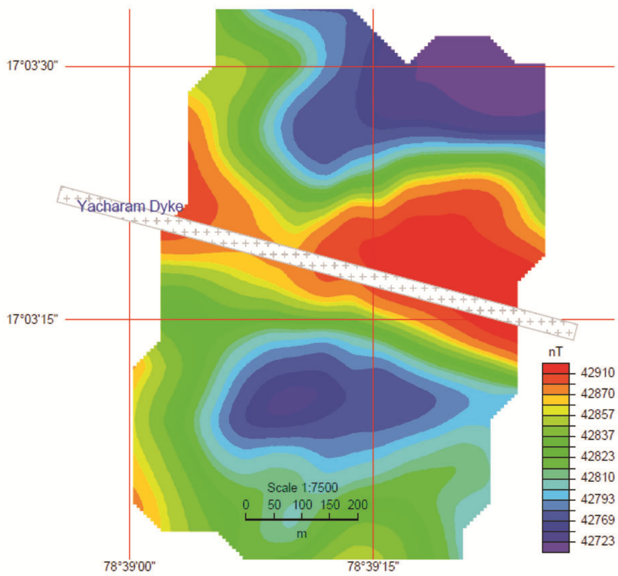

Figure 5. Magnetic contour map of the study area.

interference. MIT was conducted by keeping the magnetic sensor on ground and then the UAV was flown at different heights from the sensor while recording magnetic data. A change of ~2 nT in magnetic data was observed when the UAV was flown at ~4 m and negligible change was found at more height than 4 m. No change in magnetic data is observed when the UAV was at a height of >6 m. Based on this experiment, a separation of 5 m between the UAV and magnetic sensor was found suitable, which has been further validated during flight.

An east–west trending dyke having a variable width of 50–100 m and strike length of several kilometres near Yacharam was chosen to test the UAV magnetometer along with ground magnetic survey. The dyke can be traced on either side of the Hyderabad–Nagarjuna Sagar road (on NH-65), 51 km from Hyderabad and 200 m north of Yacharam town. It is well exposed in the form of a geomorphic ridge at the test site and at places is covered by thin (<1 m) soil cover. The mafic dolerite dyke is a Proterozoic dyke intruding Neoarchean granite gneiss in a part of the Eastern Dharwar craton (Figure 1). In general, the area consists of several dykes of different orientations, size and ages. However, the Yacharam dyke is distinctly seen both in satellite images and on the ground, and therefore was chosen as the test area for the present study.

An area of 1 km × 0.6 km was selected as the test location with a N–S profile length of 900 m and line spacing of 50 m (Figure 2). Data were acquired at 5 samples/sec along 12 profile lines (L01 to L12), while the UAV was flown at a speed of 5 m/sec 35 m above the ground surface. Considering average topographic variations of about a metre over the study region, the height of the UAV was maintained at 35 m above the average height of the study area.

However, the UAV has an option of changing flight height during voyage and this can be planned at the starting time of flight. A ground magnetic survey was conducted along Line 02 prior to the drone magnetometer experiment for comparison of results. In addition, two lines, L02 and L04, were flown twice to test repeatability of data received from the UAV magnetometer. The standard deviation (SD) of repeat data along L02 and L04 was computed for 954 locations. The average SD for L02 was 3.09 nT and for L04 it was 2.39 nT. This would further improve with diurnal correction.

Figure 3 shows the data obtained from ground and UAV magnetic surveys along line L02. A good correlation with minor mismatch can be seen. This mismatch could be attributed to the GPS position accuracy in both surveys. The measurement repeatability test was conducted along two lines (L02 and L04) and the comparison indicates good correlation (Figure 4).

The data acquired by the UAV magnetometer experiment were processed through WinGLink software (Figure 5). It was observed that the intensity of contours trend in the E–W direction coinciding with the strike of the dolerite dyke. The contour pattern clearly reveals the dyke and adjacent granitic terrain. The contours are dense with high magnetic gradient over the dyke, while they are diffuse away from the dyke. The dyke is well reflected in the central part of the contour map derived from the UAV magnetic data of the study area (Figure 5). The results clearly distinguish the mafic dolerite dyke and granitic terrain in the test area. The present study has successfully demonstrated the capability of UAV-Magnetic survey, which is cost effective, faster and reliable.

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Unique polyphase deformational structures of Lunawada metasedimentary rocks identified from remote sensing imagery

The Mesoproterozoic metasedimentary rocks of the Lunawada Group in the Aravallis, northern Gujarat, India, exhibit unique and spectacular outcrops of deformation structures in mesoscale[1]. Here we present an analysis of imagery from Sentinel-2 earth observation satellite (courtesy: European Space Agency) to identify an array of unique deformational 'meso' structures from brittle–ductile regime[2,3], which indicates polyphase deformation over an area of approximately 70 km^2. The array of deformation structures in mesoscale also makes it a pertinent candidate 'geosite' for researchers of structural geology, graduate and postgraduate students and geology enthusiasts.

The Lunawada Group is mostly constituted of quartzite and metapellites[4–6]. The microstructural evidences of deformation in these rocks have been studied in details[7–9]. Quartzites occur as high ridges, whereas brown schist forms