Preliminary tests on the UAV-enabled installation of wireless sensors for monitoring inaccessible slopes

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ABSTRACT

Although remote sensing techniques (TLS, DPS) are useful for monitoring wide areas with diffuse hazard, the deployment of sensors in contact with the ground (slopes, cliffs, rock blocks) is mandatory when a focused mechanism is underway. So far, most of the so-called ‘geotechnical sensors’ (tiltmeters, jointmeters, stress sensors), and some surveying systems or accessories (like prisms, targets, GNSS receivers), must be installed manually on the landslide body. Furthermore, in some cases cables for the power supply and data collection are needed. Besides the technical difficulties, in some scenarios this installation phase may imply a high risk for the operators. To overcome this issue, in the contribution we present some test carried out with wireless sensors installed by means of Uncrewed Aerial Vehicle (UAV). Concretely, we deployed several wireless precision tiltmeters, able to acquire several measures per minute, and with LOng-RAnge communication capability. The experiments were developed in the frame of a risk mitigation project leaded by the ICGC in the Montserrat massif (near Barcelona, Spain), an area of paramount geomechanical and societal interest. There, the targeted instability mechanisms are medium and large rockfalls. The preliminary tests show that the installation of sensors with UAV can be of great help in the aforementioned situations. The UAV-enabled deployment method should be considered to speed up the availability of real time monitoring data.

Keywords: monitoring, wireless-sensors, tiltmeter, Montserrat massif, LEWS

1. Introduction

Rockfalls are the most frequent instability in mountainous regions. The Montserrat massif, near Barcelona (Spain) is a risk area as a high hazard comes together with a large influx of visitors. Managing this risk is very difficult, especially in the Monastery area (Vilaplana et al. 2016; Janeras 2023). The steep rock columns (“agulles”, figure 1), the almost vertical fronts that are difficult to access and the blocks in limit equilibrium (Carballo 2024), are a singularity of this massif. Monitoring the different points that present risk has been very complicated in the past (Janeras et al. 2017; Janeras 2023) as can be seen in figure 2.

Remote sensing techniques like Terrestrial Laser Scanning (TLS) or Digital Photogrammetry (DPS) are useful for remote monitoring of wide areas with diffuse hazard (Janeras et al. 2017; Lantada et al. 2022). The ICGC (Institut Cartogràfic i Geològic de Catalunya), in collaboration with the public authority responsible of the Montserrat Natural Park (Patronat de la Muntanya de

Figure 1. North side of the Montserrat mountain, near Barcelona (Spain). The massif is formed by conglomerates, with intercalations of sandy mudstones, which constitute weak strata at the base of the cliffs. The right half of the photograph corresponds to the area known as “Agulles”, where the test installations for this article have been carried out. Access to many fronts is only possible by climbing.

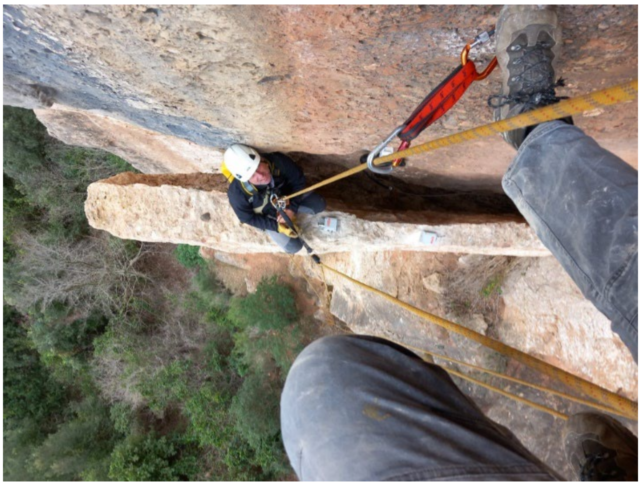

Figure 2. Installation of several sensors to monitor an unstable block, "Oliver" slab (Carballo 2024).

Montserrat, PMM) is using the aforementioned remote techniques for a global monitoring of most of the risky cliffs. However, the deployment of sensors in contact with the ground (cliffs, joints, rock blocks) is mandatory when a focused mechanism is underway (Janeras et al. 2017).

To overcome certain issues during the deployment of contact sensors, in the contribution we present some test carried out with wireless sensors installed by means of Uncrewed Aerial Vehicle (UAV). The use of drones is quite common in the engineering geology and geosciences field (Ruiz-Carulla et al. 2017; STA, 2020; Eltner et al. 2022). In the delivery field, we have also some interesting applications like BCN Dron Center (2023) or Greenwood et al (2021). Some experiences have been done in the field of sensor installation with drones. Zhang et al (2021) deployed several GNSS autonomous stations over a landsliding area in order to monitor the hazard remotely.

In the current communication, we present our technique, UAV-enabled, for deploying wireless precision tiltmeters. The experiments were developed in the frame of the aforementioned rockfall risk mitigation project (ICGC-PMM) in the Montserrat massif. In the next section, we explain the technique and the equipment. Next, we report the preliminary tests, both in the lab and in the field, along with some sample results and concluding remarks.

2. Method and instruments

Not all sensors and instruments can be installed with UAVs, both due to the maximum payload of the drone and due to the installation and remote operation of the equipment (consumption, acquisition and transmission of readings). Eligible equipment may be: wireless tiltmeters, wireless vibration meters, event detection sensors, thermometers, GNSS receivers and presence/ movement/smoke detectors. Some passive reflectors for surveying could be also be considered: prisms or targets for total station sightings, or small corner reflectors for GBSAR measurements.

Due to the rockfall mechanism that we targeted in Montserrat, involving the toppling of large blocks or columns of conglomerate, we focused on the wireless tilmeters from Worldsensing (Lluch et al. 2022; Pérez et al. 2022; WS 2023). In Montserrat we have been working with several models, some with an installation range of ±15º with the horizontal, others with a range of ±90º. The precision of an averaged value is around 0.003º or better. They are able to acquire up to 6 measures per minute, and transmit it with LOng-RAnge communication capability (data transmission within a network of nodes and gateways). For the present tests, we decided to use the Tiltmeter TIL90-i (Figure 3). This model has an internal antenna. The body is Aluminium alloy, whereas the lid is polycarbonate because the wireless transmission. This reduces the total weight, an important factor in our case. The use of an internal antenna is convenient for operational reasons, also to avoid external elements prone to be damaged by wild live.

Figure 3. Worldsensing Tiltmeter TIL90-i (weight 440g). The overall box dimensions are 10cm x 10cm x 6cm. With the 3.6Volt battery (right, weight 51g) the sensor can operate several years for a reporting period of 5 minutes and average weather conditions.

As far as the UAV is concerned, we must consider:

- Payload
- Mechanism to hang and detach the sensor
- Flying with and without the sensor: approach, drop, and flight back to 'home'.

For the first tests, we used the drones available at the ICGC: DJI Mavic 3E and DJI Inspire-II. The first one, for the inspection of the drop area, the second one, with a payload of 0.57 kg, for the actual drop of the sensor. There are experiences in overloading UAVs (Hatu 2018), but we are significantly within the payload limit.

Although there are release and drop systems on the market, operated remotely, in our case we chose to do the first tests with a passive system for engaging and releasing the sensor. Our design is a wooden "Y", which hangs from a ring and a line from the drone (figure 4). Since the piece and the line remain with the sensor, it is to some extent interesting that they are biodegradable.

Finally, it remains to describe the sensor-ground fixing system. This is the most critical point in our application to rockfall due the faint precursory signs to be detected. Laboratory tests have been carried out with 8 different adhesives: cement-glue type, quick-assembly, epoxy, chemical-plug and silicone derivatives (some can

Figure 4. Drone-sensor attach/detach system: left, detail of the "Y" piece; center, sensor hanging from the drone; right, sensor, line and "Y" piece ready for attach.

be seen in figure 7). Good initial adhesion, a long workability period (about 1 hour, without dripping), and a certain rigidity after the drying/setting period were sought. The final solution adopted combines two adhesives on the base (Figure 5): silicone-derived adhesive or mounting adhesive on the central square; a narrow but double-height cord of cement-glue on the perimeter. The center gives a certain initial adhesion, while the cement-glue provides good perimeter contact, with little deformability when it has dried.

Figure 5. Adhesive layout on the lower base of the sensor.

3. Field test and first results

After the laboratory work, tests were carried out in the field, under real conditions. The study area is the "Agulles" area of the Montserrat massif (figure 1). The blocks to eventually be monitored are very numerous, but to carry out the first tests a few locations have been selected on the north face (figure 6), where the wireless tiltmeters will be able to communicate with a previously operational gateway.

The procedure to install a tiltmeter is as follows:

- sensor initialization (power supply, setup, gateway connection test).
- configuration of the drone for flying with the sensor hanging beneath, and for approaching the ground.
- drone flight for reconnaissance of the installation point. Visual selection of the specific point. The drone approaches the ground to confirm the feasibility of the operation. The propulsion of the rotors allows cleaning the point a little and remove any leaves, twigs or loose sand. Return of the drone to the base.
- the sensor, with the adhesive already spread on its base, is hung from the drone at the beginning of a second flight.
- flight to the point, approach until the sensor contacts the ground, maneuver to detach from the drone, flight of the drone over the sensor to see how it is (dip angles with horizontal and/or orientation of the axes). Return to base.

In January 2024, controlled tests were carried out on three breakwater blocks arranged in a favorable area (blue symbol, figure 6).

Figure 7 shows the work area for configuring the sensor and preparing the adhesive, whereas figure 8 shows a detail of the initial configuration of a sensor.

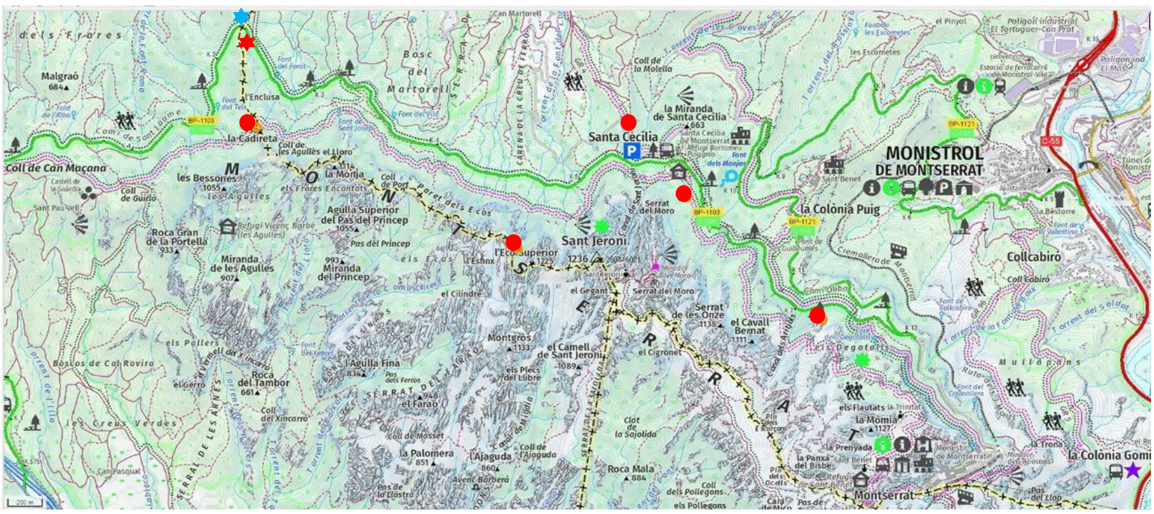

Figure 6. North face of the Montserrat massif, the red circles indicate the location of the candidate blocks to carry out the first tests. The ones described in this communication were carried out on the OVNIs curve (blue asterisk), and in the "Panxo-A" block (red asterisk) in January and February 2024, respectively.

Figure 7. Configuring the sensor and preparing the adhesive.

Figure 8. Initialization of an INC15 tiltmeter using an App from the mobile phone.

Figure 9 shows the drone approaching the test blocks, and figure 10 shows some of the first landings, with various inclination angles.

Figure 9. Controlled tests on breakwater blocks, January 2024. View of the drone approaching the blocks.

Figure 10. January 2024, first landings with dummy boxes and adhesive. The boxes were left with inclination angles of 5º, 11º and 35º, respectively.

After the success of the first tests, in February 2024 advanced tests were carried out on a real block ('Panxo-A', figure 6 and figure 11). This 'agulla' presents a very common situation in the massif: a large block of conglomerate with the support area reduced by differential erosion of the underlying claystone (mechanism one, Mec1, according to Janeras 2023).

Figure 11. Advanced tests in a block representative of the dynamics of rockfalls in the study area, February 2024. The "Panxo-A" block is the one on the left, hanging vertically over the BP-1103 highway. The TIL90 tiltmeter has been installed at its summit.

In this case, the TIL90 tiltmeter from Worlsensing, shown in figure 12, was installed at the top of the block Panxo-A.

Figure 12. Close-up view of the TIL90 sensor that was installed in the 'Panxo-A' block. Left: sensor hanging from the drone, with identification label (red) and with a system to prevent birds from landing on the equipment (white spikes). Right: sensor once placed on top of the block. Bottom: detail on how, during the drop of the sensor, the perimeter cord of cement-glue (figure 5) has adapted to the irregularity of the underlying rock.

Once installed, clinometers provide very useful information to monitor the behavior of the block or element on which it is installed. As an example, Figure 13 shows the evolution of the readings from a wireless inclinometer in the study area. The influence of daily changes in temperature can be seen (upper graph) and also a seasonal change or trend (lower graph), partially recoverable when completing the annual cycle (Carballo, 2024).

4. Concluding remarks

In this communication, the first tests carried out on the installation of tiltmeters using UAVs have been presented. A viable and relatively simple methodology has been developed to place these small self-contained nodes (sensor & logger) in places that are difficult to access. We have described the sensor-drone attachment and release system, the adhesive used for sensor-ground fixation, and the general operation.

The tests carried out make it clear that due to the irregularity of the rock on the decimeter scale, the initial inclination angles of the sensor can be quite high (35º in our tests), which indicates the convenience of using sensors that have wide working ranges. In the study area, in previous years tiltmeters with a ±15º range (INC15) were manually placed (figure 2), but for remote installation with a drone it is necessary to use the model with a ±90º range (TIL90, figure 3).

Low-consumption and long-range features of the kind of sensors used in this work allow us to achieve a highly versatile wireless network, capable of adapting to the topographical conditions of the most demanding cases.

The research shows that the installation of sensors with UAV can be of great help in situations in which there is some difficulty in working with conventional methods. For instance, when the access is very complicated, the case in Montserrat. Another reason for considering the UAV-enabled installation may be a high risk for operators due to some hazardous process ongoing: quick landslide; frequent rockfalls, unstable buildings after an earthquake, or a partial collapsed structure… This deployment method should be considered to speed up the availability of real time monitoring as an eventual base for an EWS (early warning systems).

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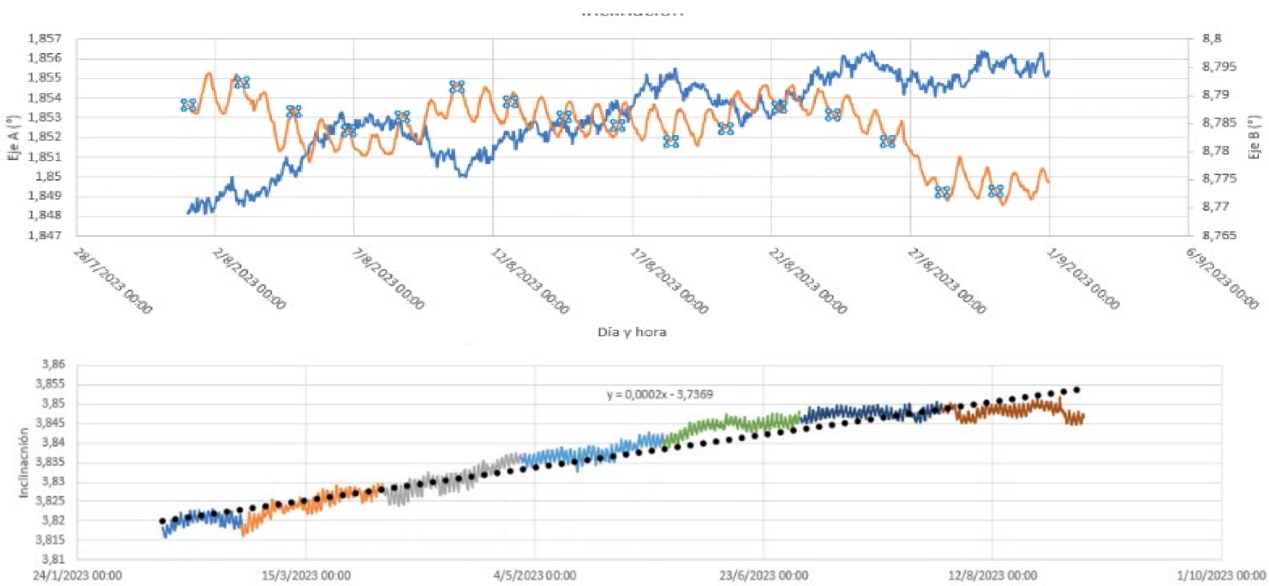

Figure 13. Example of tiltmeter readings in the study area, in the 'Oliver' block (Carballo, 2024). Above: readings on the A axis (blue) and on the B axis (orange) throughout the month of August 2023. Below: readings on the B axis throughout the months of February to August 2023.

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