Investigation of the Use of an Unmanned Aerial Vehicle to Deploy and Retrieve Ground-Based Landslide Monitoring Sensors

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Investigation of the Use of an Unmanned Aerial Vehicle to Deploy and Retrieve Ground-Based Landslide Monitoring Sensors

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1. Abstract

The monitoring of landslides and other geological hazards poses a physical challenge for researchers when the hazards are located in physically remote areas. Unmanned aerial devices (UAVs) equipped with camera-type sensors have been successfully used for environmental monitoring for the past decade, providing accurate surface data in a timely and cost-effective manner. While satellite imaging and aerial photography are an essential part of landslide management, some of the sensors employed by researchers are ground-based instruments. This project investigates the feasibility of using a modified unmanned aerial device equipped with an innovative grabber device to deploy and retrieve ground-based landslide monitoring equipment. The idea for this project emerged after a devastating landslide site in Mount Mansfield State Forest, VT, in the spring of 2019 that washed away access trails. Testing of the grabber device is still underway.

2. Introduction

2.1 Landslides

Geological hazards such as landslides can have a devastating impact on people's lives and on the surrounding environment and infrastructure, and they necessitate regular monitoring and observation to assess their risk of occurring (*Landslide Basics)*. The landslide risk assessment and management of an area includes collecting data using devices, such as the one depicted in Figure 1, that measure tilt, soil moisture, and movement to assess if a landslide site will slide again (Ruzza, 2021).

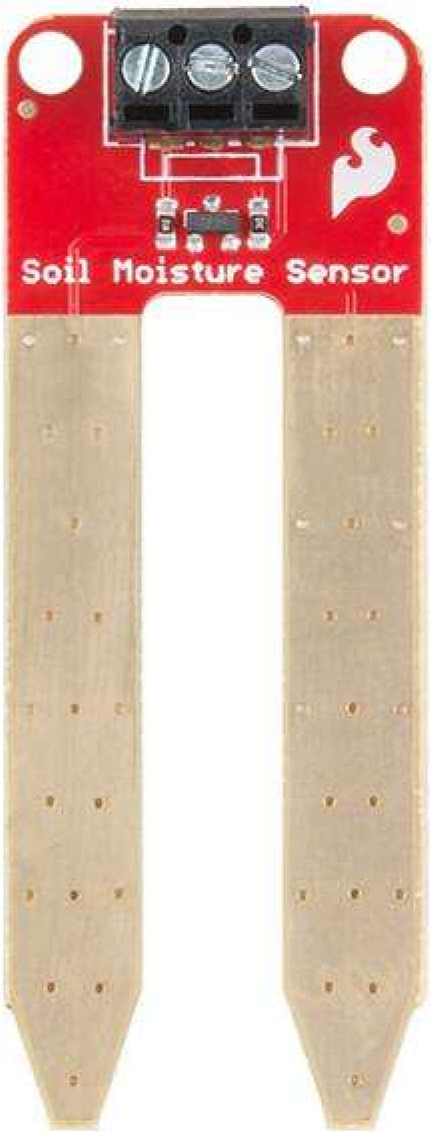


Figure 1. Soil moisture sensor (photo from SparkFun Electronics)

In the most general sense, landslide risk can be quantified by comparing the slope shear stress with the shear strength of the soil. Thus, the greater the shear stress and the weaker the shear strength, the greater the likelihood of a landslide occurring (McColl, 2022). Landslide risk factors can therefore be grouped into two general categories: external factors, which increase the shear stress on the slope, and internal factors which decrease the shear strength of the sediment.

Most landslides occur due to a combination of processes resulting in an unstable slope, followed by one or more acute events which trigger movement of the landslide (McColl, 2022).

Understanding the processes which drive up landslide risk is the first key step towards accurately predicting, and in some cases preventing, the occurrence of landslides. Within the broad categories of landslide causal processes are further subcategories, each with a different procedure for detection and measuring. For instance, ground conditions—the material properties of the slope material at a site of interest—can be surveyed by taking surface and subsurface samples of the sediment being monitored (McColl, 2022).

Another subcategory of landslide causal processes are geomorphological processes which include any processes by which topographical features evolve over time. Most topographical changes are the result of erosion or deposition. This can be wind erosion, above ground water erosion, subsurface water erosion, or glacial erosion. In some rare cases, the topographical evolution can be driven by volcanic processes. Geomorphological processes can be monitored through aerial photography or satellite imagery (McColl, 2022).

The last subcategory includes physical processes such as rainfall and earthquakes that can both increase the risk of landslides and trigger movement of the sediment itself. These processes can be monitored by on-site equipment. Rain gauges and seismographs are simple and relatively portable pieces of technology which can be deployed on-site at areas suspected of being at risk of landslides (McColl, 2022).

Landslide prevention must therefore consist of a reduction in these driving processes by strengthening mitigation measures applied to the site. One example of preventative measures taken to reduce landslide risk is internal slope reinforcement through methods such as soil nailing or planting of vegetation. In addition, the slope geometry can sometimes be modified to decrease the risk of sliding, by removing material to reduce the weight driving the landslide or by creating a shallower slope. Finally, another example of landslide mitigation measures is improvement of drainage at the site, accomplished through the use of surface drains to divert the flow of water from the slope or with drainage tunnels (McColl, 2022).

2.2 NASA SLIP-DRIP Program

In order to improve landslide risk management, it could also be useful to incorporate NASA's Sudden Landslide Identification Product (SLIP)/ Detecting Real-time Increased Precipitation (DRIP) program in addition to the techniques previously discussed. Originally developed to monitor and identify landslide risk in Nepal, the SLIP/DRIP program makes use of a global inventory of landslides recorded using satellite imagery and daily precipitation data. It is capable of automatically identifying high risk areas (Ngandam Mfondoum et al., 2021).

The software is constantly combing through satellite images and analyzing consecutive images of the same area to identify changes in soil moisture, muddiness and other visually identifiable surface features. It also works in conjunction with topographic models to pinpoint the locations of potential landslides. Moreover, the software can determine when a particular landslide occurred using a database of precipitation measurements known as the Global Precipitation Measurement mission. The satellite data allows researchers to create a map of precipitation accumulation over 24-, 48-, and 72-hour periods. When a certain amount of rain has accumulated in a high-risk region, an automatic alert can be created (Ngandam Mfondoum et al., 2021).

This software is relevant because it is open source and could be adapted and incorporated into a larger system for assessing and mitigating landslide risk (Ngandam Mfondoum et al., 2021). Gaps in the software's data, which result from limitations in the algorithm, could be refined using the drone techniques discussed in this paper.

2.3 Unmanned Aerial Vehicles

Unmanned aerial vehicles, commonly referred to as drones, are a recent addition in the realm of landslide detection and mitigation, and have the potential to complement the other assessment and prevention techniques previously mentioned. Thanks in part to the technological advancements in battery life and global position system (GPS), UAVs have been successfully used for environmental monitoring for the past decade (Quevenco, 2013*)*. Their application in landslide management has proven to be advantageous to the point of becoming an essential tool, capable of providing accurate surface data in a timely and cost-effective manner (Sun et al., 2024). Utilizing UAVs to assess landslides remotely has several advantages. A drone allows researchers to gather data without needing to trek into potentially hazardous terrain. Additionally, the UAV could increase the speed at which equipment is deployed and retrieved. This would allow researchers to place more sensors in a shorter time, potentially increasing the accuracy of their measurements.

2.3.1 UAV Applications

The easiest and simplest application of a drone when studying a landslide site is aerial photography. A digital camera attached to a drone allows researchers to visually assess the state of a potential landslide site. Aerial photographs of a site can convey valuable information such as the presence and density of vegetation on the site, providing insight regarding surface erosion. They can also record and highlight topographical changes over a time period which could help assess landslide risk. For instance, in a 2019 study, researchers used a quadcopter-style UAV when investigating volcano-tectonics. The study was performed on an active rift in Northern

Iceland. The primary means of data collection in this study was aerial photography (Bonali et al., 2019).

Additionally, a 2013 study utilized UAVs to assess the damage to man-made structures following an earthquake in L'Aquila, Italy. At the time, all buildings needed to be monitored for worsening structural stability until all reconstructions were completed. Because of the great number of buildings affected, it was not feasible to monitor them using traditional techniques. Researchers experimented with various UAV-mounted scanners to cover the wide area more efficiently (Baiocchi et al., 2013).

Another drone application in landslide management involves Light Detection and Ranging (LiDAR), a remote sensing method that uses light pulses which measure ranges. A drone equipped with LiDAR is capable of producing precise 3D topographical information. Moreover, this topographical information can be collected regularly, and without researchers trekking into potentially hazardous environments (Sun et al., 2024).

The final drone application discussed in this paper, and the main focus of this project, is performing a “pick and place” operation using a UAV. The term “pick and place” describes attaching some kind of grabber device to a UAV, picking up a piece of equipment, and accurately deploying it in the appropriate location. It is arguably more challenging than the previous two applications. The issues that arise with such an operation include the design of the grabber device, the weight distribution of the cargo, avoiding collision with the ground when flying at very low altitudes.

2.4 Mount Mansfield State Forest Case

The landslide which inspired this project occurred in late May of 2019 in the Mount Mansfield State Forest, Vermont. The landslide deposited massive amounts of sediment into

Cotton Brook, a brook which runs into the western shore of the Waterbury Reservoir, as well as removing a large section of vegetation, as seen in Figure 2. The landslide occurred about four miles northwest of Waterbury, Vermont. Using aerial images, the landslide dimensions have been estimated at 380 meters in length, and 230 meters across. The initial triggering event of the landslide is still unknown (*Cotton Brook Landslide*).

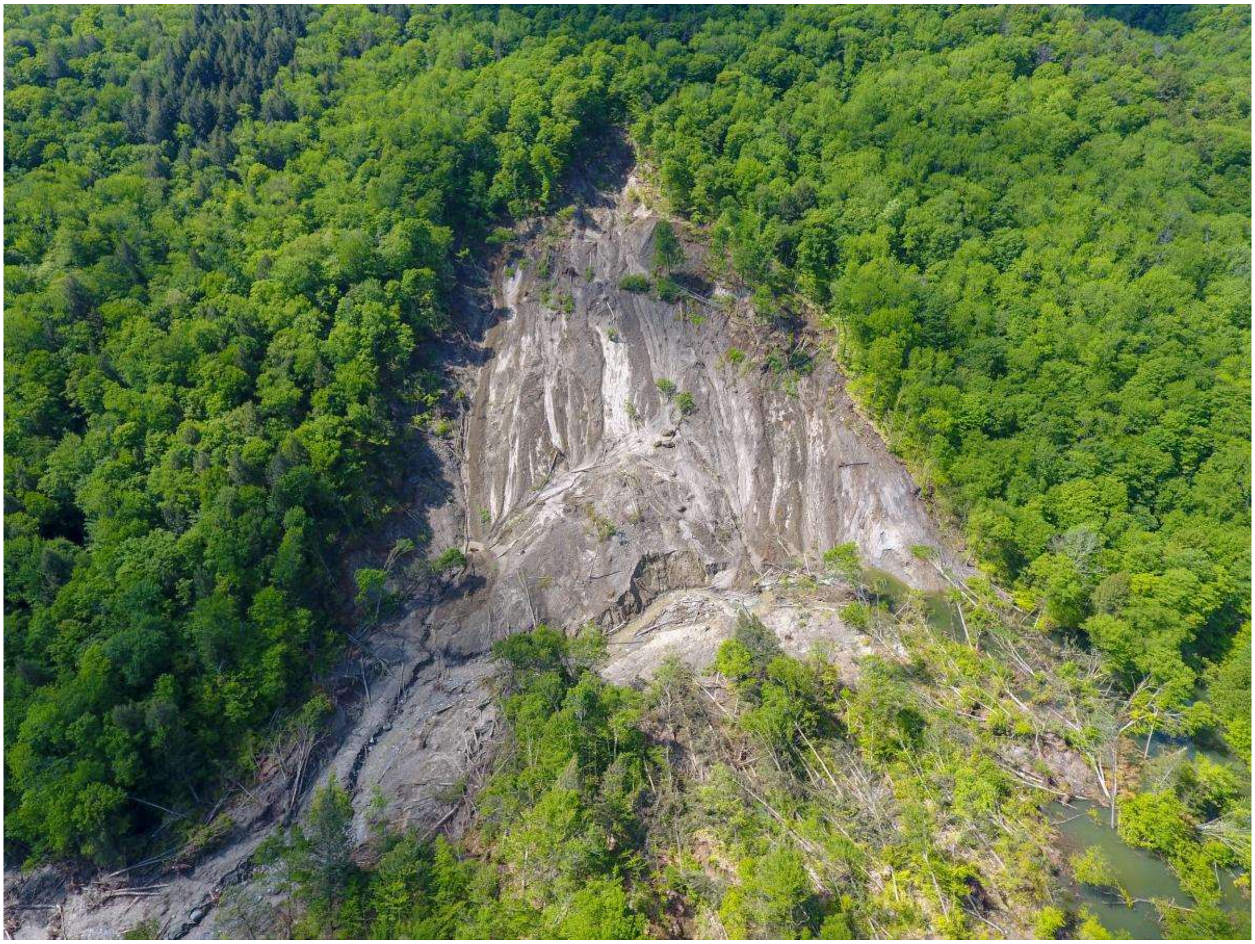


Figure 2. Cotton Brook landslide (photo from VTRANS UAS Program)

This landslide slope is approximately 28 degrees, and the material is primarily lake bottom silt and sand deposited by Glacial Lake Winooski roughly 14,000 years ago (*Cotton*

Brook Landslide). For a time, the landslide toe stretched across Cotton Brook and obstructed flow, but as of 2020, no flow obstruction has been observed. The trails which allowed access to the site were destroyed in the 2019 landslide, making deploying the monitoring equipment dangerous and potentially hazardous, as the site is still considered active (*Cotton Brook Landslide*). Consequently, the use of UAVs to monitor and assess the site began to be investigated.

2.5 Research Objectives

This paper investigates the applications of UAVs in landslide management with a focus on using a drone to deploy and retrieve ground-based sensing equipment.

In order to fulfill this objective, this thesis has the following goals:

1. Design and assemble a UAV capable of performing pick and place operations.
2. Design, fabricate, assemble, and attach a grabber attachment for the UAV.
3. Identify and evaluate possible sensors that can be deployed and retrieved with this modified drone.

3. Models and Methodology

3.1 Building the Drone

Any project that involves picking up and placing objects using an unmanned aerial vehicle comes with a host of challenges. These challenges include securing the cargo in such a way that it does not fall off the drone mid-flight, yet can be precisely deployed when the user requires. The craft must also be piloted close to the ground over uneven terrain without crashing.

Finally, the weight and weight distribution of the cargo must be carefully managed to allow the UAV to safely carry it while preserving battery life.

The UAV used for this project was specifically constructed with the pick and place task in mind. The first task in assembling the drone was putting together the carbon fiber Tarot Iron Man 650 frame (Figure 3). The frame consists of landing gear, two plates on which the internals of the drone are mounted, and four arms which hold the motors, as seen in Figure 4.

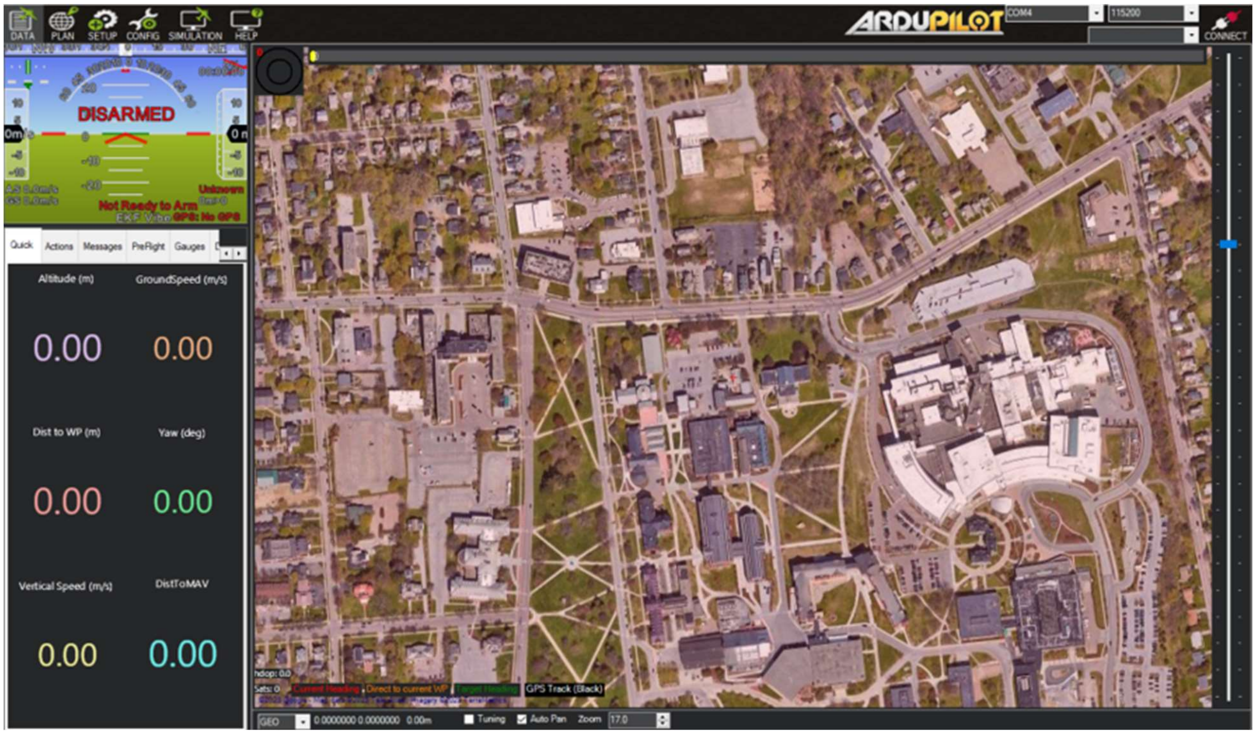
Figure 3. Tarot Iron Man 650 frame

Figure 4. Three-phase AC motors at the end of each arm

Next the larger wires which would provide sufficient voltage to the motors were fed through each of the four arms and soldered to the power distribution board mounted in the center of the drone. Since the motors used on the UAV are three-phase AC motors, it was necessary to utilize electronic speed controllers (ESCs) which would convert the DC voltage of the battery to the appropriate AC signal to run the motor. One ESC was mounted to the end of each drone arm.

The flight controller or "brain" of the drone was then mounted to the top plate. This particular UAV makes use of a Pixhawk flight controller. The electronic speed controllers were connected to the servo rail—the section of main and auxiliary input/output pins—of the flight controller. Among the other devices mounted to the drone necessary for operation are the eight-channel pulse-width modulation (PWM) receiver, the pulse-position modulation (PPM) encoder, which converts the eight PWM signals into a single PPM signal to be read by the flight controller, and the GPS which provides position data to the flight controller.

The Pixhawk flight controller and the peripheral devices attached to it are designed to work in tandem with a ground station computer running mission planner software, such as Mission Planner or APM planner. The UAV can be controlled by both delivering commands using the software, as shown in Figure 5, or using a traditional handheld RC controller depicted in Figure 6.



Altitude (m) 0.00
GroundSpeed (m/s) 0.00
Dist to WP (m) 0.00
Yaw (deg) 0.00
Vertical Speed (m/s) 0.00
DistToMAV 0.00

0.0000000 0.0000000 0.00m
☐ Tuning ☑ Auto Pan Zoom 17.0

Figure 5. Mission Planner software interface

Figure 6. Handheld RC controller

3.2 Grabber Design

The pick and place task to be performed by the drone required the designing and building of a grabber device to be mounted on the bottom of the drone which can lift and drop the sensors securely and accurately. The grabber device must be strong enough to hold the sensor in place until the desired position is reached, but not so heavy as to interfere with the flight of the UAV. Additionally, the grabber device must not use an excess of power, because the battery already heavily limits the flight time of the drone.

Two different grabber designs were considered for this project. The first iteration of the grabber design was a mechanical claw made from 3D printed parts. The claw would be powered by a servo connected to the flight controller, and opened and closed using inputs from the ground station. The second iteration of the grabber design used a simple electromagnet, as shown in Figure 7.

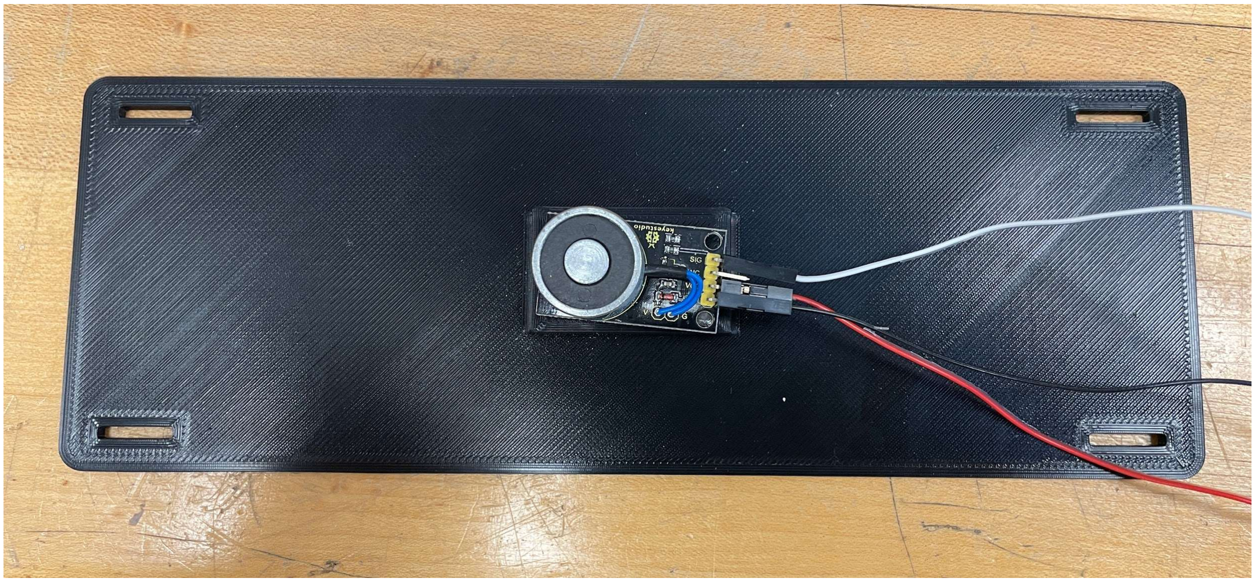


Figure 7. The electromagnet grabber

The drone utilized in this project possesses two carbon fiber “rails” on the underside of the frame, intended for mounting a camera. The baseplate of the grabber device was designed to be compatible with these rails, and mounted on via simple cloth straps or plastic zip ties. The large area of the plate is able to house additional devices. Earlier in the device's conception, the magnet was controlled via a microcontroller. However, in the interest of saving weight, the microcontroller was dispensed with in favor of controlling the magnet directly from the drone’s flight controller.

3.3 Sensor Design

It is necessary to consider the type of sensors that could be feasibly deployed by an unmanned aerial vehicle. The sensors must be lightweight, portable, and have minimal setup process to deploy on the site. For instance, a sensor that must be deployed under the surface of the slope by boring a hole would not be feasibly deployed with the currently available technology.

One of the simplest sensors that still provides valuable data in assessing landslide risk is a soil moisture sensor. A high degree of soil moisture is a strong indicator of potential landslide occurrence. Soil moisture sensors work by inserting two shallow prongs into the soil, forming a capacitor. The sensor then measures the charge time of the capacitor, and uses that information to provide an estimate of the water content of the soil. This is because varying degrees of soil moisture alters the dielectric constant of the soil, producing varying charge times (*Soil Moisture Sensor User Manual*, n.d.).

In addition, movement and changes in the shape of a slope are strong indicators of potential landslide risk. Measuring small changes from the vertical level can be accomplished by using a tiltmeter. While older tiltmeters were essentially long, stationary pendulums, modern electric tiltmeters feature a more compact design. They function using a simple bubble level principle, and any changes are recorded using a standard datalogger (Garcia et al., 2010). Tiltmeters have a long history of being used in the monitoring of geological hazards. Their applications have included assessing landslide risk as well as monitoring volcanic activity. Moreover, they have proved useful in assessing movement in man-made structures, particularly dams (Radovanovic et al., 2015).

3.4 Theoretical Assessment

It is necessary to outline a testing procedure for both the drone and grabbing device before it is employed in the field, so the capabilities and limitations of the devices are fully understood.

To test the magnetic grabber device, it should be detached from the drone and attached to an external power supply. A series of varying weights shall be used. A weight will be placed on the magnet, and the grabber will be powered on, then powered off and the weight will be replaced. This process will be repeated until the magnet is no longer capable of supporting the weight or until the heaviest weight is tested successfully.

Next, the payload capacity of the drone itself must be tested. Again, a series of weights must be used. To reduce the complexity of the test, it is not necessary to employ the magnetic grabber device, rather the weights can be fixed to the drone via simple straps. With each weight attached, the drone performs a simple takeoff and landing sequence. The test is to be repeated until the drone is incapable of producing enough lift to fly with the attached weight, or until the heaviest weight is tested successfully.

Once the devices have been tested in-lab successfully, field testing can begin. The Cotton Brook landslide site presents an ideal field-testing location. The lack of vegetation on the site ensures a clear line of sight can be maintained with the drone from the ground station at the bottom of the hill. In addition, while the trail to the upper section of the site is damaged, the bottom of the hill can be accessed via road.

4. Discussion

4.1 Drone

The first problem encountered with the drone was the lack of protection on the propeller blades. The nature of the project necessitates that the drone fly very close to uneven ground. It was therefore necessary to design and print blade guards which could prevent minor impacts from leading to catastrophic failure. In addition, the flight controller's auxiliary outputs did not function as expected, leading to difficulties with the drone interfacing with the magnetic grabber device. Therefore, it remains to be tested whether the drone could take off with the grabber and activate the electromagnet whilst in flight.

4.2 Grabber

The mechanical claw grabber design was energy efficient as it only used power while the claw was opening or closing. However, it was determined that the grip of the claw was not strong enough to withstand the motion of flight. The electromagnet grabber design proved much more secure than the claw design. However, the nature of the electromagnet necessitates that the device draws power the entire time it is carrying a payload, limiting the flight time of the device. Several means of remediating this issue were investigated, including a permanent magnet rotated into position by a servo, or an electropermanent magnet with a magnetic field which changes direction after a single pulse of current. In the interest of time, the project was continued using the basic electromagnet grabber design as proof-of-concept.

Initially, the magnet was driven by an Arduino microcontroller connected to the drone's power supply, which was activated by communications sent from the ground station computer via LoRa. In the interest of saving weight however, the microcontroller was replaced by connecting the magnet directly to the flight controller, using one of the auxiliary output pins as a relay to power the electromagnet. This change also allowed the use of the RC hand controller to power the magnet by flipping one of the auxiliary switches.

The major limitation of the current grabber design is the excessive power usage. In order for the magnet to remain active, it must be supplied with power the entire time it is holding the UAV payload. This power usage cuts into the already limited flight time of the drone, limiting the range at which the drone can deploy the sensors. Therefore, future iterations of this design should seek to make the grabber more energy efficient.

One potential solution to the grabber power usage problem is by employing an electropermanent magnet (EPM). In brief, an electropermanent magnet is a permanent magnet whose external magnetic field can be turned on or off using a single pulse, meaning that the grabber device would only use power when picking up and deploying the sensors.

Electropermanent magnets consist of two sections. One section is of a high coercivity magnetic material, meaning that it can withstand strong external magnetic fields without becoming demagnetized. The other section is of low coercivity magnetic material, which is wrapped in a coil of wire. The direction of the magnetic field of the low coercivity section is reversed by a single pulse of current through the coil of wire. When the magnetic fields of both sections are aligned, the device produces an external magnetic field. When they are in opposition, no external field is produced.

A similar effect to the EPM can be produced mechanically. Rather than sections of high and low coercivity material, two sections of high coercivity material can be used. The two magnetic fields can be kept in opposing orientations, until one magnet is rotated into the “on” position, lining up the magnetic fields and producing an external field. With this method, power would only be used to rotate the magnet in and out of position when retrieving and deploying the sensor.

4.3 Sensors

The largest challenge when deploying a soil moisture sensor is producing enough force to drive the two prongs deep enough into the soil. On loosely packed, wet soils the weight of the sensor could be enough to deploy the sensor. However, on harder soils, say dry soil high in clay content, a significant amount of force is necessary to drive the prongs.

The task of producing this force using a UAV is difficult because of the reactive force on the drone. Because the drone is suspended in flight rather than connected to the ground or braced on any surface, it will have to make rapid corrections mid-flight after delivering the force to maintain stability and avoid crashing. Since such corrections would be too small and fast to be made by a human operator, they would be performed automatically by the drone's flight controller.

As for the tiltmeter, if it is to be deployed by a UAV, it must be made compact enough to feasibly be lifted and deployed. It must also be robust enough to withstand the impact against the slope when it is deployed without damaging the mechanism within. Therefore, it would be necessary to design a holding case for the tiltmeter which is both strong, and light enough for this application.

Although the potential modifications to sensors were discussed, no prototypes were fabricated for this project.

5. Conclusion

Unmanned aerial vehicles present a unique potential tool when monitoring landslides and assessing landslide risk. UAVs possess a broad range of applications, including aerial photography, LiDAR, and pick and place operations. The Mount Mansfield State Forest case revealed the true value that these drone applications could have, allowing for faster data collection and improved safety for researchers. The prototype grabber device fabricated for this project demonstrates the feasibility of a drone-mounted device for performing pick and place operations with sensing equipment. Additionally, combining data gathered with the drone with NASA's SLIP-DRIP software could potentially create a comprehensive landslide detection and management system. With further development of sensors designed to be deployed by a drone, UAVs could become a vital tool in understanding landslides.

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