An unmanned aerial vehicle with vibration sensing ability (seismic drone)

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Summary

We describe the design, testing, and potential of an unmanned aerial vehicle (UAV or drone) with seismic sensing capabilities. The seismic or vibration sensing platform (four 100 Hz geophones plus recording electronics) is attached to a 3DR Solo Quadcopter drone. The geophone spikes become the drone's landing legs. The drone and its geophone payload have been successfully flown a number of times with take-off, programmed or remotely controlled navigation, landing, and recording. We have conducted tests (using hammer and weight drop sources) to compare the response of the landed seismic-drone system to planted geophones and a conventional cabled seismic system. The seismic traces from the drone are quite similar to those of the planted geophones. To test the spike penetration on landing, we created three different scenarios (dropping the drone on sand, grass and dry clay) and measuring the depth of penetration (up to 20 mm). We conducted a walk-away survey with the drone versus a planted geophone line. Again the drone and planted geophone responses are very similar. We conclude that the drone-mounted geophone platform can fly to a site, land, and record seismic vibrations with similar quality as planted geophones. Detachable and roving seismic platforms may further increase the drone's seismic reach. Drones show considerable promise for various kinds of seismic measurements and surveys.

Introduction

There is an exciting new technology that has become popular with recreational flyers and a growing cadre of geoscience professionals (Cicoria, 2015). It is the unmanned aerial vehicle (UAV) or airborne drone (Chamayou, 2015; Whittle, 2015) - a flying platform with propulsion, positioning, and remote or self control. Most drones also have some kind of sensors which capture and possibly transmit information. There has been considerable coverage in the news and technical press about the burgeoning promise, along with concerns, of drones (Horgan, 2013; Adams and Bushwick, 2014). The promise of UAVs is legion - from remote rescue to deliveries, farming, and forensics. Drones are being used in humanitarian response efforts after disasters. For example, after the April 2015 7.8 magnitude earthquake in Nepal, drones were deployed and able to survey sites, inspect buildings and roads, and create 3D maps of cultural heritage sites such as temples (Team Rotordrone, 2015). However, there are issues which include safety, reliability, and privacy. Preliminary regulations governing the recreational and commercial operation of drones have been outlined (and implemented in January, 2016 requiring US flier registration with the Federal Aviation Administration - FAA), but a more extensive regulatory environment is under development by the FAA and other national aviation bodies. Now, moving toward the geophysics world, measuring vibrations and a material's properties are key components of many fields, including geotechnical engineering, earthquake monitoring, and seismic surveying. Sometimes, associated sites may be difficult or hazardous to access. In addition, there might be many places to measure which could require a great deal of hand labor (3D seismic surveys). Earthquake monitoring, especially after a disastrous earthquake requires placing sensors close to the event's epicenter. This hazardous need could be made much safer by having a robotic sensor emplaced in the calamity zone. The UAV itself could mediate geophone deployment in three ways: 1) dropping the sensor from the air to the ground (or placing it) to be left or collected in another way [possibly via a Flirtey (Sonner, 2016) or Amazon Prime Air system], 2) deploying the sensor on the ground and returning aerially to pick it up, or 3) landing and using a vibration detector that is integrated into the UAV platform. We describe an integrated system here where we have added a seismic recording platform to a commercial drone (3DR Solo Quadcopter in Figure 1).

Figure 1. 3DR Solo Quadcopter (drone) with a four-legged seismic recording platform attached. The drone flew to the grassy location, landed, and recorded seismic vibrations. The vibrations recorded by the drone are compared to those from adjacent, planted geophones.

The seismic drone could be used for terrestrial operations or to land on water and make marine (pressure) measurements (Lorge, 2015). Another type of aerial drone uses fixed wings – more like a plane than a helicopter. These plane-like unmanned aircraft are often used for longer flights (Oleson, 2013) as opposed to helicopter-type or rotor-wing craft. A fixed-wing drone might drop seismic sensors as could our rotor-wing craft.

The concept of using robots to place seismic sensors has captured the imagination of at least a few (e.g., Gifford, 2005). Postel et al. (2014) describe using mobile robots for geophone placement. This paper presents the design of a seismic drone and its performance including landing issues, ground coupling, and penetration. We conducted tests to compare the drone's seismic response with conventional seismic recording. The overall goal of this research is to explore the quality, logistics, and potential of employing drones for seismic measurements and surveys.

Platform design

The sensor platform of our seismic drone contains four geophones, wired in series, on a cross-member X support structure. Recording electronics and battery are also mounted on the X structure. This work primarily tests the seismic drone concept and examines the data quality attainable. Thus, to make an equitable comparison with planted geophones, we take the raw output from the drone's geophones and plug it into the planted geophone recorder system. Thus, the only variable for our measurements is the drone mount and landing. The drone and planted geophones are all Geospace 100 Hz vertical geophones. The geophones are set at 25 cm apart on the drone's X structure. The planar X platform makes the sensors largely perpendicular to the ground surface upon landing.

Figure 2: Design of the four-geophone platform attached to the 3DR Quadcopter.

Experiments

We conducted three experiments to test the drone's seismic capabilities:

- *Coupling*

  The first experiment compares the output from the geophones, as deployed with variable coupling on different surfaces (Figure 3), with the seismic drone. This test was undertaken at the University of Houston campus.

- *Recording a shot gather*

  The second experiment compared the drone and the cabled system at our La Marque Geophysical Observatory 15 miles north of Galveston, Texas. The recording system and source are Geometrics StrataVisor NZ and 40 kg propelled energy generator (PEG.) We deployed a 24-channel 2D line. The drone flew closely to each receiver, landed, and recorded each shot.

- *Soil penetration*

  The third experiment compares soil penetration and the angle of incidence in three different soil types. This is important to ensure quality data for coupling in various soils. We also need to test whether the drone can takeoff, even when the geophones are well planted in soil.

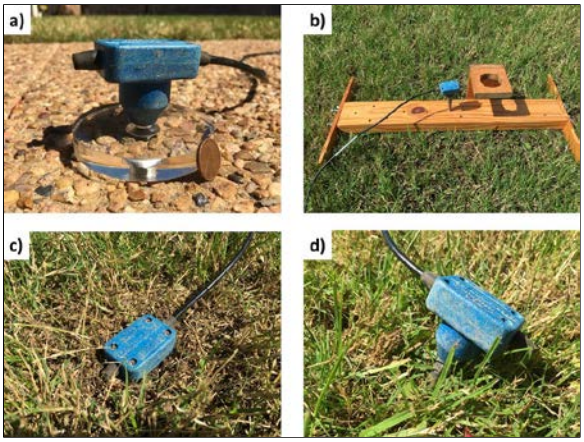

Figure 3: Different geophone configurations and setups for comparing with the seismic drone. We used a 10 lb hammer as a source recorded into: a) round platform, b) wooden platform, c) well planted geophone, and d) marginally planted geophone.

Figure 4 shows the data recorded from some of the configurations as outlined in Figure 3. The drone records a seismogram, on the hard surface, about the same as the plate-based geophone. In the long grass, the drone has a slightly ringier response as complared to the well planted geophone in this case.

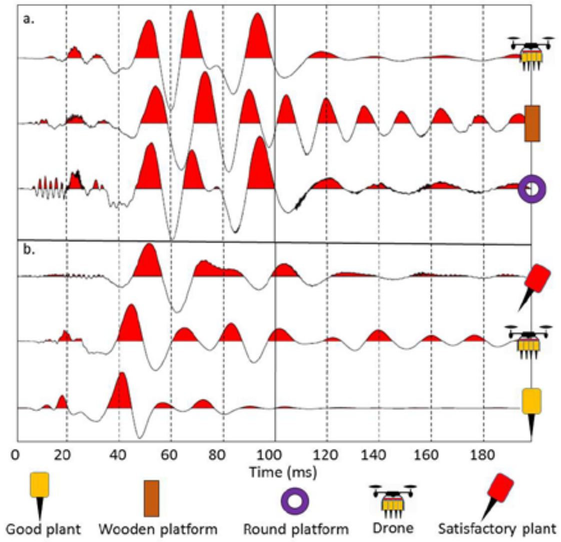

Figure 4. Displays of the seismograms generated by different geophone plants and the seismic drone. a) the drone versus different platforms (round and wooden). Oscillations in the platforms are not damped quickly since they are not fixed to the ground, The maximum amplitude values are similar and appear almost simultaneously. The drone landed quite close to the geophone setups so no time shift is observed. b) the drone versus planted geophones (well planted and marginal to satisfactorily planted). We observe mild reverberations in the drone data compared to the planted geophones. The maximum amplitude values are similar but do not appear aligned as the locations were approximately half meter apart, and hence time a shift occurred.

We undertook a longer offset survey at our La Marque Geophysical Observatory about 15 miles north of Galveston, Texas as shown in Figures 5 and 6.

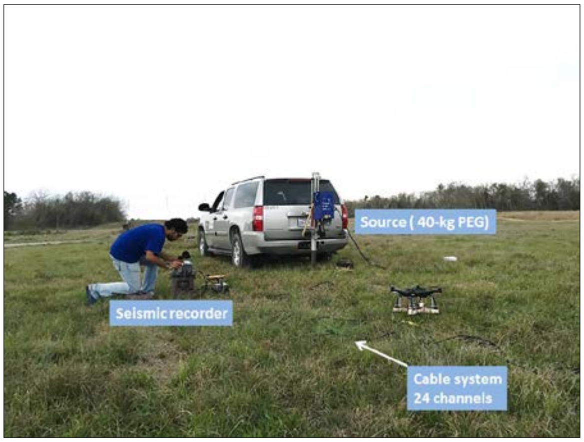

Figure 5. Field test photograph, at the La Marque Geophysical Observatory, Texas with a planted geophone and cabled system versus the drone.

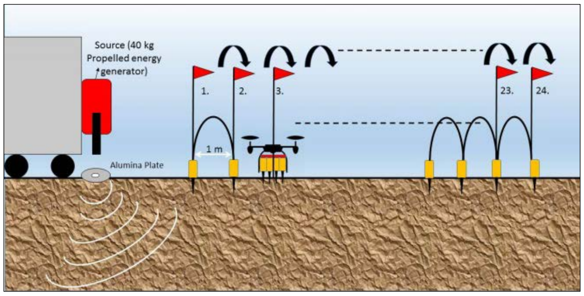

Figure 6. Schematic diagram of the drone versus planted geophone test.

Survey Results

In Figure 7, we observe the seismograms as generated by an accelerated 40 kg weight drop with the drone and planted cabled system. The drone data is a little noisier than the planted geophone data. However, most of the events are quite similar. We note that that the drone's geophones could be more rigidly attached than in this prototype model which should decrease noise and reverberations.

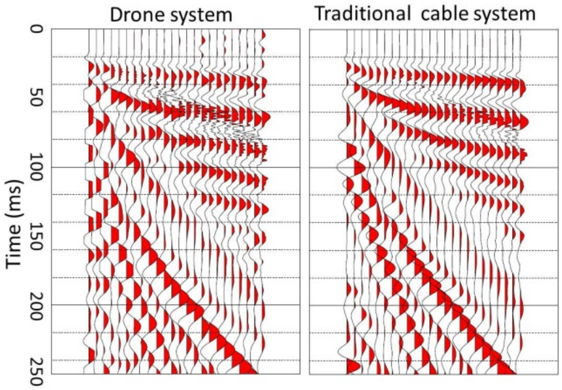

Figure 7. Shot gather comparison using a 40 kg accelerated weight drop. A planted geophone (left) and drone (right) co-located shot gather. The drone and planted geophones are connected to the Geometrics 60-channel StrataVisor. Each receiver location is 1 m apart.

This next experiment tests the soil penetration, upon landing of the seismic drone, in different soil types. Good contact with soil is important for obtaining quality data, hence the experiment explores the penetration capability of the setup in common soils. We performed the experiment in grass, sand, and dry clay. The penetration was maximum in sand followed by grass, but the drone did not have spike penetration into dry clay as shown in Figure 8. The drone was able to take-off after all landings.

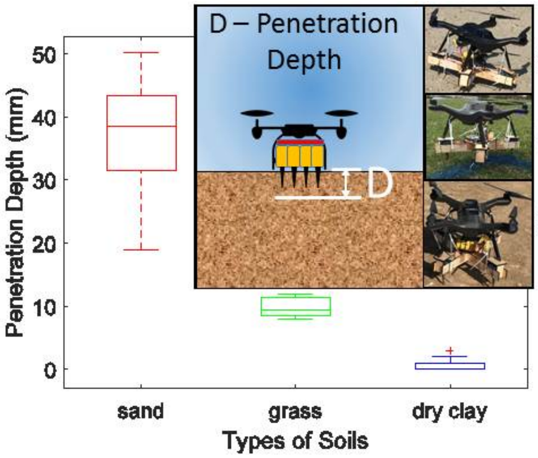

Figure 8. Box and whisker plots comparing the variations in depth of geophones attached to the seismic drone after landing.

Further capabilities

We noted previously that the vibration or seismic sensing platform could be detached from the aircraft and left to monitor In addition, the platform could also be an autonomous rover in its own right (Figure 9). It could thus move to various positions to achieve, for example, more recording locations, better coupling, sunlight, shade, etc. It could then recovered by the drone or by other means.

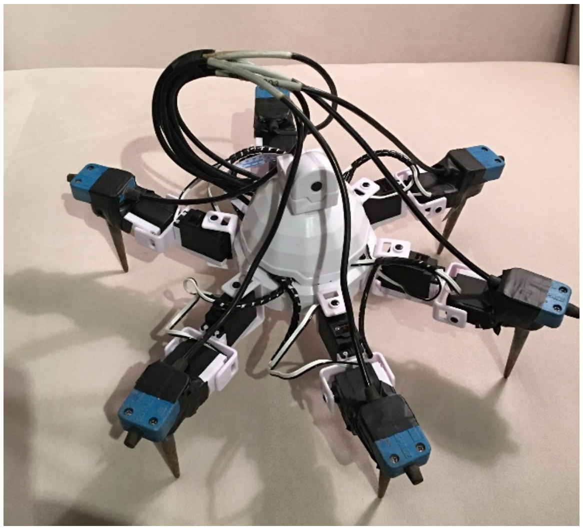

Figure 9. Hexapod robot (from EZRobot) with six, 100 Hz geophones attached as legs and sensors.

Part of the promise of the seismically equipped drone is to fly autonomously on pre-programmed paths to either take measurements and depart or leave the sensor package behind at a number of locations. We can also imagine many drones with a sensor or sensors undertaking larger surveys. There are also numerous ways that the drone can transfer or communicate its information – via radio link, WiFi, or connected download upon return to home base. The data transfer architecture could be bucket-brigade style among drones, link to a master drone or tower, or directly connected to base data repository.

Conclusions

In this paper, we have presented the design, testing, and potential of unmanned aerial vehicles with integrated seismic sensing capability. We built a seismic platform with four 100 Hz geophones and attached it to a 3DR Solo Quadcopter. The Quadcopter was able to fly preprogrammed or piloted flight paths, land, record seismic data, and takeoff again. We have thus demonstrated the proof-of-concept of mounting geophones on a drone and acquiring reasonable seismic data. The data acquired after flying, landing, and recording under various scenarios indicates that the drone can indeed record data with similar quality as that of a planted geophone. This type of sensing can be automated. There are many opportunities for future work in platform design, data processing and transmission, and logistics. Unmanned aerial systems are advancing very rapidly. There are undoubtedly many activities and requirements in the geosciences that will be assisted by drones.

Acknowledgments

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EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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