Seismic Survey with Drone-Mounted Geophones

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***Abstract*—Seismic imaging is one of the major techniques (and industries in Texas) for subsurface exploration and involves generating a vibration which propagates into the ground, echoes, and is then recorded using motion sensors. There are numerous sites of resource or rescue interest that may be difficult or hazardous to access. In addition, there is often many places to survey, which require a great deal of hand labor. Thus, there is a substantial need for unmanned sensors that can be deployed by air and potentially in large numbers. This paper presents working prototypes of an Autonomous Flying Vibration Sensor that can fly to a site, land, then listen for echoes and vibrations, transmit the information, and subsequently return to its home base. One design uses four geophone sensors (with spikes) in place of the landing gear. This provides a stable landing attitude, redundancy in sensing, and ensures the geophones are oriented perpendicular to the ground. The paper describes hardware experiments demonstrating the efficacy of this technique and comparing with traditional manual techniques.**

Keywords—Data Acquisition, Geophones, Quadcopters, Seismic Exploration

I. Introduction

Hydrocarbons (coal, oil, natural gas) are estimated to supply more that 66% of the total energy consumed on earth during the year 2014 by IEA [**?**]. Millions of dollars are pumped into exploration since these hydrocarbons are major sources of energy, it is essential for sustaining life and socio-economic developments. Avoiding hazards and maintaining safety is necessary as they are highly-inflammable and human life is at stake thus essentially requiring state of the art equipment to prevent disasters.

Traditional exploration involves planting geophones (sensors) into the soil and detecting seismic disturbances caused from Veibroseis trucks or dynamites which act as a source of vibration. As these vibrations propagate on the surface they are detected by the geophones and the data is stored. The data obtained describes the intensity of the pressure wave generated by the source over a period of time. This data is critical and is used in analyzing the underground rock structure and inferring the presence of hydrocarbons. Instead of randomly searching for hydrocarbons, explorations are carried out using elaborate technical procedures, equipment and skilled labor over a large area there by increasing the possibility of discovering hydrocarbon-reserves in an optimal fashion. Even though traditional exploration methods are extensively used they are not in par with the current advancements. The use of cables to connect the microprocessor and the senors leads

Fig. 1: Comparing manual and robotic geophone placement. 1a.) Currently, geophones are planted manually [1]. 1b.) Traditional methods require extensive cables to connect geophones to the seismic recorders and batteries. Shown are wire bundles lined up for transportation from the exploration site [2]. 1c.) The *Seismic Drone* in this paper is an autonomous unit requiring no external cables. This paper presents an automated process for sensor deployment and retrieval.

to drawbacks like increase in overall cost, inaccessibility in certain terrains. The exploration process involves deployment and redeployment of sensors repeatedly manually. With current advancements in automation, automating the process would reduce the expenditure and increase precision. Drones or unmanned aerial vehicles (UAVs) are flying platforms with propulsion, positioning, and independent selfcontrol. As drone technology improves and regulations are adopted, there are major opportunities for their use in scientific measurement, engineering studies, and education. In particular, measuring mechanical vibrations is a key component of many fields, including earthquake monitoring, geotechnical engineering, and seismic surveying. Seismic imaging is one of the major techniques (and industries in Texas) for subsurface exploration and involves generating a vibration which propagates into the ground, echoes, and is then recorded using motion sensors. There are numerous sites of resource or rescue interest that may be difficult or hazardous to access. In addition, there might be many places to survey, which require a great deal of hand labor. Thus, there is a substantial need for unmanned sensors that can be deployed by air and potentially in large numbers. We have built working prototypes of an Autonomous Flying Vibration Sensor that can fly to a site, land, then listen for echoes and vibrations, transmit the information, and subsequently return to its home base. The goal of this paper is to design, build, and demonstrate the use of motion sensing drones for seismic surveys, earthquake monitoring, and remote material testing. (??) gives a description of current state of the technology available in the industry and why Seismic Drone is better. Followed by the (??) that describes the hardware experiments performed. (??) discusses the performance of the above system with traditional methods and followed by (??) Conclusion .

II. Overview and Related Work

A. Traditional Seismic Exploration Methods

cite the book that Li sent us. Also cite some papers by Rob.

an equation describing seismic waves in earth

a) Cabled Systems

Traditional cabled systems were extensively used for seismic data acquisition in hydrocarbon explorations. A group of sensors (geophones) were connected to each other in series using long cables, and this setup was connected to a seismic recorder and a battery. The seismic recorder consisted of a microcontroller which could synchronize the data acquired with the GPS signal and store it in the onboard memory. Generally a four-cell Lithium Polymer (LiPo, 14.8V, 10Ahrs) batteries are used to power this system. This method of data acquisition required high number of manual laborers and a substantial expenditure for transporting the cables. The difficulties faced in used a tradition cabled system for data acquisition are 1. Conducting a seismic survey in rugged terrains 2. The manual labor available might be unskilled and expensive depending on the location.

b) Autonomous Nodal systems

Currently the autonomous nodal systems are extensively used for conducting seismic data acquisition surveys in USA. Unlike traditional cabled systems, the autonomous nodal systems are not connected using cables. The sensor, seismic recorder and battery are all combined into a single package, and this unit can autonomously record data and hence these systems are called autonomous nodal systems. Even in these systems the data is stored in the onboard memory and can only be acquired after the survey is completed. This poses as a disadvantage since the errors cannot be detected and rectified while conducting the survey. Recently wireless autonomous nodes have been developed, these systems can transmit data wirelessly as a radio frequency in real time. Yet these systems require manual laborers for planting the autonomous nodes at specific locations and deploying long antennas which are necessary for wireless communication.

B. Seismic Drone

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Seismic drones combine the quality of data acquisition present in the traditional exploration method with an autonomous unmanned air vehicle (UAV) which has high maneuverability and the capability of performing robust movements. A seismic recorder, battery, and four geophones are embedded onto a platform which is attached to an UAV. By inputting the specific GPS location, the UAV can deploy the seismic data acquisition system. The geophones obtain data which is processed by the seismic recorder and stored in the onboard memory. The major advantage with the current system is automating the deployment process and thereby eliminating humans from the loop. By using a robot to perform the above task, we can reduce costs and errors. Since we use the same micro-controller as in the traditional cabled systems, we obtain a 24-bit accuracy on the ADC conversion and sampled rates as low as half a millisecond. The drawback with the proposed system is that it cannot transmit data wirelessly and hence we cannot obtain seismic plots in real-time. Since the deployment is autonomous, it is precise and the system has the ability to re-deploy or return home from the current deployment site.

C. Seismic Wireless Sensor Network Drone

cite some recent robotics papers on drone sensor networks

This system also employs an UAV for sensor deployment and it has the ability to transmit data wirelessly. In the current system, the data is transmitted via Bluetooth transmission and is limited to a range of 50 m. We use an Arduino Mega processor which possesses a 12-bit ADC and a maximum sampling rate of 1 ms. The proposed system was developed using commercially accessible products and is not comparable to the micro-controller which were specifically designed for seismic data acquisition purposes. The key point to note is the feasibility of the proposed idea and the features presented can be extended to the present state of the art technology

III.Experiments

Three experiments were completed

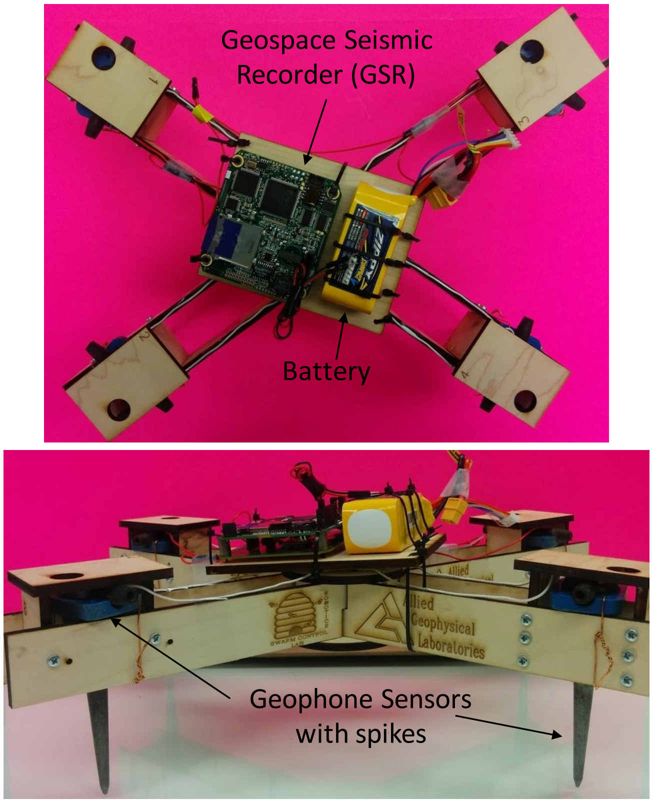

Fig. 2: The seismic drone's sensor base consists of four geophones, a Geospace Seismic Recorder (GSR) and a LiPo (14.8V, 0.5Ah, 4 cells) battery. *TODO: add a ruler for scale. Can you make both images the same size?*

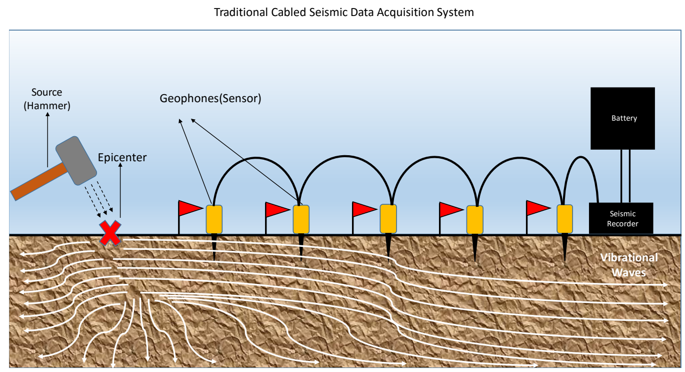

Fig. 3: A sketch of the traditional geophone system,used extensively for Seismic data acquisition..

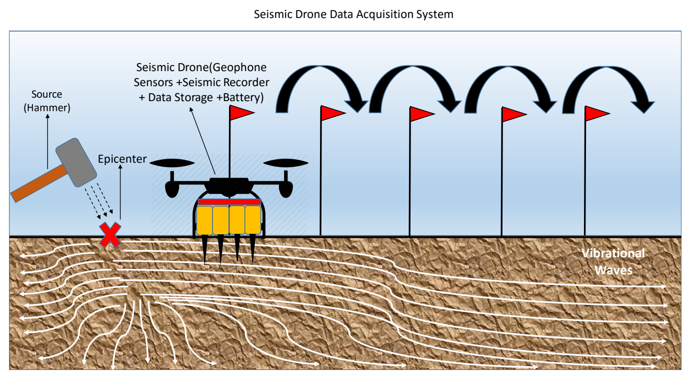

Fig. 4: A sketch of the proposed drone setup which can replace manual laborers during seismic surveys.

A. Seismic Survey Comparison

The purpose of this experiment is to compare the proposed system's (Seismic Drone) performance with the currently available systems (traditional cabled systems). The seismic drone lifted off, flew to the same locations as four cabled geophones, and was coupled to the recording equipment to obtain graphs for comparison.

Materials Required:

S No.	Materials	No. of Units
1	Sledge Hammer	1
2	Traditional Geophones	10
3	GSR	1
4	Battery,14.8V,10Ah	1
5	Seismic Drone	1

Procedure:

1) Plant the geophones vertically into the ground, 5m apart from one another. Ensure the coupling with the ground is satisfactory.
2) Attach the series geophone bundle to the GSR (Geospace Seismic Recorder).
3) Attach the GSR to the battery for power.
4) Fly drone and land it approximately next to the 1st stationary geophone.
5) At approximately 10m from the geophone setup use the sledge hammer to strike the ground, the impact causes vibrational waves that propagate below the earth's surface and is detected by the geophones.
6) Repeat steps 4 and 5, landing the drone next to each geophone.
7) Save data files from both the drone and the stationary geophones. In software line up the hammer strikes. Display data for one test with all the stationary geophones overlayed with the data from each position of the seismic drone.

Results

B. Wireless transmission of seismic disturbances

The purpose of this experiment is to compare the seismic drone system's performance with the **Seismic Wireless Sensor Network Drone** (SWSN Drone).

Materials Required:

S No.	Materials	No. of Units
1	Sledge Hammer	1
2	SWSN Drone	10
3	Seismic Drone	1

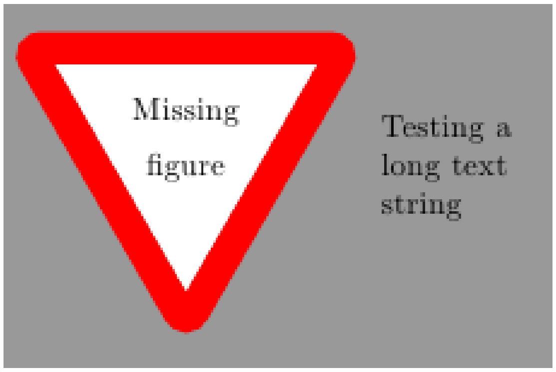

Fig. 5: 2 plots showing comparison with traditional geophone system for (1) hard surface, and (2) dirt surface

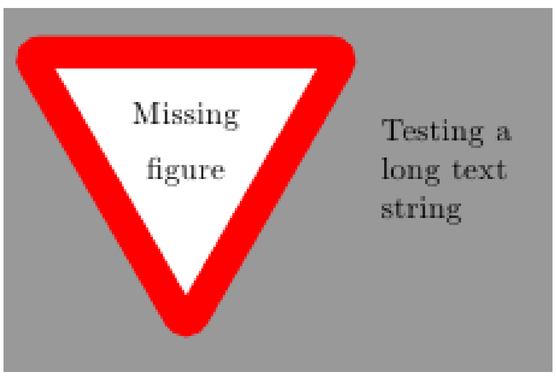

Fig. 6: Data recorded by the cable-free seismic drone

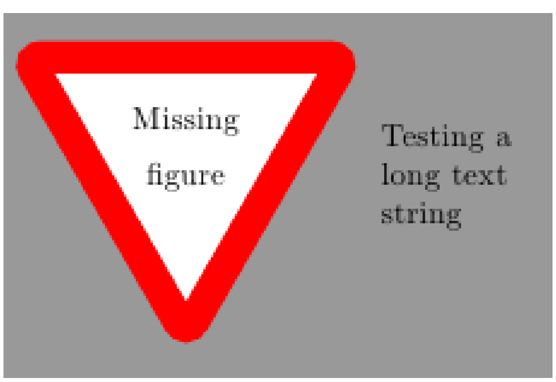

Fig. 7: One plot from the Arduino blue-tooth equipped quad copter.

Procedure :-

1. Fly the seismic drone and land it around the first survey location.
2. Use a sledge hammer to strike the ground, the impact causes vibrational waves which propagates below the earth surface and is detected by the geophones.
3. Repeat steps one and two for all survey locations.
4. Repeat steps one, two and three for the seismic wireless sensor network drone system.
5. Save the data file obtained from the seismic drone and the seismic wireless sensor network drone system (obtained wirelessly). In software line up the hammer strikes. Display data from both the test overlaid on each other for all survey locations.

Results

C. Accuracy of autonomous landing with geophone setup

Seismic exploration depends on accurate placement of geophones over a large geographic area. This experiment tested the accuracy of autonomous landing of the fully loaded seismic drone system verses the manual landing controlled by a piolot using an RC transmitter. The purpose of this experiment is to compare the accurate placement of geophones using manual control and autonomous control.

Materials Required :-

S No.	Materials	No. of Units
1	Mobile Phone	1
2	SWSN Drone	10
3	Seismic Drone	1

Procedure:

1) Mark the landing location with an x using a red insulating tape.
2) Try to land the seismic drone manually at the center of the marked x location using the wireless RF transmitter.
3) After landing, measure the displacement from the center of the seismic drone to the center of the x location.
4) Repeat steps 2 and 3 ten times.
5) Obtain the mean and variance using the displacement values.
6) Use the mobile phone (tower app) to land the seismic drone autonomously at the center of the x location.
7) Measure the distance between the center of the seismic drone to the center of the x location.
8) Repeat the above two steps ten times.
9) Obtain the mean and variance using the displacement values.
10) Compare the average mean and variance values for manual and autonomous control.

Results

D. Coupling in various soils

We land the drone in various soils, and measure the penetration using a penetrometer.

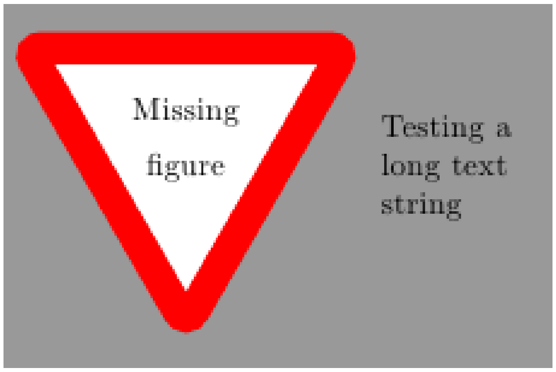

Fig. 8: The seismic drone was commanded to land at the location marked with a green 'x'. The actual positions are shown with blue 'o'. The mean and ± 1 standard deviation ellipses are drawn in red.

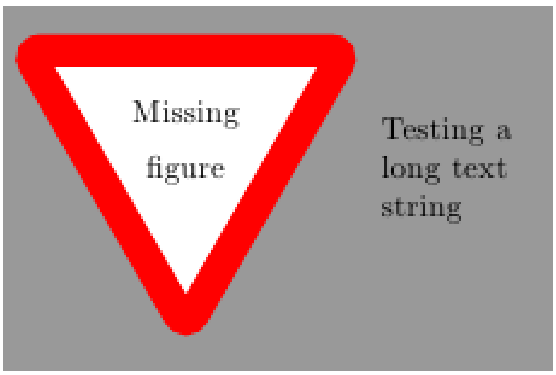

Fig. 9: (left) Photographs of seismic drone geophone feet in different soils, with a ruler visible. (right) plot of penetration depth for three different soil types.

Materials Required :-
Procedure :-
Results :-

IV. Conclusion

This paper presented an autonomous technique for geophone placement, recording, and retrieval. This can enable automating a job that currently requires large teams of manual laborers The paper described hardware experiments demonstrating the efficacy of this technique and comparing it with traditional manual techniques. There are many opportunities for future work.

The current drones are not designed for long stationary periods and must be weatherized. It may be more beneficial to deploy one or more sensor packages and return the drone to a home base. There are many opportunities for teams of drones to divide the task of sensor placement.

References