Detailed Modeling of Designs for the Polar Seismic TETwalker

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Abstract—Among the technologies developed by NASA for space exploration, the TETwalker robot is one of the latest. NASA/Goddard Space Flight Center and CReSIS (Center of Remote Sensing of Ice Sheets) are proposing to adapt this technology for polar seismic data acquisition. In this paper, we discuss the design process for this project, explaining in detail each of the models created. This document summarizes the ideas, concepts, and detailed models our team developed for the TETwalker’s employment for polar seismic exploration, including deployment of a geophone or broadband seismometer. This document also explains the design process of the incorporation of subsurface imaging equipment to the L.A.R.A (Lander Amorphous Rover Antenna) technology, which is a sheet-like TETwalker architecture. A small prototype was fabricated by the team in order to demonstrate the geophone insertion and retrieval process.

I. INTRODUCTION

The purpose of this project is to customize the TETwalker robot, developed by NASA Goddard Space Flight Center (GSFC), in order for it to be able to acquire polar seismic data. The TETwalker was originally developed for deep space exploration and data acquisition [1]. The uniqueness of this robot is that it can assume almost any shape in order to move along a certain path by changing its center of gravity. NASA GSFC and CReSIS (Center for Remote Sensing of Ice Sheets) propose testing this technology in extreme environments on Earth. CReSIS is an organization focused on studying ice sheets, this in response to climate change and the impact on sea level rise [2]. With the use of these robots, CReSIS will be able to autonomously collect polar seismic data faster and more efficiently than planting and arranging the geophones by hand. In this paper, the development of ideas and concepts in this project are explained in detail, including the designs of the data acquisition systems for the 12-TETwalker and the 4-TETwalker, the development of the center node used by the 4-TETwalker, and the use and applications for broadband seismometers. Incorporation of subsurface imaging equipment to the L.A.R.A (Lander Amorphous Rover Antenna) [4] technology and a small prototype the team developed in order to demonstrate the geophone insertion and retrieval process are also discussed.

II. BACKGROUND

Global warming can be defined as a gradual increase in the planet’s temperature in the Earth’s near-surface air and oceans, this increment is projected to continue in the future. CReSIS is an organization established in 2005 by the (NSF National Science Foundation) to study of the effect of climate change on the sea level rise [2]. This project focuses on customizing a TETwalker robot, which is a tetrahedral machine developed at NASA GSFC capable of changing its shape in order to move by shifting its center of gravity and making itself topple over [1]. Therefore, this robot is capable of overcoming obstacle-laden terrain and was originally intended for deep space exploration. This robot will be equipped with several sensors and equipment used for seismic data acquisition in the polar environment, such as geophones (or seismic sensors) and broadband seismometers. A simulation image depicting a 4-TETwalker is shown in Fig. 1.

![Fig. 1: Simulation image depicting the 4-TETwalker robot [1].](image-url)
A seismic sensor is a device that listens to vibrations in the ground and transforms them into data. Applying an explosive charge close to an array of geophones, seismic waves travel through the soil and reach the geophones. Then by using algorithms and computer visualization, scientists can retrieve information about the composition of a particular region or layer. A broadband seismometer follows the same principle of the conventional geophone; however, this geophone is much more sensitive to vibrations on the ground, allowing it to collect data from a larger distance without the need for an explosive charge. Using this technology in the Polar Regions allows us to get an image of subsurface material and geology, including water in the ice sheets and the state of the glacier-rock interface. In order to have a more concrete concept of the design the team used PRO-Engineer software [3].

### III. Seismic 12-TET Walker Design and Modeling

In order to achieve our goal the team considered various designs. The first design that the team developed was the Seismic 12-TET walker, which consisted of a cubic shaped robot whose architecture was composed of 12 geometrical shapes. The main idea was to attach a geophone to each of its eight nodes and find a way for it to completely unfold, planting all nodes into the ground. This will allow the team to use eight geophones at the same time arranged in a rectangular shape (which is necessary for an accurate reading). More than one TET can be used to record a specified area. If the team could develop a swarm of at least 100 TET walkers, the data of 800 geophones could be acquired simultaneously. Fig. 2 shows an image of the Seismic 12-TET, while Fig. 3 shows the seismic node design involving a geophone element and dedicated geophone spike.

![Fig. 2: Seismic 12-TET design, where all geophone spikes would be deployed for recording.](image)

This design, although offering an interesting approach for the project, presented a few problems. In order for the TET to completely unfold it would require one of the links to detach from each of the top nodes. Detaching one link and reattaching it again would need a great amount of precision, a very sophisticated mechanism to be placed in the link, and a strong refolding mechanism to survive toppling in a polar environment. Having a detachable link could jeopardize the mission, because if this mechanism is damaged the TET walker would not be able to unfold or fold back together. Another issue found in the design was that the forces needed to completely fold back together after a recording session was too large there fore would be energy-inefficient. Taking all of these problems into consideration, this approach was discarded as the folding process would require a great amount of energy and precision.
Fig. 3: Ground node with geophone element (cylindrical object in the middle of the right image) and spike for insertion into the polar surface.

IV. Seismic 4-TETwalker Design and Modeling

The second model considered by the team was the implementation of the 4-TETwalker to polar data acquisition. Unlike the 12-TETwalker, the 4-TETwalker is composed of only 4 geometrical shapes therefore offered a much simpler design while significantly reducing the space for placing geophones on the robot. At first the design having one geophone in every node was considered, allowing each robot to have three geophones recording at the same time. This approach was not deeply considered as a triangular-shaped array is not very commonly used when making a geophone array, so a new design was quickly developed. This new design utilized the 4-TET’s center node to house one or more geophones, each with a spike. The center node can be then placed down by the robot into the ground by extending the strut that is vertical during deployment. Fig. 4 shows models of the center node, designed with a geophone and spike for deployment using any side of the TETwalker, and the 4-TET containing the center node and deploying the downward-pointing geophone in a gimbaled manner.

Fig. 4: Center node with geophones (left) and 4-TET vertically aligning the downward-pointing geophone.

It is necessary to mention that this design offered a way for the TET to be able to easily control the angle and positioning of the geophone. By using gravity to align the center node the TET can orient the geophone into a fully vertical position. This is very important as it is necessary for the geophone to be oriented as vertically as possible to acquire an accurate reading. This design restricts the TET to use one geophone. Even though this reduction in the quantity of geophones used is an issue, having to use just one geophone in the TET reduces the system complexity, and the number of robots in a swarm can be increased in order to use more geophones at the same time. If the TET only has one geophone in its center node, it would be more difficult for the TET to position itself if it stopped toppling while having the geophone looking upwards instead of facing the ground. In order to counter this problem, a new design for the center node was created which had four flat surfaces, each parallel to a face of the TETwalker. Now the center node was equipped with four geophones, enabling the robot to deploy through any of its faces (see Fig. 4). Fig. 5 depicts the robot in upright position (prior to deployment) and deployed position (geophone inserted).
With this design no matter which side the TETwalker had facing down when it stops, there will always be a geophone pointing down for deployment. One of the major challenges with using a geophone in the arctic is that a geophone must operate in areas which are as free of noise and vibration as possible. Polar environments have considerable amounts of wind gusts which will be constantly hitting the TETwalker while it is recording and therefore creating undesired vibration. To counter this, an alternative system for the geophones was designed. Instead of each geophone being fixed inside the center node, the geophones can be individually housed in a detachable case inside the center node. When it is time to record, the TET will place the geophone in the ground and lift the center node, leaving the device in the ground. The center node will then separate from the geophone’s case far enough for its vibration not to affect the geophones reading, but still will be close enough to the case so the wind won’t hit it directly. Fig. 6 shows the alternative center node design and TET model.

V. ALTERNATIVE SENSOR PACKAGE: BROADBAND SEISMMOMETER

A new approach to the TETwalker design was to replace the seismometers with a broadband seismometer. A broadband seismometer is capable of gathering information from a large area with no explosive charges just by listening to the ground for a few weeks. The seismometer can be mounted in the center node. This is a big device, so a TETwalker would only be able to carry just one seismometer in its center node. However with this technology, a small swarm of 4 TETwalkers would be able to record a large area (e.g., 5 km square) without needing to be moved but every couple weeks. Once the data is gathered the TETwalkers will just move to a different location and begin the data gathering process all over again. Since the TETwalker will just have one side with a geophone, when close to arrive to the desired location the TET
will stop on the side of the geophone and then it will just crawl the rest of the way until it gets into position. Fig. 7 shows the adapted center node design as well as a model of one being deployed into the surface.

![Fig. 7: Broadband seismometer in center node (left), deployed (middle), and resulting robot model (right).](image)

Using this approach the TET we will be able to record a large area and since it won’t have to move for a couple of weeks this movement energy will be saved. A disadvantage of this sensor package is that it is heavy and considerably larger than a conventional geophone element and will likely need more energy to operate. This device offers the advantage of being able to store data onboard the seismometer, as well as record three component (3C) data. But if this technology can be redeveloped in order for it to be smaller and lighter, this seismometer can be applied to the TETwalker resulting in a more efficient way to gather data. Not only will it be more economical to send a small swarm to cover a considerably large area, but the need for energy will be significantly reduced as well.

### VI. Seismic L.A.R.A (Lander Amorphous Rover Antenna) Design

The final design that the team developed for this project was the seismic data applications to the L.A.R.A project [4] is a larger TET robot which resembles a shape-shifting sheet or mattress developed by NASA. The idea for this robot was to attach a geophone to every node that composes the body of the robot. This way we can have an array of geophones ready to use as a shape-changing, mobile device. Different from the 12-TETwalker, this TET could unfold itself as if it was a sheet on the surface allowing all the geophones to touch the ground (be deployed) at the same time. This robot would have the capability of moving in several ways, including sliding along a path around and over obstacles like a snake, making it perfect for seismic exploration in rugged environments.

The first design for this robot was to apply the geophone to every grid intersection nodes for a large quantity of geophones. This design was improved by adding a geophone to the node at every grid connection point, granting more data collecting power to the robot. Since the robot moves by toppling, it could be equipped with an array of geophones on both sides to record the area, no matter what side it is facing when it stops moving. Fig. 8 shows a model of what the Seismic L.A.R.A platform may look like, along with the two variations in geophone payload.
VII. Physical Demonstration Prototype

Using a Vex Robotics design system [5], a prototype was constructed to demonstrate the deployment and retrieval concept for a polar seismic TETwalker robot. This was done using sliding links and attaching a small motor to the top link of the center node in order to show the vertical movement of the geophone. The robot can wirelessly or automatically lower and raise the center node. Therefore the prototype is capable of autonomously demonstrating the geophone insertion and retrieval process. Fig. 9 shows images of the prototype in an office setting.

Fig. 9: The prototype in an office setting: upright (left) and deployed (middle and right).

VIII. Conclusion

In this paper we have discussed the different designs and approaches for a polar Seismic TETwalker. This document included the comparison between two principal designs: the 12-TETwalker and the 4-TETwalker. The 12 TETwalker is a robot whose architecture is composed of 12 geometrical shapes, whereas the 4-TETwalker offers a more simple design as it is composed of only 4 geometrical shapes. The 12-TETwalker offered room for up to eight geophones, but in order to be able to use all of the geophones at the same time the design became too complicated. The 4-TETwalker design only allowed the team to use one geophone at the same time; however, it offered a much simpler design which allowed us to control the position of the geophone with much more precision. The broadband seismometer alternative was also mentioned in this document, even though it provides a wider range and it helps to save energy because it does not require the TET to move from its position in order to gather data from a large area. Its technology is big and heavy, which will make it difficult for the TETwalker to transport it. The L.A.R.A application for polar seismic data acquisition was also described, where L.A.R.A is a new type of TETwalker which resembles a moving sheet or mattress. This type of TET offers the capability to house a
large amount of geophones and use them at the same time thanks to its design and ability to move in a
variety of ways. A prototype was also developed to demonstrate the geophone insertion and retrieval
process. Using a TETwalker swarm for seismic data gathering, these designs can be applied at virtually any
location on the planet. If this project is a success, the technology could be used to gather seismic data on
other planets or asteroids in space.

IX. REFERENCES