An Exploration of a Self-Burrowing Robots Vertical Penetration into Granular Media.

Garth Sommers, Dr. Julian Tao, Sarina Shahhoseinni

Lesson Details

Subject Area(s): Environmental Science

Focus Grade Level: 11th.

Grade Level Range: 10- 12th.

Research Background

Researchers with the Center for Bio-mediated & Bio-inspired Geotechnics (CBBG) at ASU have taken on the challenge of understanding the mechanics of self-burrowing, to develop a robot that can independently burrow and maneuver underground. Moving underground is an inherently difficult problem, but it is one that nature has already solved in a variety of ways; from plant seeds that can embed roots, razor clams that bury themselves in sand, to ants and mole rats that construct elaborate underground habitats. CBBG scientists study these evolutionary innovations and look for ways to apply them to further our technology.

A small portable robot that can burrow and maneuver through soil could have a wide range of scientific, commercial, and military applications; they could be used for small scale tunneling, to embed sensors underground for seismic monitoring, test soil properties, obtain samples, search for mineral and fossil fuel deposits, and potentially enable exploration under the surface of other planets and moons.

Lesson OVERVIEW

This lesson challenges students to apply knowledge of Newton's laws of motion to describe an object's motion using appropriate physical science vocabulary. Prior to giving this lesson, students should already be familiar with Newton's laws, force descriptors, and free body diagrams.

This problem-based activity has 3 objectives:

1. Give students an opportunity to apply the tools and vocabulary of physics to an unsolved engineering problem, connecting the abstract concepts of forces and Newtons laws to a real-world problem.
2. Give students a better understanding of the process of science, through the application of science and engineering practices.
3. Introduce students to the Center for Bio-inspired and Bio-mediated Geotechnics, to connect classroom activity to real ongoing University level research projects.

ASU researchers are working on better understanding the mechanics of self-burrowing to potentially develop a working self-burrowing robot. This lesson makes use of a simple prototype robot to demonstrate the progress and challenges of self-burrowing. Students are asked to describe the motion of the robot in one dimension, using Newtons laws. They are challenged to identify specific problems that must be overcome to achieve the goal of a self-burrowing robot that can move and change direction underground, then propose design solutions and plan the next stage of research.

Materials and Equipment

This activity requires a demonstration of a self-burrowing robot's motion in granular media. The demonstration can be presented on video (attached) or live.

A live demonstration will require the following:

A glass tank filled with 1.5mm diameter glass beads.

A prototype self-burrowing robot consisting of a 3D printed stator containing two 5V motors driven by motor drivers, two 3D printed augers, a laptop computer and an Arduino board to program and control the robot.

Attachments

Video of robot reaching maximum depth: _DSC0023.MOV - Google Drive

Educational Standards

Arizona Science Standards:

HS.P2U1.6 Collect, analyze and interpret data regarding the change in motion of an object or system in one dimension, to construct an explanation using Newton's Laws.

HS.P3U2.7 Use mathematics and computational thinking to explain how Newton's laws are used in engineering and technologies to create products to serve human ends.

Next Generation Science Standards:

HS-PS2-1 Motion and Stability: Forces and Interactions: Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

HS-PS2-3 Motion and Stability: Forces and Interactions: Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.

HS-PS3-3 Energy: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Learning Objectives

Students will be able to describe the motion of a self-burrowing robot in granular media using Newton's Laws and construct an explanation of the robot's observed motion in the demonstration, to propose potential design improvements and plan the next stage of research.

Students will examine the mechanical forces of locomotion through other media (water and air) to identify the additional challenges of moving through soil.

Lesson Procedure

Bell work question: 1. Identify at least 3 organisms that can burrow through soil. Submit responses in Canvas.

Class Discussion: Think pair share: Students will share their responses to the bell work question with a neighbor, then some will be called on to share with the class until we've collectively identified and thought about several burrowing organisms. Draw attention to different strategies, i.e. razor clams, mole rats, seeds, etc.

Next, imagine if we had a robot that could self-burrow; what could such a robot be used for? List as many possible applications as you can think of in 5 minutes. Share and discuss responses.

Consider if it is possible to create a robot that can self-burrow. Students will be asked to describe what such a robot might look like, and what potential problems or obstacles developing such a robot might face. Students will submit a written response.

Presentation: Students will be given an overview of the CBBG and some examples of their ongoing research, before focusing on the self-burrowing robot project. Students will observe a demonstration of the CBBG self-burrowing robot moving first horizontally, then vertically in a tank of glass beads simulating soil. The demonstration can be presented through recorded video but will preferably be done in person if the materials are available. The key point of the demonstration is that the robot is able to move, but its motion is limited. When moving horizontally it tends to push upward rather than keep a linear path. Vertically it is only able to move a short distance before the increasing pressure of the granular media brings it to a halt. As yet there is no capacity to steer the robot.

Problem based learning activity: Students will be asked to observe the robot's motion, then describe and explain their observations using Newton's laws. Students will write a research proposal with an idea for a change or improvement to the robot's design that addresses one the engineering challenges. Given that experimental trials are costly and time consuming, students must explain and justify their idea, referencing Newton's Laws of motion and using the vocabulary of forces and motion. They will include a free body diagram of their proposed design change, which correctly identifies the forces that determine or restrict the robot's motion.

Introduction/Motivation

What are some potential applications of a self-burrowing robot?

Is it possible to create a self-burrowing robot?

What engineering problems or technological challenges must be overcome to achieve a working prototype?

What is the current state of the research on this subject?

What next step should be taken to advance our progress toward the development of self-burrowing robots?

Learning Activities/Strategies

Bellwork: Students are given a prompt, question or instructions to follow immediately upon entering the room. It is written on the board and gets them started working or thinking while thinking while attendance is taken.

Think-Pair-Share: The bell work for this lesson asks students to think of 3 organisms that burrow and record their response in canvas, the bell work serves as the 'think' portion. Once attendance is finished the teacher moves on to 'pair', and asks students to trade responses with a neighbor. After a moment or two the Teacher invites students to share out with the class and calls on students as needed until we've brought up and discussed a variety of burrowing organisms.

Demonstration of self-burrowing robot: Students record and describe their observations, then attempt to explain what happened using Newtons laws. Identify a problem that limits the motion or function of the robot and propose a design change or improvement. Explain how the proposed change will improve the robot's function. Students submit written responses on Canvas.

Draw a Free-body diagram: Correctly identify and describe the forces both causing and restricting the motion of the robot. Illustrate your proposed design change and explain how it will improve the robot's function.

Closure

If we are able to acquire a classroom prototype of the robot, students will be directed to Tinkercad and Solidworks. They will be given the option to redesign robot components on their own. We could potentially 3D print and try out their designs.

A list of the student's design improvement ideas will be shared with the ASU researchers who developed the self-burrowing robot project.

Assessment

Formative Assessment

The bell work, think-pair-share and classroom discussions provide opportunities for formative assessment. During instruction and demonstration, we will talk through the forces and laws of motion and discuss how they apply to what is observed. I ask students to explain to me verbally what they will later be asked to put into writing, so I can provide feedback before they submit the graded response.

Summative Assessment

Students will be graded on their free body diagrams and the written responses submitted on Canvas. Their diagrams should accurately identify the normal force, contact forces, rotational thrust, gravity, and show how the interaction of forces determines the robot's motion. It should illustrate how their proposed change will change the balance of forces to affect the robot's motion.

They will not be graded on the quality or feasibility of their design improvement idea; only on whether they submit a clearly articulated idea that shows they understood at least one of the engineering challenges or problems encountered by self-burrowing robot and put some thought into how to go about solving it.

Contributors

Individuals

Dr. Julian Tao, Sarina Shahhosseini, Jannette Marti-Subirana

References

List citation information for any graphics or copyright material used in the development of this lesson.

J. Tao, "An explanation with a geotechnical flavor," 2023. [Online]. Available: https://juliantao.github.io/big/self-burrowing.html#an-explanation-with-a-geotechnical-flavor. [Accessed: Jun. 24, 2023].

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