A tiltable head could improve the ability of undulating robots to navigate disaster debris (w/ video)

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Using this robot, researchers at Georgia Tech were able to show that when its wedge-shaped head was set flat on the horizontal plane, negative lift force was generated and the robot moved downward into the medium. As the tip of the head was raised from zero to 7 degrees relative to the horizontal, the lift force increased until it became zero. At inclines above 7 degrees, the robot rose out of the medium. Credit: Georgia Tech/Daniel Goldman

Search and rescue missions have followed each of the devastating earthquakes that hit Haiti, New Zealand and Japan during the past 18 months. Machines able to navigate through complex dirt and rubble environments could have helped rescuers after these natural disasters, but building such machines is challenging.

Researchers at the Georgia Institute of Technology recently built a robot that can penetrate and "swim" through granular material. In a new study, they show that varying the shape or adjusting the inclination of the robot's head affects the robot's movement in complex environments.

"We discovered that by changing the shape of the sand-swimming robot's head or by tilting its head up and down slightly, we could control the robot's vertical motion as it swam forward within a granular medium," said Daniel Goldman, an assistant professor in the Georgia Tech School of Physics.

Results of the study will be presented on May 10 at the 2011 IEEE International Conference on Robotics and Automation in Shanghai. Funding for this research was provided by the Burroughs Wellcome Fund, National Science Foundation and Army Research Laboratory.

The study was conducted by Goldman, bioengineering doctoral graduate Ryan Maladen, physics graduate student Yang Ding and physics undergraduate student Andrew Masse, all from Georgia Tech, and Northwestern University mechanical engineering adjunct professor Paul Umbanhowar.

"The biological inspiration for our sand-swimming robot is the sandfish lizard, which inhabits the Sahara desert in Africa and rapidly buries into and swims within sand," explained Goldman. "We were intrigued by the sandfish lizard's wedge-shaped head that forms an angle of 140 degrees with the horizontal plane, and we thought its head might be responsible for or be contributing to the animal's ability to maneuver in complex environments."

For their experiments, the researchers attached a wedge-shaped block of wood to the head of their robot, which was built with seven connected segments, powered by servo motors, packed in a latex sock and wrapped in a spandex swimsuit. The doorstop-shaped head -- which resembled the sandfish's head -- had a fixed lower length of approximately 4 inches, height of 2 inches and a tapered snout. The researchers examined whether the robot's vertical motion could be controlled simply by varying the inclination of the robot's head.

Before each experimental run in a test chamber filled with quarter-inch-diameter plastic spheres, the researchers submerged the robot a couple inches into the granular medium and leveled the surface. Then they tracked the robot's position until it reached the end of the container or swam to the surface.

The researchers investigated the vertical movement of the robot when its head was placed at five different degrees of inclination. They found that when the sandfish-inspired head with a leading edge that formed an angle of 155 degrees with the horizontal plane was set flat, negative lift force was generated and the robot moved downward into the media. As the tip of the head was raised from zero to 7 degrees relative to the horizontal, the lift force increased until it became zero. At inclines above 7 degrees, the robot rose out of the medium.

"The ability to control the vertical position of the robot by modulating its head inclination opens up avenues for further research into developing robots more capable of maneuvering in complex environments, like debris-filled areas produced by an earthquake or landslide," noted Goldman.

Georgia Tech School of Physics assistant professor Daniel Goldman and his team were able to show that by tilting this undulating robot's head up and down slightly, they could control the robot's vertical motion as it traveled forward within a granular medium. The robot is built with seven connected segments, powered by servo motors, packed in a latex sock and wrapped in a spandex swimsuit. Credit: Georgia Tech/Daniel Goldman

The robotics results matched the research team's findings from physics experiments and computational models designed to explore how head shape affects lift in granular media.

"While the lift forces of objects in air, such as airplanes, are well understood, our investigations into the lift forces of objects in granular media are some of the first ever," added Goldman.

For the physics experiments, the researchers dragged wedge-shaped blocks through a granular medium. Blocks with leading edges that formed angles with the horizontal plane of less than 90 degrees resembled upside-down doorstops, the block with a leading edge equal to 90 degrees was a square, and blocks with leading edges greater than 90 degrees resembled regular doorstops.

They found that blocks with leading edges that formed angles with the horizontal plane less than 80 degrees generated positive lift forces and wedges with leading edges greater than 120 degrees created negative lift. With leading edges between 80 and 120 degrees, the wedges did not generate vertical forces in the positive or negative direction.

Using a numerical simulation of object drag and building on the group's previous studies of lift and drag on flat plates in granular media, the researchers were able to describe the mechanism of force generation in detail.

"When the leading edge of the robot head was less than 90 degrees, the robot's head experienced a lift force as it moved forward, which resulted in a torque imbalance that caused the robot to pitch and rise to the surface," explained Goldman.

Since this study, the researchers have attached a wedge-shaped head on the robot that can be dynamically modulated to specific angles. With this improvement, the researchers found that the direction of movement of the robot is sensitive to slight changes in orientation of the head, further validating the results from their physics experiments and computational models.

Being able to precisely control the tilt of the head will allow the researchers to implement different strategies of head movement during burial and determine the best way to wiggle deep into sand. The researchers also plan to test the robot's ability to maneuver through material similar to the debris found after natural disasters and plan to examine whether the sandfish lizard adjusts its head inclination to ensure a straight motion as it dives into the sand.

Provided by Georgia Institute of Technology