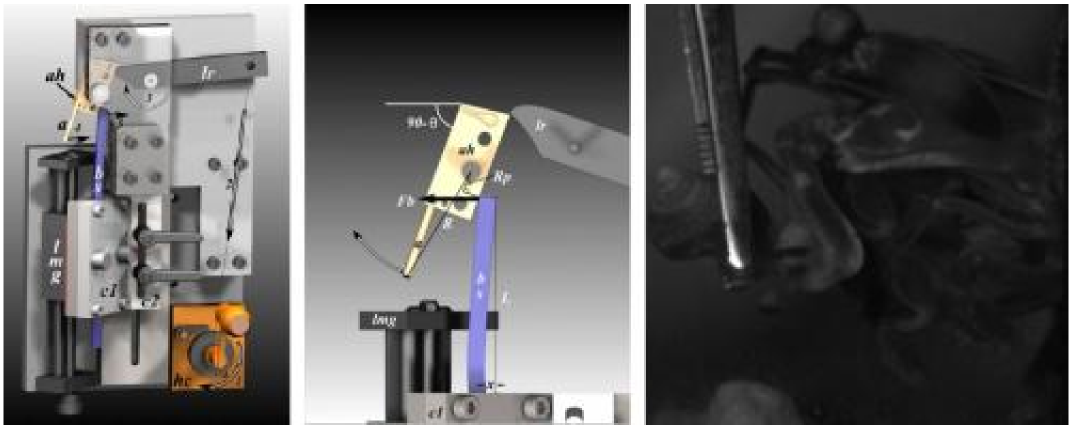
Ninjabot strikes with force of a mantis shrimp

February 28 2014, by Lisa Zyga



(Left) In Ninjabot, a hand crank (hc) is used to rotate a loader (lr) clockwise, which causes the appendage holder (ah) to rotate counterclockwise. This causes the beam spring (bs) to deflect while also rotating the appendage (a) into the pre-loaded position. (Center) To release Ninjabot's appendage, the loader slides past the end of the appendage holder to release the stored energy in the beam spring, exerting a torque on the appendage holder and causing the appendage to rapidly rotate clockwise. (Right) Screenshot of O. scyllarus using a similar spring-loading mechanism to smash a snail shell from the video below. Credit: S. M. Cox, et al. © 2014 IOP Publishing Ltd

Although mantis shrimp have captured the public's fascination with their ability to strike and kill their prey with stunning force, the underlying mechanisms involved in the high-speed strike are not fully understood by scientists. So a team of researchers, S. M. Cox, et al., from the University of Massachusetts, Amherst, has designed and built a robot, called Ninjabot, that imitates the mantis shrimp's strike and may help reveal the kinematics behind the powerful maneuver.

Powerful little shrimp

Imitating a mantis shrimp's appendages is a complicated endeavor for many reasons, with the most obvious being the appendages' extreme speed. Previous research has shown that the shrimp's fast movement causes cavitation, which is the formation of bubbles due to a quick drop in pressure. When these bubbles move to areas of higher pressure, they quickly collapse to form shock waves that are so powerful that they can break open mollusk shells and erode holes in nearby metal, such as boat hulls. The heat produced by these shock waves equals the temperature at the surface of the sun (over 5000 K).

As the scientists note in their study, mantis shrimp are not the only animals that harness the intense forces of cavitation bubbles. For example, whales can create cavitation bubbles by flapping their tails, stunning large schools of fish. Fungal spores and some insects also rely on cavitation for different purposes.

In this study, the researchers for the first time measured the strike velocity (30 m/s) and acceleration (1.5×10^5 m/s^2) of the mantis shrimp *Gonodactylus smithii*, which they caught off the coast of Australia. These values are the highest reported to date for any species of mantis shrimp. For comparison, this acceleration is only somewhat lower than the average acceleration of a bullet in the muzzle of a gun (4.4×10^5 m/s^2), although a bullet has significantly faster velocity (around 400 m/s).

Although many human inventions can achieve accelerations in the mantis shrimp's range, they usually require explosive materials, like in a gun or an engine. In contrast, mantis shrimp use a spring-like mechanism that is tightened and then released to generate acceleration.

No explosives required

To mimic the mantis shrimp's striking appendage as closely as possible, the researchers designed Ninjabot to also use a spring to achieve high acceleration. While a mantis shrimp uses muscle to load the spring and a latch to release the stored elastic potential energy, the Ninjabot uses a crank system for loading and slides the loader away for release. In both cases, the release of the spring causes an appendage to rotate forward with extreme velocity. The researchers compare the mechanism to pushing on a door, since pushing close to the door's hinges requires little movement while the part of the door closer to the door knob experiences a much larger rotational motion.

In experiments, Ninjabot achieved a maximum velocity (25.9 m/s) and peak acceleration (3.2×10^4 m/s^2). Although these values are less than those of *G. smithii*, they closely match those of the second-fastest mantis shrimp species, *Odontodactylus scyllarus* (21 m/s, 10×10^4 m/s^2). Before this study, *O. scyllarus* had the fastest known strike of any mantis shrimp.

To the researcher's knowledge, Ninjabot's peak acceleration exceeds that of any biomimetic robot published to date, with the previous highest value belonging to a flea-inspired jumping robot (2×10^3 m/s^2).

"This study shows just how difficult it is to achieve these sorts of accelerations in water," coauthor Suzanne Cox, a graduate student at the University of Massachusetts, told *Phys.org*. "What the mantis shrimp are doing is astounding. The design principles that we learned in the process of building Ninjabot could be useful to anyone interested in generating super-high accelerations without explosives: store the energy in a big spring and use it to power something tiny."

Models imitating reality

By studying the Ninjabot with high-speed cameras, and controlling its parameters, the researchers also gained new insight into the kinematics of the mantis shrimp. One important finding was that the Ninjabot's velocity is the single most influential parameter on the formation of cavitation bubbles. Nevertheless, the bubbles still regularly form at velocities well below predictions and often fail to form at velocities well above predictions, indicating that stochastic components heavily influence the formation of these bubbles. The researchers hope that further experiments will shed more light on the formation of cavitation bubbles, in particular the mystery of how mantis shrimp manage to prevent bubble formation during non-impact strikes, allowing them to avoid self-injury.

Despite Ninjabot's record-breaking acceleration performance, it still has several physical limitations that prevent it from behaving exactly like its biological counterpart. For example, Ninjabot consists of 9 kg of steel, while one of *G. smithii*'s appendages is only about 0.4 g. In addition to weight and material differences, the robot's components are also of different shapes and sizes than those of the animal. The researchers view these differences as a testimony to the efficiency of biological design, as well as an indicator of the crucial role that materials play in any biomimetic system.

With the robot's limitations in mind, the researchers reflected upon the advantages and disadvantages of building a robot to study animal behavior compared to developing theoretical models to do the same. One advantage of performing tests on a physical robot, they note, is that while mathematical models risk simplifications that may miss key relevant performance parameters, "physical models cannot break the laws of physics."

"Mathematical models are only as good as our knowledge of the underlying physics and our ability to implement that understanding numerically," they succinctly wrote.

Still, the researchers acknowledged, in a very eloquent way, that Ninjabot's imperfections caused them question its usefulness and recall the purpose of creating physical models:

"One question recurred throughout Ninjabot's development: what could we hope to learn from a model that was not a perfect replica of the mantis shrimp? Picasso once said, 'We all know that Art is not truth. Art is a lie that makes us realize truth.' Building a model is like constructing a work of art, with only certain aspects actually mimicking reality. And often it is only through contrasting something that is close, but not identical, to the world that we come to notice details that were otherwise hidden. By changing one property at a time while holding others constant, Ninjabot could make apparent the effects of individual properties on ultrafast movements in a way that was difficult or impossible with natural variation alone. Systematic exploration is often useful when nature's response to design constraints are different enough from human solutions that our failure of imagination makes them difficult to discern."

More information: S. M. Cox, et al. "A physical model of the extreme mantis shrimp strike: kinematics and cavitation of Ninjabot." *Bioinspiration & Biomimetics*. DOI: 10.1088/1748-3182/9/1/016014

Citation: Ninjabot strikes with force of a mantis shrimp (2014, February 28) retrieved 18 April 2024 from https://phys.org/news/2014-02-ninjabot-mantis-shrimp.html