The physics of popping: Building better jumping robots

Researchers in Japan unlock the secrets of shell-structure jumping

Inspired by a simple children's toy, a jumping popper toy, researchers have unlocked a key to designing more agile and predictable soft robots. Soft robots, made from flexible materials, hold immense promise for delicate tasks, but their complex movements have been difficult to predict and control, especially dynamic actions like jumping. Now, a team from Keio University and The University of Osaka has published a study in *Advanced Robotics Research* detailing the physics behind the jump of thin hemispherical shells, a fundamental building block for jumping soft robots.

The team meticulously analyzed the jumping dynamics of these half-sphere shaped shells. Using a combination of precision experiments, numerical simulations, and theoretical calculations, they focused on the critical role of contact between the shell and the ground. They fabricated various silicone rubber hemispherical shells and used a desktop-scale experimental setup with air pressure to control their deformation. Multiple sensors captured the rapid shape changes, providing detailed data for analysis. To further investigate this phenomenon, they employed the Material Point Method (MPM) to create a numerical simulation, accurately reproducing the shell's complex deformation during the jump.

The key breakthrough lies in understanding the changing contact area between the shell and the ground. As the inverted shell snaps back to its original shape, the contact area transitions from a ring-like shape to a full disc. This seemingly simple transition is crucial for understanding the energy transfer that propels the shell upwards. By analyzing this contact dynamics, the researchers developed a predictive formula for jump height, dividing it into two key phases: the initial lift and the final snap. This formula accurately reflects both experimental and simulated results.

The ability to predict jump height is a significant advancement for soft robotics. It eliminates the need for extensive and time-consuming trial-and-error testing, enabling researchers to design robots tailored to specific tasks and environments. This is especially crucial in fields like exploration, search and rescue, and environmental monitoring, where robots must navigate complex and unpredictable terrain.

“This research highlights the importance of analyzing individual components to understand the overall performance of soft robots,” explains lead researcher Tomohiko Sano. “It demonstrates a shift towards theoretically driven design, enabling us to manufacture more sophisticated and effective soft machines.”

Co-author Ryuichi Tarumi, a professor at The University of Osaka, expands on the broader impact: “This foundational understanding of a fundamental building block opens doors to designing novel soft robots optimized for specific loading conditions without extensive parameter surveys.”

This research not only advances soft robotics but also offers valuable insights into elastic energy and movement principles, contributing to fields like biomechanics, materials science, and even aerospace engineering. It represents a significant leap towards robust, predictable, and truly capable soft machines.

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The article, “Snap and Jump: How Elastic Shells Pop Out,” was published in *Advanced Robotics Research* at DOI: https://doi.org/10.1002/adrr.202500041.

Summary:
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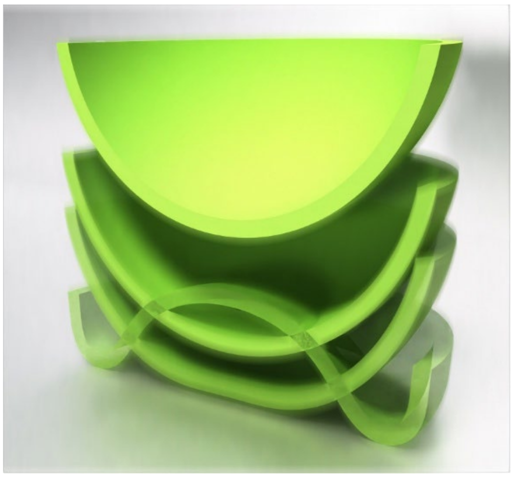

Fig. 1
Typical jumping behavior of a spherical shell obtained from simulation: it jumps from the inverted configuration back to its original shape.

Fig. 2
Jumping popper toys

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Credit: T. G. Sano (2025).

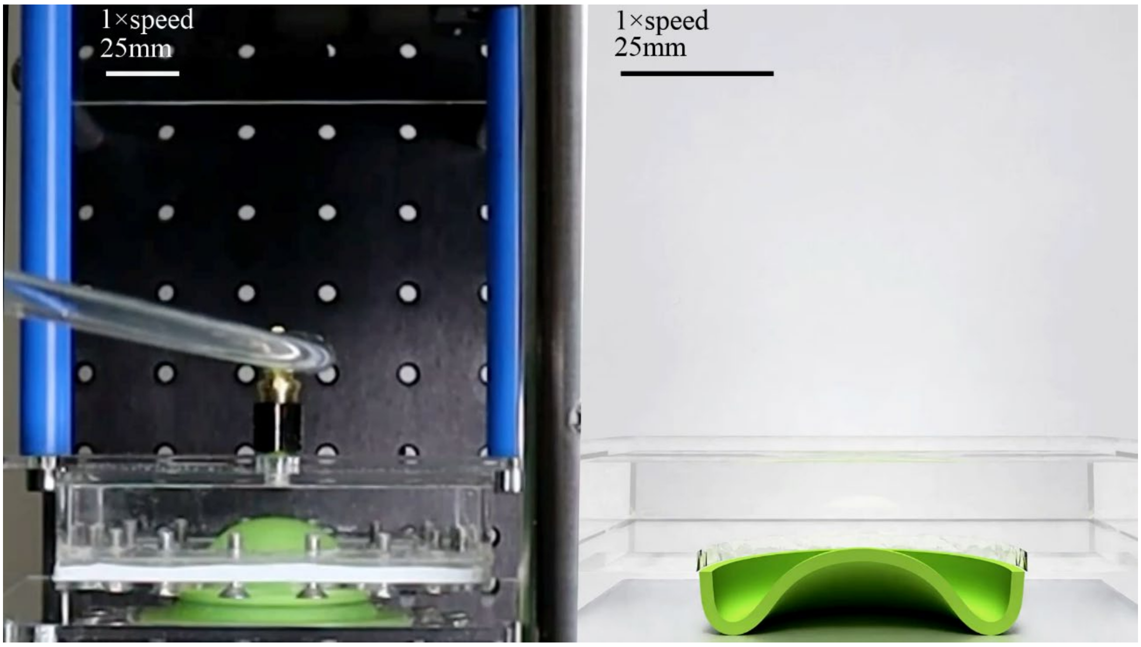

Fig. 3
Movie of the jumping moment in the experiment and simulation.

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Credit: 2025, T. Abe, I. Hashiguchi, Y. Nakahara, S. Kobayashi, R. Tarumi, H. Takahashi, G. Ishigami, T. G. Sano, Snap and Jump: How Elastic Shells Pop Out, *Advanced Robotics Research*

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About The University of Osaka

The University of Osaka was founded in 1931 as one of the seven imperial universities of Japan and is now one of Japan's leading comprehensive universities with a broad disciplinary spectrum. This strength is coupled with a singular drive for innovation that extends throughout the scientific process, from fundamental research to the creation of applied technology with positive economic impacts. Its commitment to innovation has been recognized in Japan and around the world. Now, Osaka University is leveraging its role as a Designated National University Corporation selected by the Ministry of Education, Culture, Sports, Science and Technology to contribute to innovation for human welfare, sustainable development of society, and social transformation.
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About Keio University

Established in 1858 by Yukichi Fukuzawa as a small school of Western learning, Keio has a history as Japan’s very first private institution of higher learning. Over 160 years since its founding, Keio has thrived under its founder’s motto of *jitsugaku*, or empirical science, as it continues to transform Japan as a modern nation through contributions to education, research, and medicine.
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