# Precise enough to pick fruit, powerful enough to lift a person—how the elephant trunk may revolutionize robotics

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Researchers have developed a soft robot that moves like an elephant's trunk—precise enough to pick fresh fruit, yet powerful enough to help lift a patient. Lucia Beccai, an expert in soft robotics at the Italian Institute of Technology in Genoa, had an idea while watching a documentary about elephants. She was amazed by the versatility of their trunks, which can delicately remove a single leaf from a tree and then shift massive logs.

That versatility was missing from today's robots. But what if researchers could emulate the anatomy and function of an elephant's trunk? It could revolutionize how robots handle objects, with applications from helping around the house to searching for survivors in rubble.

"The elephant trunk is really attractive because it's very dexterous and sensitive," said Beccai. "It is a sensory organ that is large-scale, boneless, but extremely versatile. Today, its performance is unmatched in robotics."

That observation became the seed for PROBOSCIS, a five-year research initiative that brought together biologists, engineers and materials scientists to decode the mechanics of the elephant's trunk.

The goal was to move beyond today's specialized grippers and create a more universal robotic hand—one that can gently grasp a grape or firmly lift a heavy object, and adapt to a wide range of shapes and textures without major hardware changes.

## Trunks: One continuous structure

Today, most robots have a rigid arm with motorized joints and a gripper on the end—separate elements with distinct limitations. These robots cannot perform what Beccai calls "whole-body manipulation": wrapping their entire arm around an object in a continuous, fluid way, unlike an elephant's trunk.

The trunk is what biologists call a muscular hydrostat, just like an octopus tentacle or a human tongue. With more than 100,000 individual muscles and no skeleton, it can extend, contract, bend and twist in any direction simultaneously, with no distinction between arm and gripper—it is one continuous structure.

The trunk is also remarkably strong, capable of carrying loads of almost 300 kilograms. African elephants even have two small finger-like protrusions at the tip for more delicate tasks.

## Simple moves, complex results

To better understand how the trunk works, Professor Michel Milinkovitch, an evolutionary biologist at the University of Geneva, led a team who turned to movie making techniques.

Bands of reflective marker spots—like those used in blockbuster films—tracked precise trunk movements as elephants manipulated objects of different shapes, sizes and textures at a South African reserve. Footage was taken with high-speed cameras, capturing a surprisingly efficient system.

"What we realized is that they are combining a small set of behaviors," said Milinkovitch. "Shortening of some sections, elongations of some sections, bending of some sections, and they combine them to achieve the task."

Milinkovitch found one movement particularly spectacular. When the elephants reached behind their heads—often to take a treat from a keeper—they did not just curl their trunk backwards.

Instead, they stuck out and temporarily stiffened the top section, creating two "pseudo-joints" that functioned like a shoulder and an elbow, with the lower section swinging backwards to grab the treat.

"That was absolutely mind-blowing, because nobody had ever seen this before. They do it very fast," Milinkovitch said. It showed that the trunk can form distinct sections separated by joints.

The team also performed anatomical studies on one male African and one male Asian elephant trunk, collected from deceased zoo animals.

## 3D muscles

To translate Milinkovitch's findings into robotics, Beccai's team focused on the trunk tip. They used 3D printing to merge sensing and artificial muscles, or actuators, into one seamless body. These pneumatic, balloon-like structures extend and contract as they are inflated and deflated with air. By varying their size and geometry, the researchers can program specific movements into the system.

To create a trunk-like soft robot, the researchers combined pneumatic actuators with a mesh-like lattice structure that can deform in multiple directions.

The device is printed in one continuous process from the same soft resin, including optical sensors that provide feedback on touch and the bending of the trunk tip.

The single material is key, Beccai said. "This is really important because it removes the material and mechanical interfaces between the different components, and that allows this continuity of motion, combined with sensory feedback."

The prototype can elongate, compress and bend, and also perform movements such as pinching, scooping and reaching. This design marks a step towards a truly universal gripper, capable of handling everything from soft, delicate objects to heavier, irregularly shaped items with a single, adaptable system.

The research project wrapped up in April 2025, and while the soft robotic arm remains a laboratory demonstrator for now, the team says it already overcomes most of the design issues holding back today's robotic arms.

## Gentle control

One of the key insights from the elephants was about control. The trunk contains thousands of muscles, but the elephant does not control them all.

Instead, Beccai explained, their brains control a small number of muscle synergies discovered by Milinkovitch's team, coordinated collaborations of muscles to perform a movement. The trunk's physical structure handles the rest.

This showed researchers how to make functional soft robots viable outside the laboratory: design future systems around synergies, not individual actuators.

Beccai hopes this will reduce complexity and energy demands, allowing devices to be battery-powered and easier to deploy. She envisions wide practical applications, from soft fruit harvesting—a major challenge in today's robotics—to domestic tasks such as sorting laundry or handling fragile dishes.

Such robots have potential in environmental applications, from handling debris and sorting waste to operating in fragile ecosystems without damaging surrounding plants, soil or marine life. In search and rescue, a soft arm could squeeze through rubble and use its sense of touch to help find people.

But it is assistive robotics that Beccai cares about most. "My dream is to build a system in health care that can help, for example, a disabled or elderly person by lifting them, but at the same time hand over a fork or a fresh piece of fruit," Beccai said.

A single robot, strong enough to assist with transfers yet gentle enough to handle daily objects, could allow people to live more independently. And unlike a conventional machine, its softness means it need not feel intimidating.

For Beccai, the goal was never just a better gripper. It was a robot that feels natural to be around—strong when it needs to be, gentle when it matters.

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