The soft power of nature-based robotics: Working towards a future artificial heart

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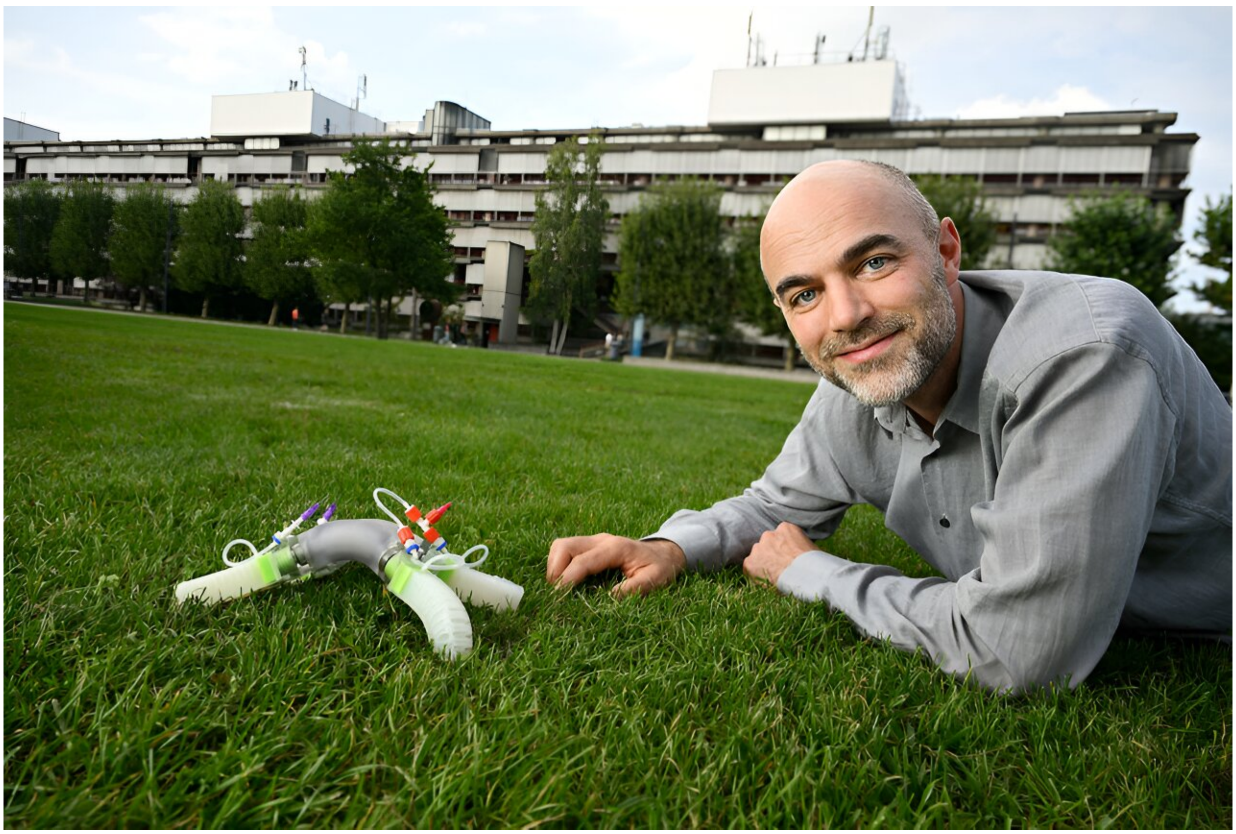

Luuk van Laake. Credit: Bart van Overbeeke

Implantation of a total artificial heart offers a solution for patients with severe heart failure, but existing artificial hearts have major limitations, which means there is a need for a better alternative. Through his doctoral research, Luuk van Laake has contributed to the development of a future artificial heart based on soft robotics.

His innovation is the use of a soft valve that causes the artificial muscles to contract and relax periodically, pumping blood through the body without the use of electronics. Van Laake defended his dissertation at the Department of Mechanical Engineering on 5 October.

Soft robotics is a relatively new but dynamic and multidisciplinary research field that explores the benefits of soft and flexible materials and structures. A lot of soft robotics research is based on biomimicry, or the creation of innovative solutions inspired by nature.

"Softness and flexibility are ubiquitous in nature and play an essential role in a variety of vital functions," Van Laake explains. "Think, for example, of a fish tail, which works more efficiently because it is flexible, or an octopus, which can crawl through a very small hole because it can compress its body, or an elephant's trunk, which can grasp all kinds of objects."

Embodied intelligence and autonomy

Soft robotics researchers study these benefits of soft structures—such as resilience, efficiency or versatility—and explore how the underlying principles can be applied in our devices. As an example, within soft robotics much work has been done on soft grippers that automatically adapt to the shape of whatever they are gripping, much like a human hand or an elephant's trunk.

"With a soft gripper, you can grasp all sorts of things without having to design a new gripper every time," he explains. "But the control is also easier. You just say 'grab,' instead of having to control the motion in detail."

This intelligence inherent in the mechanics themselves, without the use of electronics or software, is a basic example of embodied intelligence. Van Laake says, "Because there are soft parts in the robot, you get a system that automatically adapts to its environment."

This applies to the gripper, but on a more advanced level, this principle also underlies his doctoral research. In it, he demonstrates that a soft artificial heart can automatically adjust its heart rate to the patient's blood pressure, without the use of electronics in the heart and without external control signals. "If you think carefully about the combination of control, mechanics, and the environment, you can make soft robots that work autonomously," he asserts.

His dissertation is part of the "Hybrid Heart" project funded by the EU, in which a consortium of partners is working to develop an artificial heart, also called "total artificial heart" (TAH), based on soft robotics technology.

The consortium has brought together three things: in situ tissue engineering (bringing a substance into the body that is broken down there and replaced with the body's own cells), soft robotics for the mechanical structure and control, and a technology to wirelessly send the energy into the body—somewhat like a wireless phone charger—which allows the patient's skin to remain intact.

"If you successfully manage to bring these three things together, you can create the ideal artificial heart," says the Ph.D. candidate, who himself has made a contribution in the area of control.

"There are currently two TAHs in existence that already provide a solution for patients with severe heart failure, but both have major limitations," he continues. "They're made of rigid materials, so blood flows differently than in the human heart where everything is constantly in motion, and this can lead to blood clots. That requires medication which in turn has side effects, so it's not ideal."

"Moreover, existing TAHs are currently only used as a temporary solution for patients waiting for a donor heart; it's not a suitable long-term solution for several reasons," he continues. "For example, a tube runs through a hole in the patient's chest, connecting the artificial heart to a device outside of the patient's body. Because the tube passes through the skin, there is a risk of infection, and you can never disconnect the device, which restricts the patient's mobility quite a bit."

A soft alternative

The application of soft robotics results in a more natural circulation of blood. Combined with in situ tissue engineering, this eliminates the need for medication. Also, a soft heart fits more easily into any body because it is lighter, smaller and deformable.

"An added benefit is that you can also perform chest compressions on a soft heart, whereas for current artificial hearts, a first responder really can't do anything if something goes wrong," he adds.

"The challenge is to design an artificial heart that lasts for years. Drastically reducing the number of components helps in that regard. We do this by replacing electrically controlled valves and other electronics with soft, mechanical parts as much as possible."

Ketchup bottle

Instead of an electronic controller, Van Laake developed a so-called hysteretic valve that can create a heartbeat. The principle is surprisingly simple and can be understood easily and intuitively. This is because the valve is nothing more than the small rubber membrane we all know from the cap of a ketchup bottle. "My Ph.D. supervisor did his doctoral research in the United States. One day, when he was at a diner, he became fascinated by the behavior of the ketchup bottle cap. I decided to explore the idea further," he explains.

The idea is that under certain conditions, a continuous airflow results in pulsating, cyclic behavior. "When you squeeze a ketchup bottle harder and harder, nothing happens for a while, until suddenly ketchup squirts out, after which the process repeats itself," explains Van Laake.

The same mechanism is applied in the soft artificial heart using the hysteretic valve. "You blow a constant stream of air around in the system, which builds up pressure in front of the valve. When enough pressure has built up, the compressed air suddenly flows through the valve into the artificial muscles of the soft artificial heart, causing the heart to contract," he explains.

This resets the process which then starts to repeat itself. The result is a periodic alternation of contraction and relaxation, but based purely on mechanics, without external electronic control.

Broader application

Van Laake also applied the hysteretic valve he developed in robots with multiple artificial muscles that need to contract in a certain order to work properly. Among other things, he created a robotic hand that can drum its fingers and a walking mini-robot whose four legs take alternating steps.

Because of the way the control works, and because the legs are soft, such a walking robot can sense its surroundings, allowing it to, for example, turn around if it touches the wall. As such, this remarkably simple system has a wide range of applications.

Experiments have shown that the mechanism works and that the artificial heart can pump blood in this way, without the use of electronics. However, before it can be implanted in the first patients, several issues still need to be resolved, such as designing a pump that can be safely implanted.

Therefore, the promising project has now been awarded a follow-up grant and a new consortium, consisting of both current and new partners, will further develop the soft artificial heart. Van Laake is not yet sure whether he will be part of the new consortium, but he will remain involved in the project in any case, as it is very dear to his heart (no pun intended).

More information: Dissertation: research.tue.nl/en/publication … beat-for-soft-robots

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