UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA

GLOBAL RESEARCH IMMERSION PROGRAM FOR YOUNG SCIENTISTS (GRIPS)

Wireless Soft Actuators with Phase-Change Technology

A Leap Forward in Medical Robotics

Lin Yanxun, National University of Singapore, e0879242@u.nus.edu

BACKGROUND

Soft actuators, made from flexible materials, can be stimulated by heat, light, or magnetic fields to change their shape, move, or exert forces. Their unique properties, including adaptability and minimally invasive, made them promising tools for various applications, especially in the medical industry for intricate surgical procedures like balloon angioplasty. However, their effectiveness is limited by small output force and low work capacity. This research aims to overcome these limitations by advancing the design of soft actuators and improving force generation and operational efficiency through leveraging on phase change materials. Through introducing a low boiling point liquid into the balloon and subsequently heating it, the liquid undergoes a phase transition from liquid to gas. This transition occurs at relatively low temperatures, allowing the actuator to operate efficiently and safely within the body. As the liquid vaporises, it expands rapidly, generating the necessary pressure and force needed to inflate the balloon. This inflation capability is crucial for applications such as balloon angioplasty, where precise expansion is required to effectively clear arterial blockages and restore proper blood flow.

METHOD

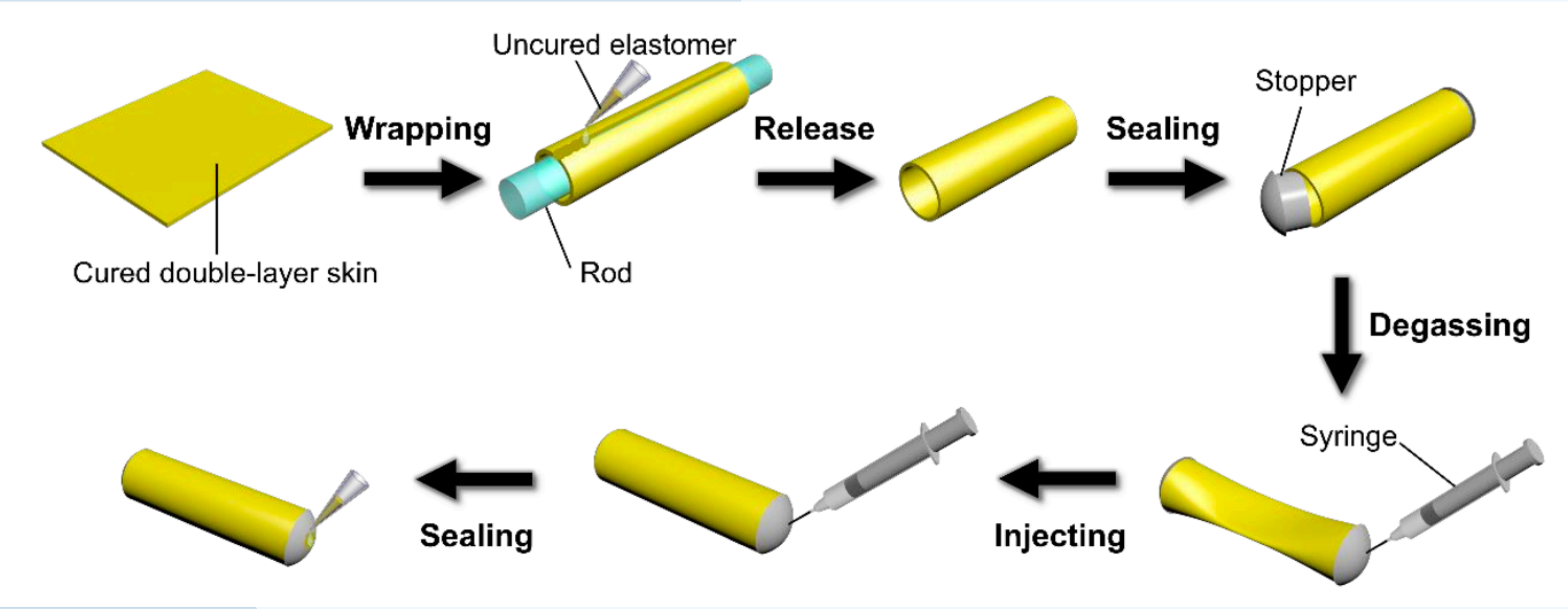

Figure 1: Fabrication process of phase-change actuator

1. Rectangular double-layer film is wrapped onto the surface of a glass rod to construct the cylindrical shape.
2. The edges and two ends are sealed up.
3. The magnetic moment is programmed to be along the axial direction of the actuator with a uniform magnetic field.
4. Low boiling-point liquid was injected into the interior of the actuator.
5. Magnetic radio-frequency heating of the actuator.

RESULTS & DISCUSSION

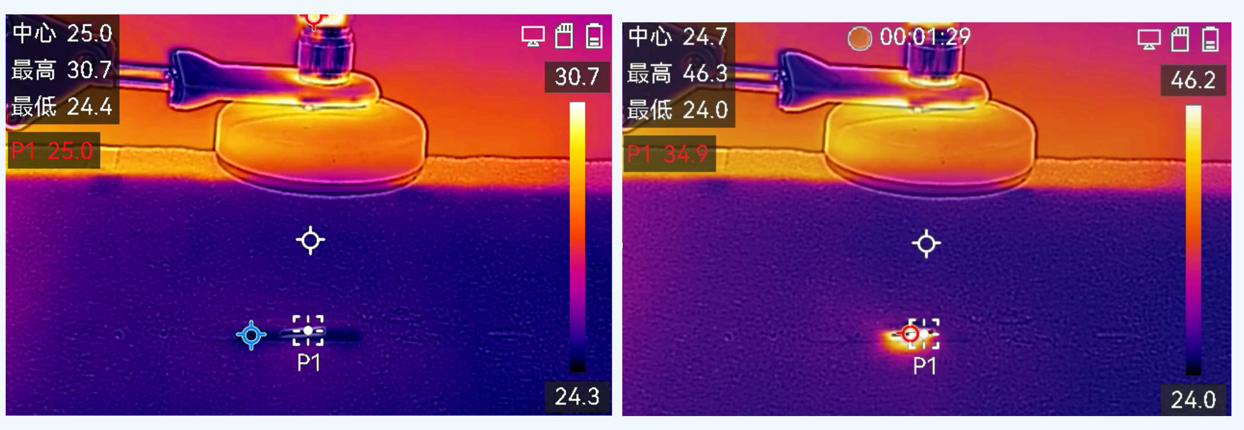

Figure 2: Infrared images of the phase-change actuator under heating

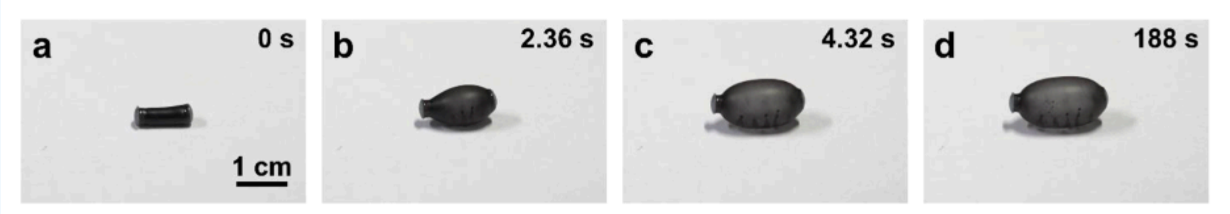

Figure 3: Camera images of the phase-change actuator when heated

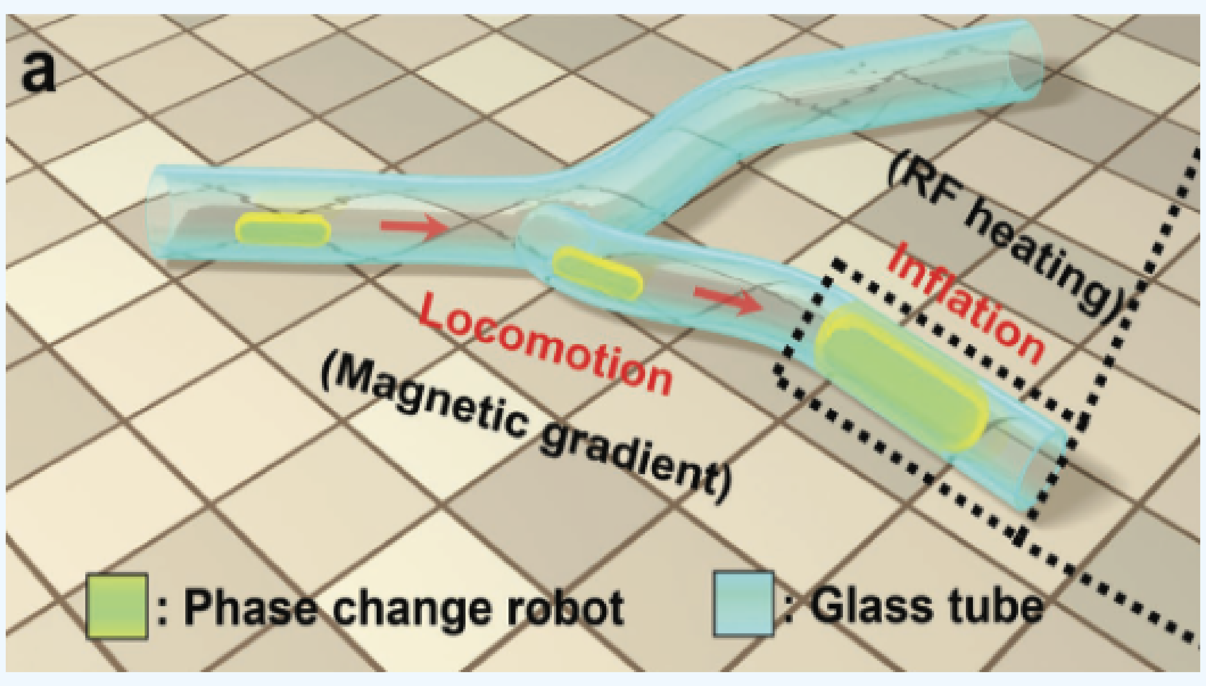

Figure 4: Camera images of the phase-change actuator changing direction by applying external magnetic field

A novel approach to treat stenosis and occlusion of arteries is provided by the proposed magnetic phase-change actuator, which can be used in an untethered balloon angioplasty. This innovative actuator not only inflates the balloon to clear blockages but can also navigate within blood vessels by applying an external magnetic field. This feature ensures targeted treatment by precisely guiding the actuator to hte location of the artery obstruction. By manipulating the magnetic field, the actuator's movement can be more precisely controlled, allowing it to navigate through the intricate and narrow pathways of the vascular system with minimal invasiveness.

Under the magnetic RF heating, the internal layer of the actuator can be heated, causing the entire actuator temperature to increase. Therefore, the internal low boiling point liquid vaporises, eventually leading to inflation of the actuator.

With a knowledge of the internal pressure and inflation stroke, output force and work capacity can be evaluated. The output force of the actuator can be defined as:

$(P-P_c) \times 2\pi RL$

where R, P and L indicate the radius, internal pressure and the length of the actuator after inflation, respectively; Pc is the internal threshold pressure when the actuator reaches the corresponding radius and length. This soft actuator exhibits an expanding deformation and enables up to 70N output force and 175.2 J/g work capacity under remote magnetic radio frequency heating, which are 10^6 - 10^7 times that of traditional magnetic soft actuators.

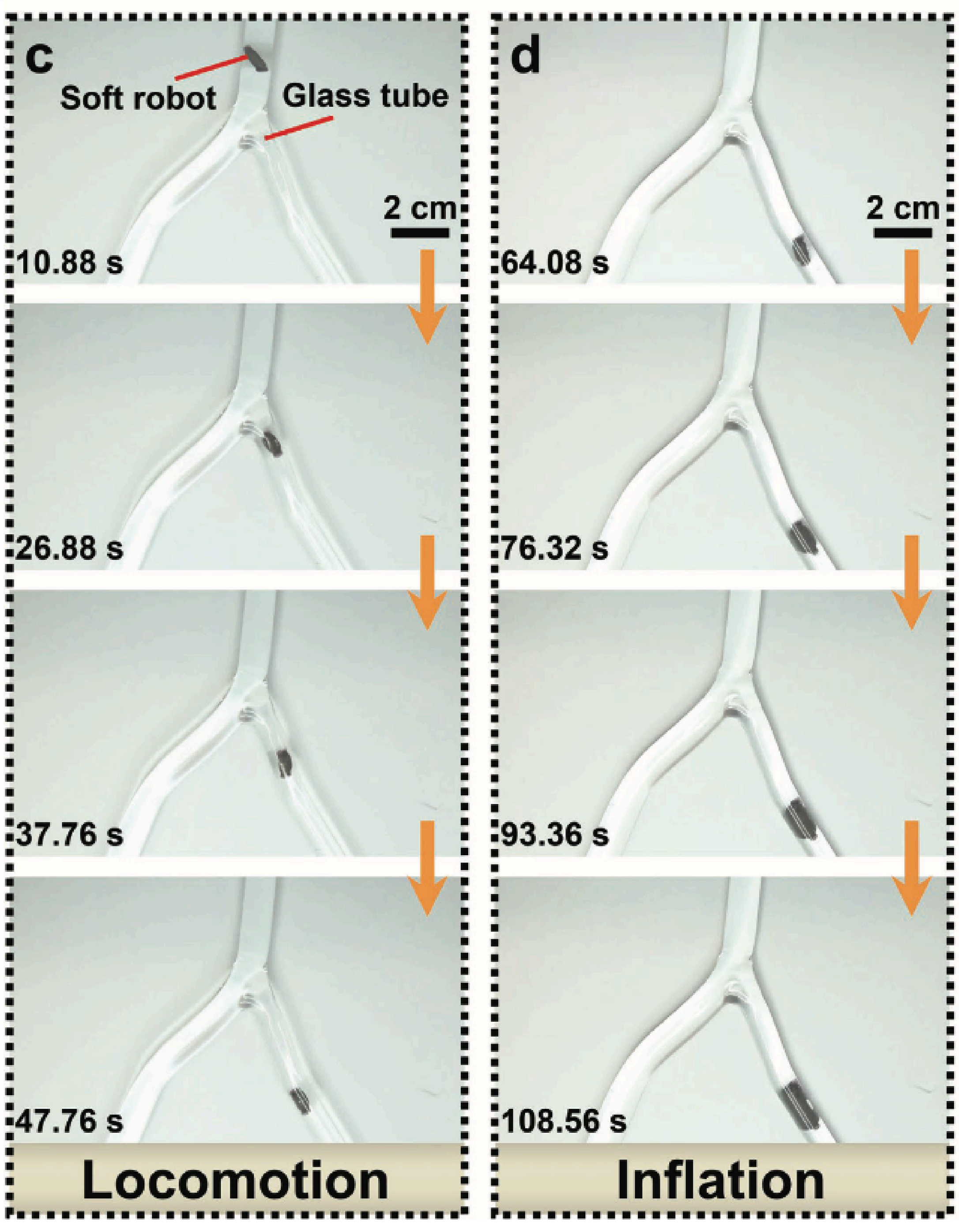

Figure 5: Image of phase-change actuator's locomotion and inflation

CONCLUSION

The development of a miniature phase-change soft actuator, as discussed in this study, represents a major advancement in the medical industry, offering enhanced mechancial output and versatility for a wider range of medical applications. The dual functionality of navigation and localized inflation can also potentially improve the efficiency and effectiveness of treatments for arterial stenoisis and occlusion. Further research should focus on optimizing the magnetic control mechanisms and ensuring biocompatibility to maximize the clinical viablity of ths innovative approach.

REFERENCES

Tang, Y., Li, M., Wang, T., Dong, X., Hu, W., & Sitti, M. (2022). Wireless Miniature Magnetic Phase-Change Soft Actuators. Advanced Materials, 34(40). https://doi.org/10.1002/adma.202204185