MAMMOBOT: A Robotic Platform for Early Detection of Breast Cancer Based on Soft Growing Robot Technology

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Introduction

The breast cancer has been one of the most dangerous cancers threatening the health and wellbeing of human beings. Only in the UK more than 55000 cases are reported per year, with a significant increasing trend [1]. The early detection of breast cancer has been proven as a key approach to improve the chances of survival for patients, which will also reduce the economic burden and physical suffering during the treatment procedure [2]. Different technologies have been developed to the detection of stage 0 breast cancer, that is DCIS (Ductal Carcinoma in Situ). While severe limitations exist among most of them, which makes them difficult to be widely employed as an efficient detection methods.
Therefore, the MAMMOBOT has been proposed and developed to address these limitations, which is a robotic platform based on millimetre-scale steerable soft growing robot for surgical applications. It aims to access the breast through the nipple and navigate the mammary ducts to detect the precursors of early-stage breast cancers.

Benefited by its significant safety and remarkable flexibility, the soft growing robot has been increasingly popular in medical robotics research community. Inspired by the natural growth of plants, the movement of it is achieved by tip eversion growing, thus there is no translational motion between the robot body and the surroundings. This property make it ideal candidate to navigate within lumen and deliver surgical instruments into the desired deep site of human body, like miniature endoscope, biopsy needle, catheters or optical probes. This helps to protect the delicate tissue from possible hazards that are introduced during the intervention procedure. Its clinical relevance and advances have been evaluated in the benchtop experiments using breast and mammary main duct phantoms.

Method

The MAMMOBOT system consists of a soft growing robot and a steerable catheter to navigate within the mammary duct and assess to the desired deep site. The soft growing element is fabricated by precise-localized heat sealing using dual LDPE sheet. The growing and extraction of the soft growing robot is regulated by the internal pressure. The actuation is controlled by a gamepad controller.

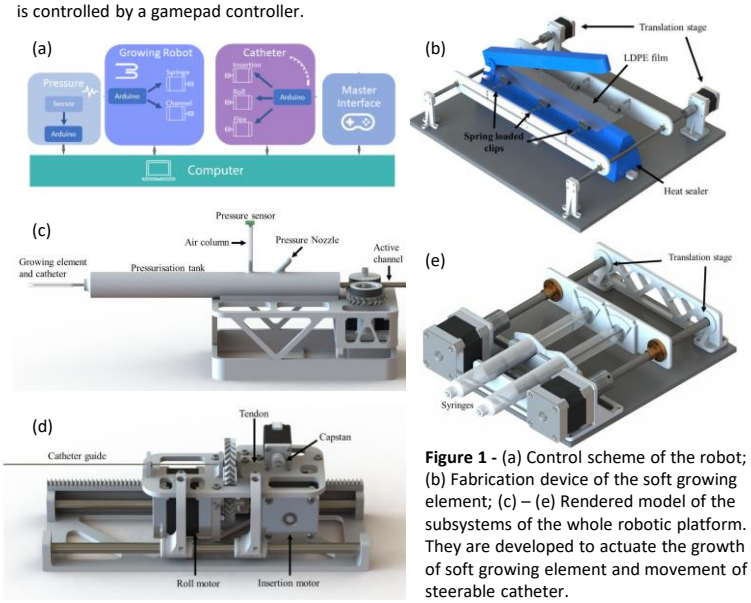

Figure 1 - (a) Control scheme of the robot; (b) Fabrication device of the soft growing element; (c) – (e) Rendered model of the subsystems of the whole robotic platform. They are developed to actuate the growth of soft growing element and movement of steerable catheter.

Results & Discussion

The benchtop experiments have been performed to evaluate the robot's capabilities. A duty cycle controller governs steering versus growing to achieve navigation in complex environments within a human-in-the-loop framework. The reduced order model is employed for dynamics modelling.

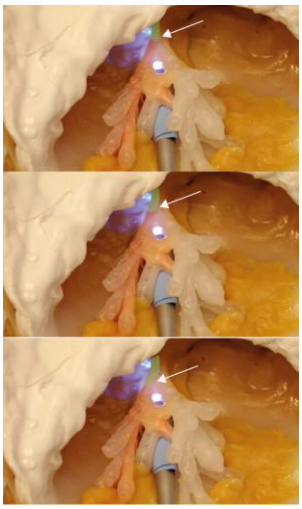

Figure 2 Robot insertion and catheter navigation within the main duct of the breast phantom. The catheter is labelled in green for better visualization.

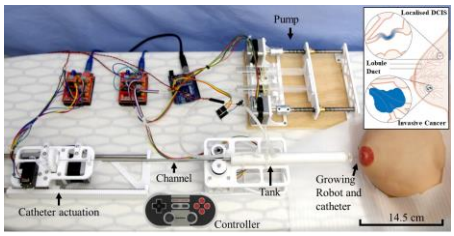

Figure 3 The experimental setup of MAMMOBOT. The catheter is navigated into the main duct of the breast for early detection of the breast cancer.

The features of MAMMOBOT were evaluated with a realistic bespoke breast phantom, which demonstrated the clinical relevance and potential impact of MAMMOBOT. A modelling framework is presented and verified in experiments to facilitate the control of robot. The future work will mainly focus on introducing force feedback onto the MAMMOBOT to guarantee a safer intraluminal navigation. The shape sensing is also considered. Theoretical investigation of growing sheath buckling, stiffening role of internal fluid pressure, and realistic environment interaction are also interesting research topics that worth investigating.

Current Optimization

To improve the performance of MAMMOBOT, Dynamixel motors are employed to actuate the steering, rotating, forward and backward motion of catheter, as well as the growing and extraction of soft growing element.

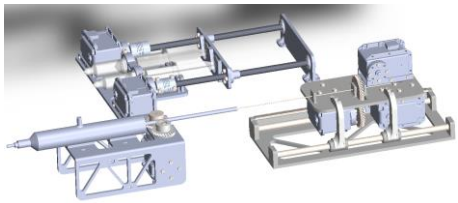

Figure 4 Remodeled MAMMOBOT with Dynamixel motor.

Figure 5 Steerable catheter with 3-DoF force sensing tip.

To reduce fatigue and improve the structural strength, a steerable catheter is redesigned with optimized notch. A sensing tip is designed to place FBG fibres to achieve multi-DoF (degree of freedom) sensing to guarantee a safety intraluminal navigation and operation. The multicore shape sensor are also going to be integrated for real-time shape sensing during the intervention procedure.

References

[1] Berthet-Rayne, P., Sadati, S., Petrou, G., Patel, N., Giannarou, S., Leff, D.R. and Bergeles, C., 2021. MAMMOBOT: A Miniature Steerable Soft Growing Robot for Early Breast Cancer Detection. IEEE Robotics and Automation Letters. Available from: https://ieeexplore.ieee.org/abstract/document/9387605?casa_token=3PtPhuTYLogAAAAA:h7sue9_whP7x8wgsxaljVzbPeCrmhYnhDey2EDawpyc3vuTW4MblvJdLK9V4jk5rYdKuod9Bg [Accessed 30th April, 2021]

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