Ultrasound-Guided Robotic Assistance in Low-Dose-Rate Breast Brachytherapy

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INTRODUCTION

A treatment for early-stage breast cancer is lumpectomy (tumor removal) followed by radiation therapy [1], mostly in the form of external beam radiation therapy (EBRT). EBRT is performed for near-daily sessions over the course of 5-6 weeks following a lumpectomy [2]. This is a highly demanding schedule, especially for those who live in rural communities.

One method to reduce the days required for treatment and localize the treatment is low-dose-rate (LDR) brachytherapy. In this treatment, radioactive seeds are permanently implanted via needles in the breast within or near the seroma (the cavity left after tumour removal) to deliver targeted radiation. The seeds emit radiation with a sharp gradient, limiting dose to healthy tissue. However, because of the low range, it is important to ensure that seed placement is accurate. Manual seed placement can be inaccurate due to limited visualization. To address this challenge, this work introduces an ultrasound (US) image-guided robotic assistance system designed to improve the clinician's ability to precisely and intuitively place the seeds without disrupting the typical brachytherapy procedure.

MATERIALS AND METHODS

The system utilizes a robotic arm equipped with a 2D US probe. Preoperatively, the robot autonomously performs a back-and-forth scanning motion across the patient's breast, recording the US images. The images are then stitched together and passed through U-Net, a convolutional neural network. U-Net returns a 3D model of the seroma and its position inside the breast.

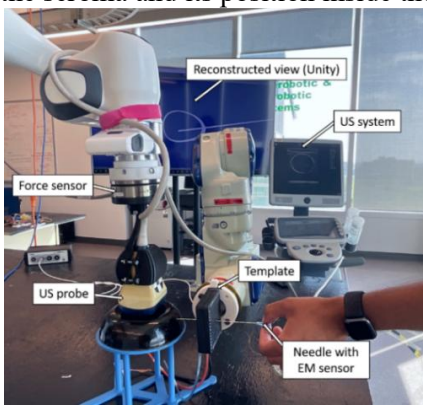
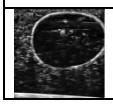
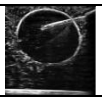
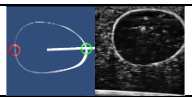


Fig 1 System set up [3].

The system also tracks the needle with an electromagnetic sensor during surgery, displaying a live view of the needle, both in a US view and a perpendicular virtual environment of the 3D-reconstructed seroma to the clinician.

For experimental validation, the system was tested with four modes (Table 1): Mode 1 – live axial view only; Mode 2 – live sagittal view only; Mode 3 – live axial view combined with a reconstructed sagittal view; and Mode 4 – live sagittal view combined with a reconstructed axial view. Each mode is defined by the view(s) provided to the clinician. The accuracy and mental strain of needle insertion into the seroma was measured and compared.

Table 1: Experimental modes [3].

Mode 1	Mode 2	Mode 3	Mode 4
			

RESULTS AND DISCUSSION

Modes incorporating the side US view (Modes 2 and 4) yielded significantly higher accuracy than Mode 1, with Mode 4 providing the best balance of accuracy and usability. Participants reported reduced mental load and frustration in Mode 4, highlighting the importance of intuitive visualization for effective guidance. These findings suggest that combining side US imaging with 3D reconstruction offers the most ergonomic and effective workflow for clinicians.

CONCLUSIONS

This robotic platform integrates automated imaging and real-time visualization to assist clinicians in LDR breast brachytherapy. Experimental results demonstrate improvements in accuracy and reductions in mental strain, highlighting the potential for safer, more efficient clinical workflows. Future work will focus on clinical trials and integration with planning systems for full intraoperative guidance.

REFERENCES

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