[DC] XR for Improving Cardiac Catheter Ablation Procedure

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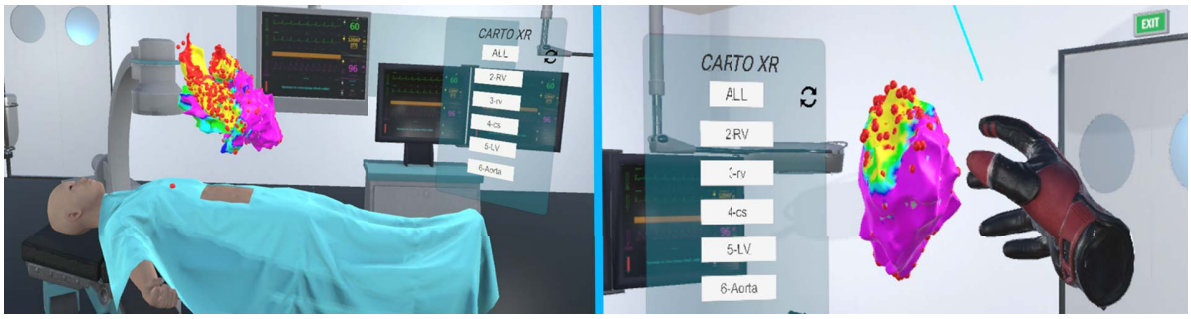

Figure 1: Initial prototype design with an immersive electrophysiology lab environment, an interactive 3D construction of electroanatomical data, and a GUI to control the visibility of each part of the constructed cardiac map.

Abstract

Cardiac arrhythmia refers to abnormalities of heart rhythm, and *cardiac catheter ablation* procedure provides the best therapeutic outcomes to cure this life-threatening pathology. An electrophysiologist clinically performs the procedure that involves navigating 'catheters' into the chambers of the heart through peripheral blood vessels, studying the cardiac electrophysiology and performing ablations. An electrophysiologist must possess a comprehensive understanding of cardiac electrophysiology and precise instrument handling due to the sensitiveness of the procedure. In the conventional approach, electroanatomical mapping systems and fluoroscopic visualizations are utilized to assist the procedure; however, their limitations reduce the procedure's effectiveness. Two main scenarios have been identified to improve the effectiveness of the procedure: intraoperative guidance and procedure training. This study aims to examine how extended reality technologies (eg. AR/VR) can be used to improve the effectiveness of the cardiac catheter ablation procedure.

Keywords: Arrhythmia, Cardiac Catheter Ablation, Extended Reality, Visualization, Intraoperative Guidance, Procedure Training

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interactive systems and tools; Human-centered computing—Visualization—Visualization systems and tools;

1 Introduction

Cardiac arrhythmia refers to abnormalities that occur in the heart rhythm due to complications in cardiac conduction pathways [3]. As arrhythmia leads to organ failures due to reduced blood ejection from the heart to the organs, and it can increase the risk of stroke, heart failure, and other heart-related complications [8], it is considered as a life-threatening pathology [7]. Catheter ablation, the best available therapy [8], is a minimally invasive procedure [3] that is performed by electrophysiologists to disrupt abnormal conduction pathways and stable the heart rhythm. Two potential scenarios have been identified where each of them consists of challenges that could negatively affect the procedure's effectiveness: intraoperative guidance and procedure training. Extended reality (XR) collectively refers to immersive technologies such as virtual reality (VR) and augmented reality (AR), which are increasingly used in medical/surgical HCI research contexts to improve immersive visualization and interaction.

Intraoperative Guidance- Although minimally invasive procedures provide fast recovery and effective results, electrophysiologists face significant challenges during the catheter ablation procedure that could affect the effectiveness of the procedure [6]. Cardiac catheter ablation procedure involves several phases: catheter navigation & vascular access, electrophysiology (EP) study, arrhythmia diagnosis and ablation delivery. Electroanatomical mapping systems (EAMS) and fluoroscopic imagery aid the visualization during the procedure. EAMS allows the user to understand catheter position, catheter tip orientation, cardiac anatomy and electrophysiology by displaying them as 3D electroanatomical maps. In these visualization methods, 2D screens are utilized to visualize 3D electroanatomical maps, which are often far from the position of the electrophysiologist. 2D screens do not offer depth perception of the 3D models, and that leaves an extra cognitive task [3, 6] of processing depth perception while determining catheter positions relative to the cardiac surface. In the contemporary EP lab setting, visualizations of the EAMS are handled by a technical operator, where the electrophysiologist requires to verbally instruct to manipulate the visualizations as needed. However, the drawback is that the electrophysiologist has to verbally instruct the operator each time even a fraction of a rotation needs to be changed and sometimes needs to repeat a few times until the satisfactory view occurs. The process produces extra stressful and tense situations [6] due to the misinterpretations of verbal commands. Since there are already challenges involved in each phase of the procedure, these technological limitations could negatively affect the outcome of the procedure. As AR enables visualization of 3D data with enabled depth perception, and user-based interactions where the user can explore electrophysiology data more closely, without disconnecting with the real world it can be considered as a feasible technology to utilize for an intraoperative guidance solution.

Procedure Training- Catheter ablation is a challenging procedure to perform and an even more challenging procedure to practice and master within a short predetermined training time period [4]. Electrophysiologists must possess a comprehensive understanding of cardiac electrophysiology and precise instrument handling with

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hand-eye coordination [7] due to the sensitiveness of the procedure. The procedure training also consists of several challenges that could affect the effectiveness of the procedure [7]. Although the current method of procedure training involves a set of strengths such as extensive arrhythmia education and one-to-one interactions with patients, it is identified that the limited time is allowed them to practice tasks. If a trainee takes much time, the supervisor takes over the procedure and finishes it, as the following case is due. Face-to-face interaction with real patients is required; however, it becomes a challenge if there are too many patients to handle with time limitations. The contemporary procedure training involves higher expenditure, ethical concerns for employing patients to the learning curve [5], and fewer opportunities for complete training [7]. Increased attempts of procedure training lead to increased duration of the procedure and increased exposure to the radiation for both patients and the trainees [9]. As there is a trade-off between patient's health and trainee practice, the current training method can be justified; however, it can be enhanced by using VR-based training simulators that eliminate the time and pressure dependencies. VR simulator-based training provides a low-cost and risk-free immersive training environment with patient specific data where trainees can iteratively practice skills without time dependencies.

In this research, two potential scenarios have been identified to improve the effectiveness of the cardiac catheter ablation procedure: intraoperative guidance and procedure training. The research aims to identify the most appropriate scenario and develop an XR-based software solution to address the challenges and limitations. This research will help to the knowledge of integrating XR technologies in cardiac electrophysiology.

2 Proposed Research

The proposed software solution is for the use of medical professionals so that the system design focuses on the user requirements to provide an effective user experience. A user-centred design approach [2], was followed to conduct the research because it defines how a system should be developed interactively, focusing on user requirements and interests, following ergonomic criteria and usability methods to improve productivity, acceptance, reduce errors and time to training as well as the best possible user experience. The research project is divided into four iterative phases.

Phase 1 - Understanding Context of Use: Initially, the research will explore the methods, practices, and challenges associated with the training and procedure. Then identify what aspects can be improved by using XR-based technologies to improve the procedure's effectiveness. Literature analysis and semi-structured interviews with electrophysiologists are conducted at this stage.

Phase 2 - Requirements: Semi-structured interviews will be conducted with electrophysiologists to identify the needs and interests of the users. At the end of this stage, a potential scenario from intraoperative guidance and procedure training will be chosen by considering user needs and technical feasibility.

Phase 3 - Design & Implementation: This phase includes designing and developing the software solution. Based on the initial prototype and the user feedback, the XR solution will be developed.

Plan A - Intraoperative Guidance: An AR application will be developed to visualize exported 3D cardiac electroanatomical data from CARTO EAMS (Biosense Webster, Inc.) in AR space, where users can interact with patient data more closely, manipulate as prefers using gaze/dwell based interactions and make effective intraoperative diagnosis. More features will be added by analysing user needs and interests.

Plan B - Procedure Training: A VR training simulation will be developed to practice challenging tasks that trainees need more experience such as catheter navigation, EP study, decision-making skills on ablation targets, and delivering effective ablations. An immersive training environment, interaction with patient-specific data, repeated training will be offered along with the risk-free, low-cost method for training. More features will be added by analysing user needs and interests.

Phase 4 - Evaluation: This phase includes the system evaluation. The initial prototype will be evaluated using formative usability testing to improve the usability and the user experience. The developed XR solution will be verified according to user needs and validated with user testing. Then summative usability testing will be conducted to find the effectiveness of the solution.

3 Research Progress

Currently, the research is in *Phase 2* where interviews are conducted to identify user needs and interests. Ethical approval was taken to conduct interviews with electrophysiologists from the Human Ethics Committee, Victoria University of Wellington. At the end of the stage, a potential scenario will be chosen by considering the user needs and technical feasibility associated with medical data with proprietary formats. Thematic analysis [1] will be used to analyze the qualitative interview data. The initial prototype (see Fig. 1) consists of VR-based visualization and interaction to CARTO exported electroanatomical data and operating room environment to reflect intraoperative guidance and the procedure training solutions.

In summary, the research aims to design and develop an extended reality software solution to improve the effectiveness of the cardiac catheter ablation procedure. This research follows a user-centred design approach to offer an effective solution aligned to the user needs. Following are the questions that I would like to discuss during the Doctoral Consortium: (1) What user needs to be included in the design between significant needs with a minority and ordinary needs with a majority? (2) What are the appropriate ways to conduct evaluation studies for an intraoperative guiding solution? (3) Is there anything else in this research that should be focused?

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