Interactive Cardiovascular Surgical Planning via Augmented Reality

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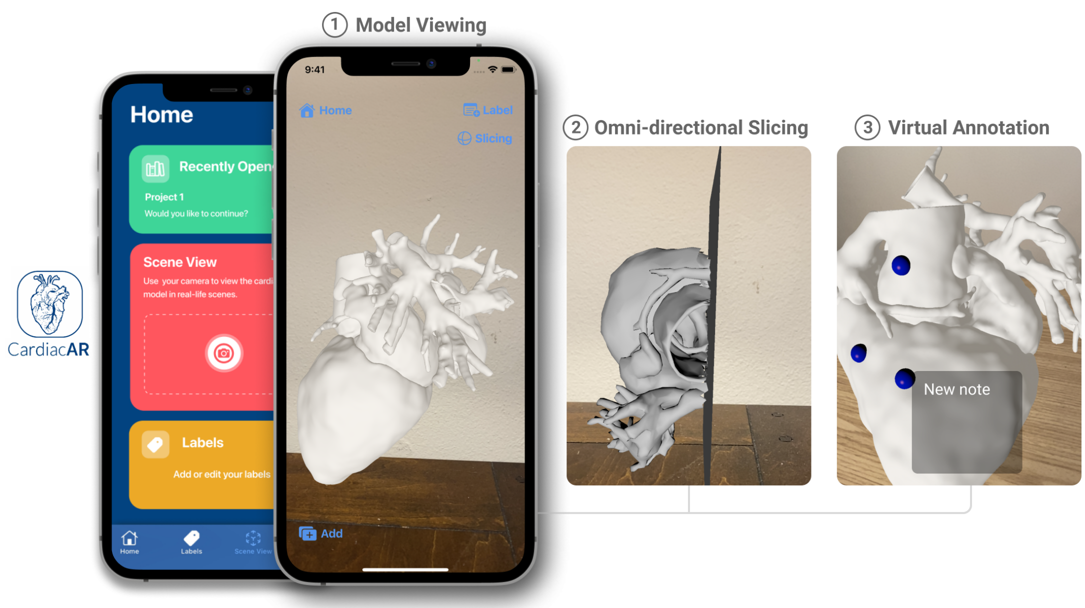

Figure 1: CardiacAR, an iOS augmented reality application that enables users to perform interactive surgical planning on mobile devices. (1) *Model Viewing* of the a heart model, supporting model rotation and re-sizing. (2) *Omni-directional Model Slicing* enables surgeons to flexibly perform reversible planar cuts of the model to reveal internal heart structure, which is important for planning cardiovascular surgeries. (3) *Virtual Annotation* allows users to tap on any locations on the heart model and attach notes.

ABSTRACT

The current practice for planning complex cardiovascular surgeries includes printing and cutting physical heart models. Unfortunately, such cuts are permanent, thus it is not possible to interactively experiment with different cuts, slowing the planning process. In collaboration with *Children's Healthcare of Atlanta Heart Center* (CHOA), we are exploring new ways to improve cardiovascular, or heart, surgical planning through augmented reality (AR). We

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are developing CardiacAR, an iOS AR application that enables interactive surgical planning on mobile devices. CardiacAR offers powerful and flexible tools critical for surgical planning, such as omni-directional slicing of patients' 3D heart models and virtual annotation to assist planning. We believe the ubiquity of iOS devices will help broaden access to the CardiacAR technology and streamline its deployment.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**.

KEYWORDS

augmented reality, mixed reality, surgical planning, ARKit

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1 INTRODUCTION

In collaboration with *Children's Healthcare of Atlanta* (CHOA), our research team is exploring new ways to improve cardiovascular, or heart, surgical planning through augmented reality (AR). Existing methods start by creating a *Digital Imaging and Communications in Medicine* (DICOM) file of the patient's heart data from *Magnetic Resonance Imaging* (MRI), *Computerized Tomography* (CT), or other types of scans. Then, the images of the heart are processed to build a digital model, saved as a 3D geometry definition file format, such as an OBJ file. A physical 3D model of the heart, printed from the digital model [4], can be beneficial for planning a safe surgery strategy [5] or training resident and novice surgeons. Unfortunately, cutting a printed model is an irreversible process. It is not possible to interactively experiment with different cuts, or "undo" a cut, hence significantly slowing the surgical planning process. The primary goal of our research is address this major shortcoming of current practices for planning a cardiovascular surgery. Our ongoing research makes the following contributions:

(1) **Enhancing surgical planning via interactive augmented reality tools.** We are developing CardiacAR, an iOS AR application that aims to enhance surgical planning by providing users with novel interactive tools important for planning, such as omni-directional slicing of patients' 3D heart models to reveal the organ's internal structures and virtual annotation to assist in recording clinical observations. CardiacAR takes as input digital 3D heart models (OBJ) built from MRI or CT scans (Figure 2). Different from virtual reality (VR) environments, which take away spatial intuition due to the lack of visual data of the real world and could induce motion sickness [6], AR offers the benefits of enabling surgeons to interactively work with digital heart models, and "anchoring" them in the physical space to support collaborative planning by multiple surgeons. Recent research suggested that devising surgical plans in a mixed reality environment were well-received by surgeons [1].

Figure 2: Patient MRI/CT heart scans are converted into 3D heart models, which can be input into CardiacAR.

(2) **Broadening technology access and streamlining deployment via iOS mobile deployment.** In contrast to current AR and VR headsets (e.g., Microsoft HoloLens, Oculus Quest 2), CardiacAR benefits from the ubiquity and portability of iOS devices, and their support of a wider range of interactions and gestures that are easy to use [2]. As the long-term goal of our research is to extend CardiacAR to support more types of models and surgical planning, our decision to build on the iOS ecosystem enables us to leverage its TestFlight online service for over-the-air installation and testing of our system. The Apple App Store will further help ease the distribution of our application, bringing it to more surgeons and health care providers.

2 SYSTEM DESIGN AND IMPLEMENTATION

CardiacAR is developed in XCode while utilizing ARKit[1] and SceneKit, native iOS frameworks which render virtual 3D objects within the real-world using the device's cameras and sensors.

2.1 Model Slicing

Conventionally during surgical planning with 3D printed heart models, surgeons will physically cut heart replicas to examine its internal structures (Figure 3). Seeing various internal segments and cavities of the heart helps surgeons prepare for what they will see in surgery [3].

[1] https://developer.apple.com/documentation/arkit

This is also confirmed by our collaborating cardiothoracic surgeon. For instance, the surgeon can put the plane across the ventricular septum or orient it across the left ventricular outflow tract and be able to see a ventricular septal defect and the aortic valve at the same time, which is helpful with closing some complex defects.

Model slicing is not a native feature within either ARKit or SceneKit. Our novel method renders polygons of the surface mesh on one side of the plane and hides those on the other side. While planar slicing for simpler solids using software like Unity is possible in iOS, it does not work for 3D heart models, as they contain hollow chambers and tubes. To the best of our knowledge, our approach is the first interactive model slicing app on iOS that is designed for surgical planning.

When the user is using the slicing tool, they can rotate and translate the slicing plane to update the sliced model in **real-time**. Rotating the slicing plane about its x-axis can be done by panning one finger horizontally across the screen, as shown in Figure 4. Y-axis rotation is done by panning vertically. Translating the plane is allowed through a two-finger pinch gesture; pinching out translates the plane by its normal, pinching out translates in the opposite direction. Leveraging the benefit of the AR environment, our approach allows the heart model to be "anchored" in the physical space, enabling a surgeon — with the potential to support multiple collaborating ones — to get a better view of specific sections of the model by simply moving around it.

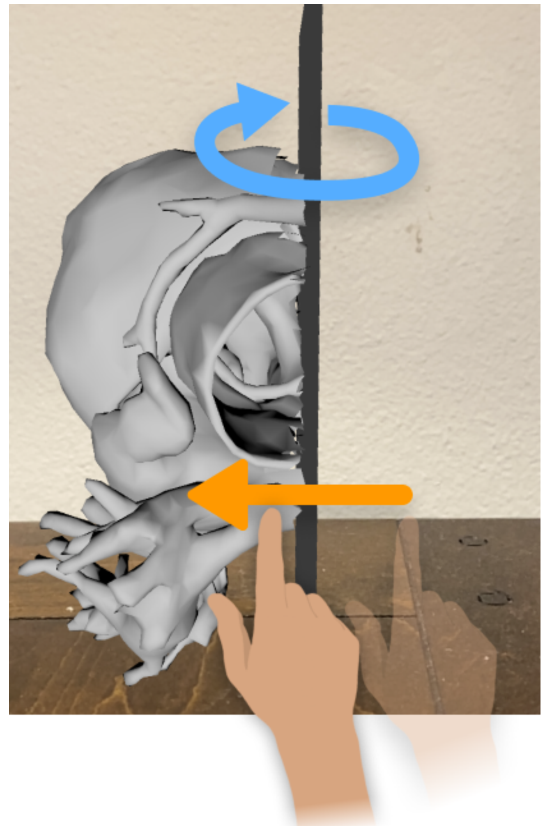

Figure 4: Rotating the plane around it's Y-axis can be done by finger panning horizontally.

Figure 3: A physically-cut 3D printed heart model

2.2 Virtual Annotation

Using CardiacAR, surgeons may annotate different parts of a heart model with notes in real time and revisit them at a later time. The user can annotate a precise location on the model by tapping on the screen. CardiacAR projects the tapped 2D location on the screen onto the 3D heart model using *raycasting*. A textbox will show up prompting the user to write their note, which is anchored to the point on the 3D heart model so it's relationship to this location is preserved (Figure 1.3).

2.3 Model Viewing and Importing

CardiacAR allows users to upload custom 3D models of a heart, via an OBJ file, which can be placed within an AR setting. Users can choose to add the model within open space directly in front of the camera or on any detected surface. Changing the position of the model is done by holding the 'add' button (Figure 1.1) to keep the model a set distance from the phone, moving the phone itself, and releasing once the right location is found. Resizing the heart can be done using a pinch-gesture, pinching out enlarges the heart and pinching in shrinks it.

3 USAGE SCENARIO: ASSISTING SURGEONS WITH CARDIOVASCULAR SURGICAL PLANNING

We now present a usage scenario to illustrate how CardiacAR may assist surgeons with cardiovascular surgical planning. This scenario is motivated by real-world practices of how 3D heart models are used for surgical planning. Ashley is a surgeon who will be performing a time-sensitive operation on a young patient with a complex heart condition. Due to the patient's young age, she knows that operating on the heart will necessitate careful, delicate cuts to the heart. For typical patients, she would have followed the conventional approach of first 3D printing a physical model of the heart. However, as time is limited, she cannot afford to wait. She decides that it would be best to plan her surgery using CardiacAR by interacting with the patient's 3D heart model and studying potential approaches to operate on the heart. Working with her cardiologist who has performed a CT scan for the patient, she first obtains the 3D model of the patient's heart in the OBJ file format supported by CardiacAR. She imports the heart model into the application, and it is rendered on her screen, similar to Figure 1.1 As she interacts with the model by rotating and scaling it, she uses CardiacAR's *virtual annotation* feature to write down her observations of areas of the heart with defects and where she may perform her initial cuts on the heart surface (Figure 1.3). To evaluate the feasibility of each possible approach, Ashley proceeds to use CardiacAR's *model slicing* feature to virtually reveal the internal structure of the heart (Figure 1.2) As virtual slicing is an interactive, reversible process, she can easily revert a sliced model back to its original state. CardiacAR provides Ashley with new ways to quickly plan, assess and practice her entire procedure.

4 CONCLUSION & ONGOING WORK

We have presented our ongoing CardiacAR research that aims to improve cardiovascular surgical planning through AR. CardiacAR offers novel tools important to planning, such as omni-directional slicing and virtual annotation, and may be readily deployed.

Planned Evaluation & Deployment. We plan to conduct a multi-phase evaluation to study how CardiacAR may benefit surgical planning procedure outcomes. With the help of CHOA, we will recruit surgeons familiar with cardiovascular surgical planning so that participants in the study have the necessary expertise. In phase 1, we will study the usability of CardiacAR, and how it may help the surgeons with what they had performed. We will ask the surgeons to load the heart models of their previous patients into CardiacAR, try out its features, assess whether the features are easy to use and understand, and see if it can help them plan the surgeries in the way that they desire. Based on the user feedback from phase 1, we will improve CardiacAR's usability and features. In phase 2, we will evaluate comparing the effectiveness of CardiacAR with the conventional approach that uses physical 3D models.

We are working on deploying the CardiacAR application through Apple's TestFlight online service, which will allow surgeon participants to easily install CardiacAR on their devices for evaluation.

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