Ultrasound Image Registration for Intra-cardiac Surgical Guidance: Proof of Concept

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MOTIVATION

- Navigation is a crucial aspect of every intra-cardiac surgery.
- Recognition of cardiac structures remains an issue with less experienced professionals.
- Trans-septal puncture is a pre-requisite for many intra-cardiac interventions like catheter ablation and mitral valve repair surgery.
- Such procedures depend highly on the anatomical information from ultrasound.
- Inaccuracies in localization of exact puncture site lead to puncturing of aortic valve and perforation, causing blockage and death.
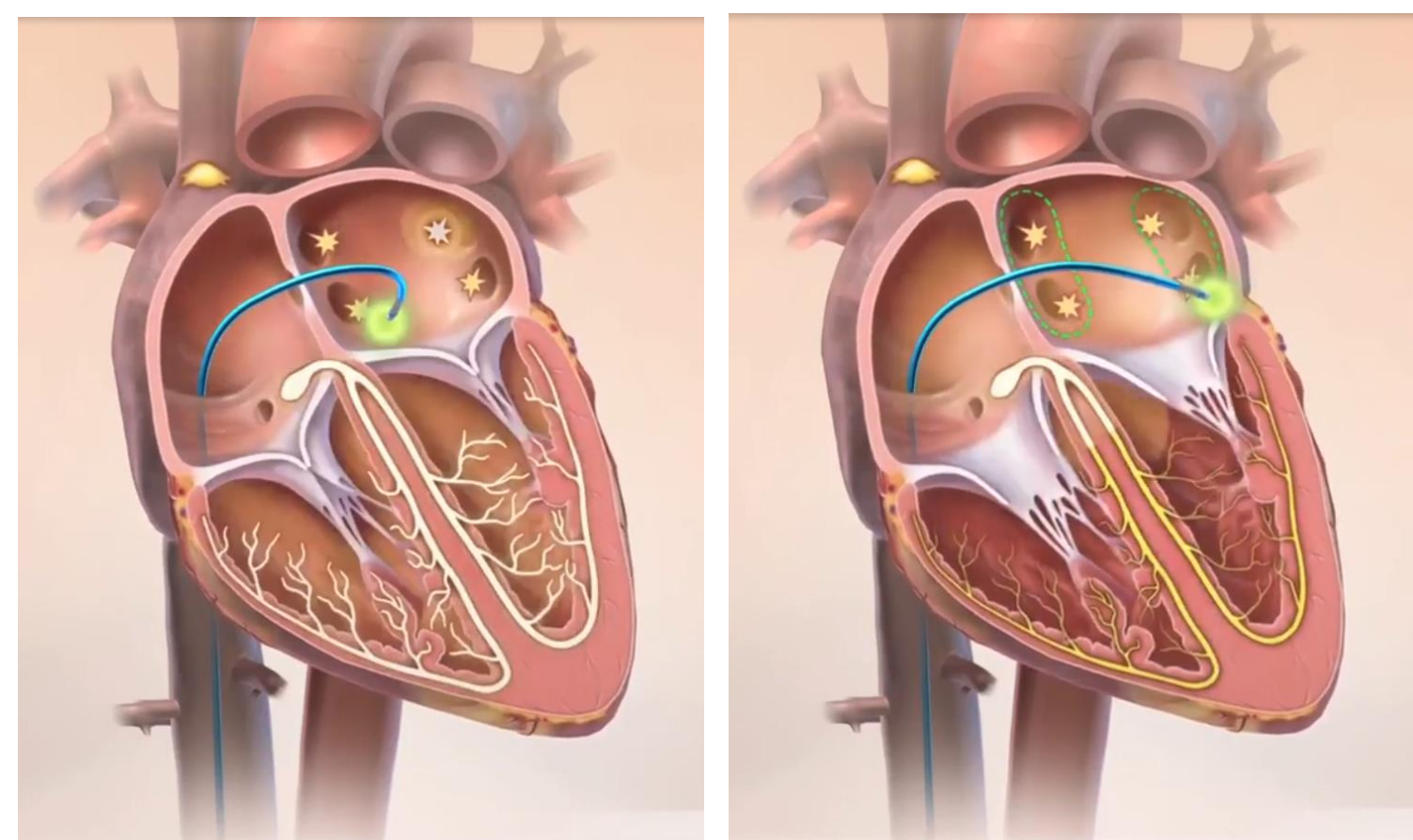
Figure 1. Trans-septal puncture for Catheter Ablation
Courtesy of American College of Cardiology

BACKGROUND

INTRA-CARDIAC ECHOCARDIOGRAPHY (ICE)

- ICE is an ultrasound imaging modality used to guide intra-cardiac surgical interventions.
- Conventional ICE is slower and limited in resolution, resulting in unsteady images because of beating heart.
- Radial ICE images taken by Conavi Foresight ICE system have:
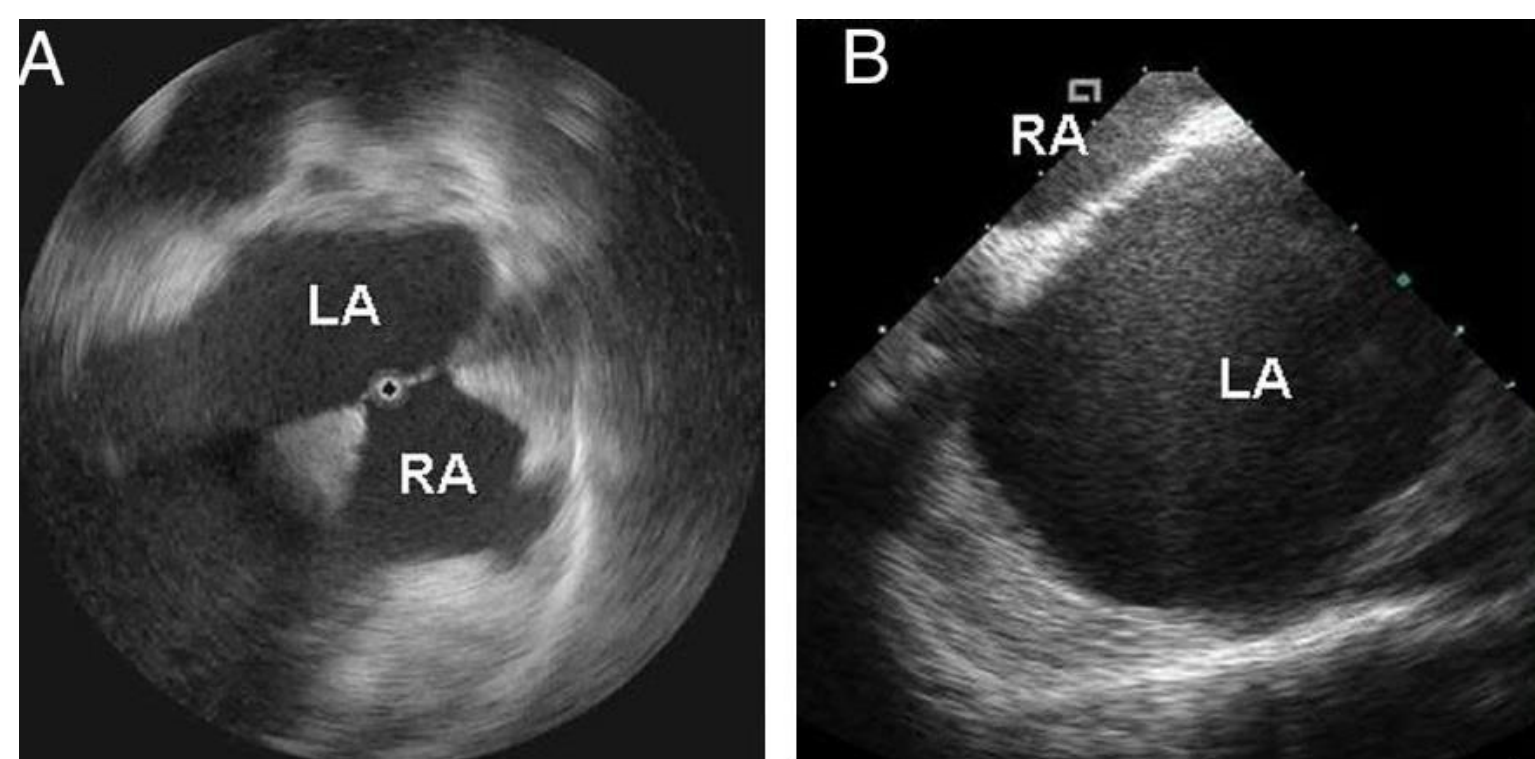 - 360⁰ field of view
  - High speed
  - Fine resolution

Figure 2. Comparison of (A) Radial ICE and (B) Conventional Phased Array ICE Images of Atria
Courtesy of Journal of the American college of Cardiology

TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE)

- TEE is another ultrasound modality that shows real time 3D data from outside heart

OBJECTIVE

We aim to place the high resolution Conavi Foresight ICE images in the context of low resolution 3D TEE volume to facilitate navigation and identification of anatomical features within heart.

METHODS

ECG signal → Temporal Synchronization

2.5D ICE — 2D surface in 3D space

3D TEE

ICE data stored as 2D rectangular image → Reconstructed circular image → Removal of artefacts → Reconstruction to 3D

Image Processing

2.5D ICE images → Binary Masking cone → Similarity Metrics → Evaluation using Target Registration Error (TRE)

3D TEE Volumes

Normalized Cross Correlation | Squared Sum of Differences | Normalized Mutual Information

Image Registration

Anatomical Landmarks

3DSlicer
Implementation in 3D Slicer for clinical trials

Validation

Psycho-Human aspect

Navigation | Positioning

Volume rendering | Surface rendering | 2D slice overlay
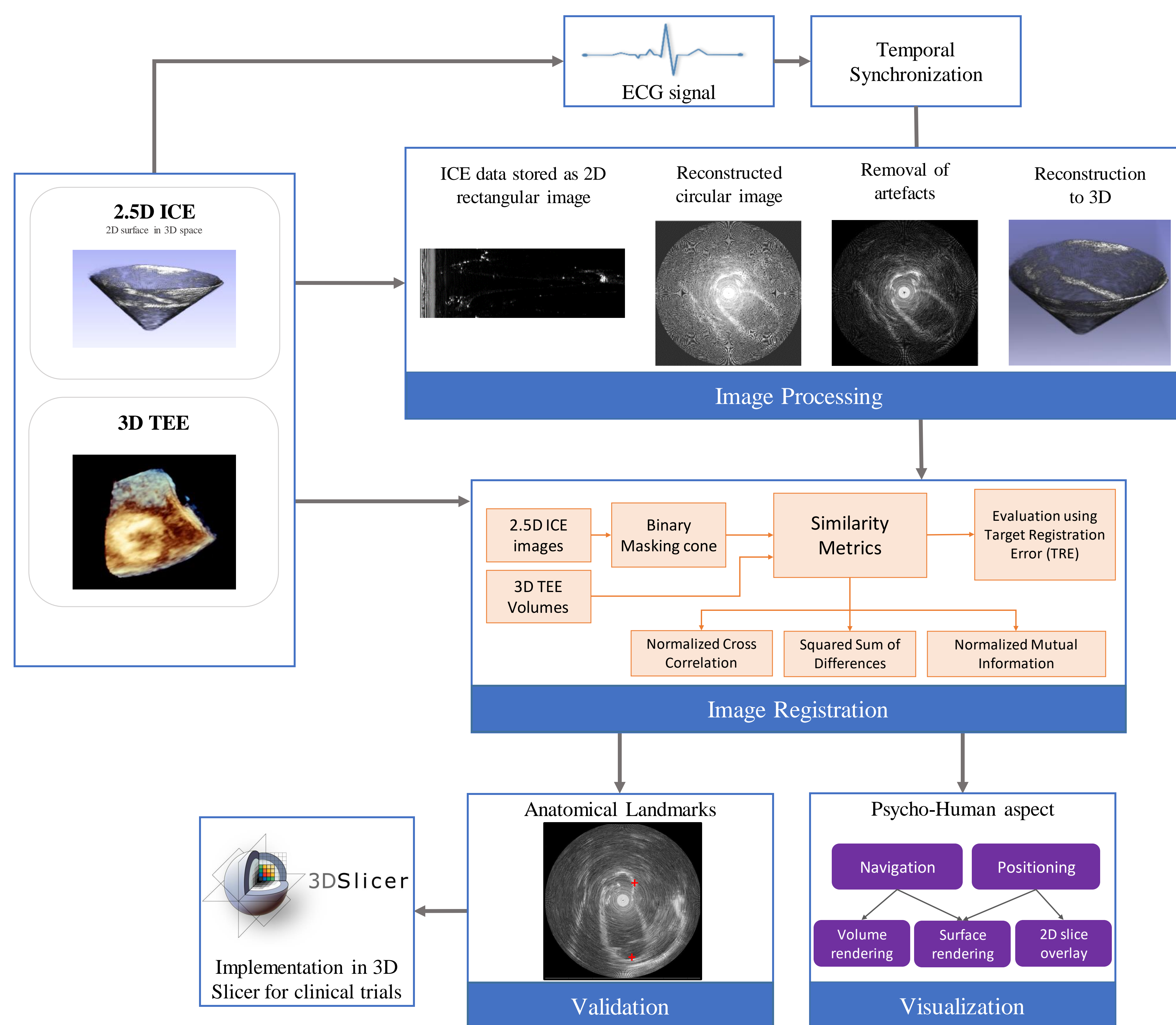
Visualization

Figure 3. Block Diagram of the Workflow of Proposed Study

DATA ACQUISITION

- A model of left atrium and parts of right atrium – superior and inferior vena cava is prepared by 3D printing the simulated blood pool inside left atrium to generate a Polyvinyl Alcohol (PVA) surface model.
- The heart phantom is imaged using Philips iE33 ultrasound machine to acquire 3D TEE volumes.
- Side-viewing radial ICE images are acquired using Conavi Foresight with viewing angles in between 70⁰ and 90⁰.
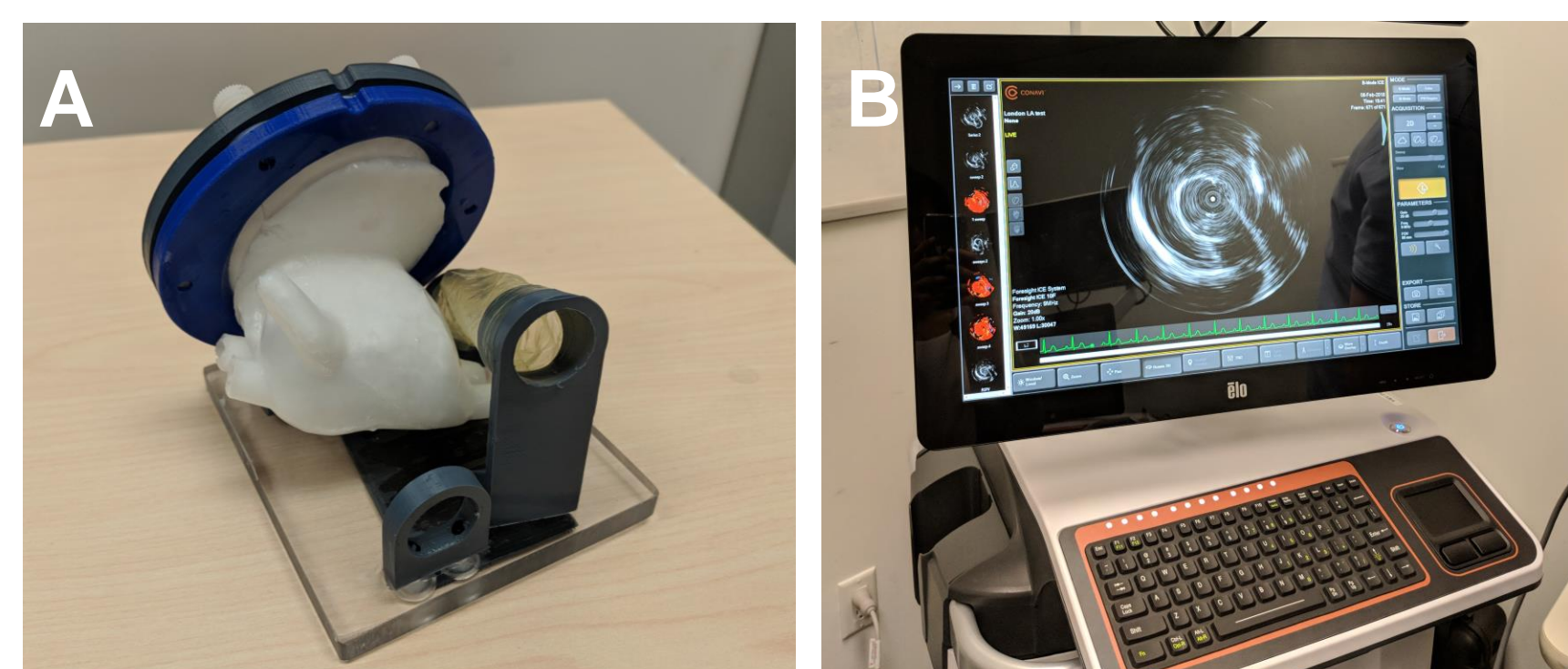
Figure 4. Data Acquisition (A) PVA Heart Phantom and (B) Conavi Foresight ICE system

- Using electrocardiography gating for temporal synchronization.
- Both ICE images and TEE volumes showing left atrial appendage, inter-atrial septum and left and right pulmonary veins are acquired.

IMAGE PROCESSING

- Reconstruction of 3D conical surface image from 2D rectangular image data.
- Removal of artefacts caused by resampling in Cartesian and spherical coordinates.

IMAGE REGISTRATION

- ICE images are registered to the corresponding 3D TEE volumes using rigid registration algorithms with different similarity metrics.
- Similarity metrics – normalized mutual information, normalized cross correlation and squared sum of differences are analyzed for their speed and robustness.

VALIDATION

- Blind evaluation of anatomical landmarks identified by an expert anesthesiologist.

VISUALIZATION

- Depends on the application and type of surgical intervention.
  - Navigation
  - Positioning

RESULTS

- Target registration error for standard procedures using anatomical mapping is up to 5mm.
- We expect the ultrasound registration system to have an error of 5mm or less.
- The image overlay will potentially
  - Improve navigation
  - Better recognition of cardiac structures
  - Guide the ablation of pulmonary veins for atrial fibrillation
  - Decrease surgery time
  - Eliminate the need of X-ray fluoroscopy and electro-anatomical mapping

CONCLUSIONS

- In this study, we proposed a novel application of radial ICE images taken by Conavi Foresight ICE system.
- ICE images, when registered with 3D TEE volumes, can provide better visualization for cardiac interventions.
- The system could potentially be used to guide ablation and discard the use of fluoroscopy
- The proposed method evaluated various similarity metrics to find the optimum image registration technique.
- Future work includes:
  - Algorithm design for forward viewing ICE images.
  - Evaluate robustness of registration algorithm at different viewing angles.

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