

CHAPTER 5

CONCLUSION AND FUTURE WORK

In this section, the thesis's contribution, as well as its conclusions and recommendations for future study, are presented. The contributions of this thesis are given in Section 5.1, followed by the conclusion in Section 5.2. In Section 5.3, we offer suggestions on potential courses of action that could be taken in the future with regard to research projects.

5.1 Contribution of Thesis

The main contribution of this study is creating an automated trimodality image registration framework since it is potentially used during intraprocedural navigation for cardiovascular treatment, particularly in Transcatheter Aortic Valve Implantation (TAVI) and Transcatheter Aortic Valve Replacement (TAVR). It involves the preoperative three-dimensional (3D) cardiac CT and MRI fused with 2D Ultrasound (US) intraoperative images. Within the context of this investigation, a registration pipeline is broken down into three primary stages: 1) temporal registration development, 2) spatial registration development, and 3) validation of trimodality image registration scheme validated on the ‘Mercedes Benz’ sign view. A US imaging frame is automatically selected for spatial registration during the temporal registration process based on its similarity to cardiac CT and MRI frames. The second step is spatial registration, which was carried out by aligning a two-dimensional (2D) planar US image with a static 3D cardiac CT and MRI volume using a rigid geometrical transformation and an intensity-based registration technique.

Step 3 entails a qualitative and quantitative validation of the trimodality image registration. Note that the preoperative cardiac CT and MRI with the intraoperative US image can be brought into perfect alignment with the help of the described registration algorithm.

In a nutshell, this study makes a dual contribution to the field. Firstly, it introduces a trimodality registration framework designed to facilitate cardiovascular treatment for aortic valve diseases through intraprocedural navigation during TAVI and TAVR. This facet of the research collectively addresses societal and clinical impact by guiding cardiovascular treatments in TAVI and TAVR procedures for aortic valve diseases and enhancing image-guided systems during cardiac treatments.

Secondly, the study's contribution extends beyond medical domains, influencing both economic and societal dimensions. The trimodality image registration technique's societal impact manifests in the improvement of the image-guided system during cardiac treatment, providing heart disease patients with enhanced and safer treatment options compared to conventional open-heart surgery. This improvement in patient care is integral to the societal and clinical impact of the research.

Shifting focus to the economic impact, the subsequent effect is observed in the potential reduction of post-monitoring costs for heart patients. The advanced techniques proposed in this study are anticipated to result in lower post-monitoring expenses compared to those associated with open-heart surgery. Consequently, the decrease in the overall cost of heart disease treatment is expected to expand accessibility, enabling a larger population of heart patients to receive care, thus contributing positively to national health.

5.2 Conclusion

This study explored the practical application of a trimodality image registration system in Cardiovascular Disease (CVD) treatment procedures, particularly TAVI and TAVR. It discussed how combining US, CT, and MRI in a trimodality approach could benefit aortic valve treatments and other applications in clinical practice. The trimodality US-CT-MRI system highlights the importance of imaging in guiding aortic valve treatment procedures by capitalizing on each imaging modality's strengths while reducing their limitations. The objective is to establish a registration framework to fuse 2D US images of the aortic valve with preoperative cardiac CT and MRI volume images.

To the best of the author's knowledge, this is the initial exploration and discussion of trimodality image registration specifically for aortic valve procedures. The study evaluated the accuracy of the trimodality registration method using the Dice Similarity Coefficient (DSC) and Hausdorff Distance (HD) measures. Moreover, the results demonstrated that the trimodality approach achieved a DSC of 0.92 (± 0.05) and 0.92 (± 0.04) when compared to US-CT and US-MRI, respectively, in short-axis "Mercedes Benz" sign views. The corresponding HD were 1.49 (± 0.20) and 1.49 (± 0.19) for both pairings. These outcomes, based on data from 20 patients, indicate the excellent accuracy of the proposed technique in enhancing image-guided systems for aortic valve surgical procedures.

Despite being a relatively new approach, this trimodality image registration system already demonstrates its potential for adoption in clinical practice, showcasing substantial clinical results and achieving good agreement between observers. Nevertheless, further research and clinical studies are necessary to validate its usefulness in broader clinical settings.

5.3 Suggestion for Future Work

The following subsections highlight several intriguing and valuable areas of research that could be explored to further expand upon the findings presented in this thesis.

5.3.1 US-CT-MRI Image Registration for Other Anatomical Structures

For future work, it is recommended to explore the application of trimodality image registration techniques to other anatomical structures beyond the current focus. This study has primarily investigated US, CT, and MRI registration for aortic valves. Hence, extending this approach to different body regions could offer valuable insights and advancements in medical imaging. By adapting and refining the trimodality registration framework, researchers can investigate its effectiveness in aligning and integrating images from diverse modalities for various anatomical structures. It could involve exploring the unique challenges and considerations associated with different regions, such as the brain, abdomen, or musculoskeletal system. Additionally, developing specialized algorithms and methodologies tailored to these specific regions can further enhance the accuracy and applicability of the trimodality registration approach. This line of research holds the potential to advance our understanding and clinical utilization of trimodality imaging for a broader range of anatomical structures, leading to improved diagnosis, treatment planning, and patient care.

5.3.2 Trimodality Image Registration for Other Types of Diseases

One promising direction for future research is to extend trimodality image registration methods to other diseases. Although the current research has concentrated mostly on CVD and, more particularly, on the aortic valve, expanding this technique to a wider variety of disorders can lead to important discoveries and breakthroughs in medical imaging. Researchers can evaluate the potential benefits of trimodality registration for accurate disease characterization, treatment planning, and monitoring by exploring its applicability to various disease types. These diseases include neurological disorders, oncological conditions, respiratory diseases, and other cardiovascular conditions. This research would necessitate modifying the trimodality registration framework to accommodate individual diseases' unique difficulties and imaging features. Note that trimodality image registration can potentially increase diagnostic accuracy, optimize treatment options, and improve patient outcomes across a wide range of diseases if used successfully in various clinical conditions.

5.3.3 Exploring AI Tools for Automatic Image Registration

Investigating using Artificial Intelligence (AI) tools for automatic image registration in medical imaging is an interesting and appealing idea that could be considered for future study in trimodality image registration (Hosny et al., 2018). Researchers can automate and streamline the image registration process between US, CT, and MRI using the power of AI and machine learning. This approach involves training AI models on large datasets of registered medical images, enabling them to learn complex spatial relationships and patterns. Consequently, these AI tools can be deployed to automatically align and fuse multimodal images, eliminating the need for manual intervention and reducing the burden on clinicians. Besides, exploring AI-based

techniques for uncertainty estimation, quality assessment, and real-time feedback can enhance the registration process's accuracy, reliability, and efficiency. AI techniques for automatic image registration have the potential to significantly improve medical imaging workflows, leading to more accurate diagnosis, treatment planning, and image-guided interventions in a wide range of clinical contexts.

