© OCT 2025 | IRE Journals | Volume 9 Issue 4 | ISSN: 2456-8880

Development and Application of a Digital Twin of the Human Heart

SANIYA NOOR FATHIMAN[1], ZAINAB SITARA[2]
[1, 2] 5th Semester BCA Student, Department of Computer Science, BET Sadathunnisa Degree College Bengaluru, Karnataka India

Abstract* - Cardio-vascular diseases (CVDs) are the leading cause of death worldwide, highlighting the urgent need for innovative diagnostic and therapeutic solutions. The digital twin of the heart, a real-time, patient-specific virtual replica, integrates medical imaging, physiological data, and artificial intelligence (Al) to provide personalized treatment and predictive simulations. This thesis examines the foundations of cardiac digital twins, their development methodologies, medical applications, challenges, and future prospects. The Digital Heart Twin enables simulation of cardiac anatomy, physiology, hemodynamic, and electrophysiological activity in real time. By replicating the patient's heart, it allows clinicians to test "what-if" scenarios, such as blocked arteries, arrhythmias, or surgical interventions, without exposing the patient to risk.

I. INTRODUCTION

Cardio-vascular diseases account for approximately 18 million deaths annually (World Health Organization, 2023). Traditional diagnostic tools and treatments are often based on generalized population data, which may not adequately address individual variability. The digital twin of the heart offers a paradigm shift by creating a personalized computational model that mirrors a patient's real heart. Such twins continuously update with real-time data, allowing clinicians to test treatment stries, predict disease progression, and optimize interventions with reduced risk (Corral-Acero et al., 2020). The digital twin of the heart is a virtual 3D replica of a patient's heart that mirrors its structure, function, and behaviour in real time. It is built using data from medical imaging techniques such as MRI, CT scans, and echocardiography, along with physiological signals like ECG and blood pressure. By combining this data with advanced computer modelling, artificial intelligence, and machine learning, the digital twin can simulate how the heart beats, pumps blood, and responds to stress or treatment. Doctors can use this virtual model to predict potential heart problems, plan surgeries, test different drugs or therapies, and provide highly personalized treatment without invasive procedures. This technology not only supports early diagnosis and precision medicine but also reduces risks, improves patient safety, and transforms the future of cardiology. This makes it possible to track changes in heart rhythm, blood flow, and structural conditions as they happen. Beyond diagnosis, the technology enables doctors to run "what-if" scenarios—such as predicting how a patient's heart would react to a new medication, lifestyle change, or surgery—before applying them in reality.

II. LITERATURE REVIEW

The digital twin concept originated in aerospace engineering (Grieves, 2014) and has since expanded into healthcare. Early cardiac models were limited to electrophysiology or hemodynamic simulations, but recent advancements in high-performance computing, machine learning, and biomedical imaging have enabled integrated cardiac twins (Viceconti & Henney, 2021).

❖ Studies demonstrate that digital heart models can:

- Predict arrhythmias with higher accuracy than conventional ECG (Trayanova et al., 2021).
- Improve surgical planning by simulating interventions (Bashir et al., 2019).
- Enhance drug testing by reducing dependence on animal models (Baillargeon et al., 2014).
- The literature shows growing momentum toward adopting cardiac twins in clinical practice, though large-scale validation is still in progress.

III. PROPOSED SYSTEM

The proposed system for a digital twin of the heart works by collecting patient data from medical imaging, sensors, and health records, then processing it to build a 3D model of the heart. This model is combined with physics-based simulations (blood flow, heartbeat update in real time with new data. Doctors can use the system to test treatments, predict disease progression, and plan surgeries before applying them to the patient. A secure clinical dashboard provides visualization, reports, and decision support, ensuring personalized, safe, and effective cardiac care.

IV. METHODOLOGY

a) *Step 1: Data Acquisition*
- Imaging: CT, MRI, and echocardiography for heart structure.
- Physiological signals: ECG, blood pressure, oxygen saturation.
- Electronic Health Records (EHRs): Patient history and genetic data.

b) *Step 2: Modelling & Simulation*
- 3D Geometric Modelling: Reconstructs anatomy of chambers, valves, and vessels.
- Computational Fluid Dynamics (CFD): Models blood flow and pressure gradients.
- Electrophysiology Models: Simulates electrical conduction and arrhythmias.

c) *Step 3: AI Integration*
- Machine learning algorithms enhance predictive capacity by analyzing patient-specific datasets and adapting the digital twin over time.

d) *Step 4: Validation*
- The twin is validated against clinical test results, ensuring accuracy before being used in medical decision-making.

V. APPLICATIONS

- Personalized Medicine: Drug dosage and treatment strategies tailored to the individual.
- Surgical Planning: Simulating stent placement, valve repair, or bypass surgeries.
- Predictive Diagnostics: Detecting early signs of arrhythmia, heart failure, or valve disease.
- Medical Education: Providing virtual training platforms for students.
- Pharmaceutical Development: Reducing costs and ethical concerns of clinical trials.

VI. RESULT

P001	58%	56%	3.4%	success
P002	42%	44%	4.7%	success
P003	61%	60 %	1.6%	success
P004	35%	37%	5.7%	success
P005	48%	47%	2.1%	success

Figure 1: Read Dataset

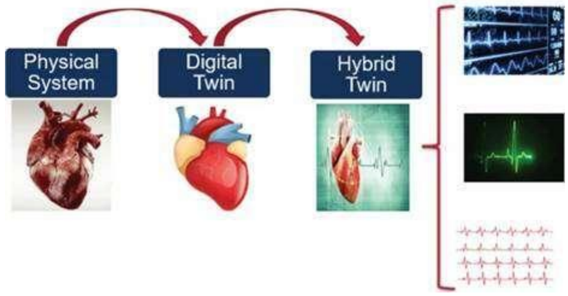

Figure 2: Data Acquisition

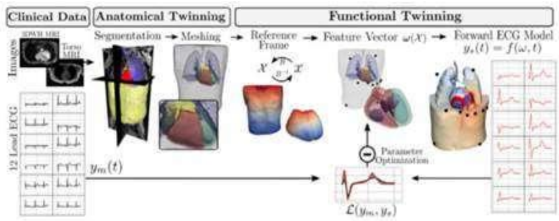

Figure 3: Modelling and Simulation

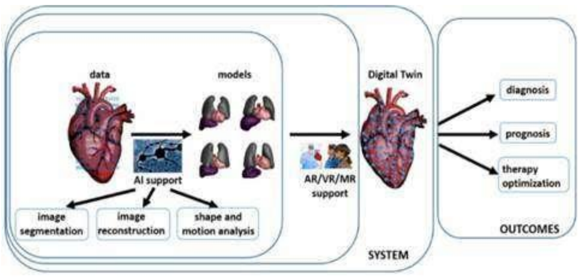

Figure 4: AI Integration

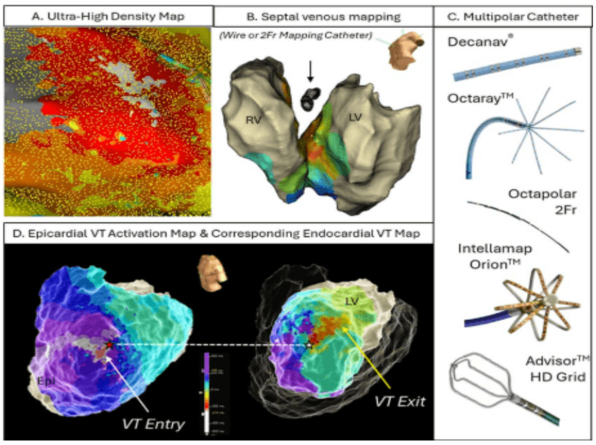

Figure 5: Validate Results

VII. CONCLUSION AND FUTURE ENHANCEMENT

The digital twin of the heart represents a transformative step in precision cardiology. By combining real-time patient data with advanced simulations, these models enable predictive, preventive, and personalized healthcare. Despite challenges in data security, computational demands, and clinical validation, digital twins hold immense potential to redefine diagnosis, treatment, and medical training in the near future. In the future, digital heart twins will become more advanced by using real-time data from wearable devices and detailed imaging to create highly accurate models of a patient's heart. They will help doctors test treatments virtually, predict heart problems early, and plan surgeries with lower risk. With AI support, these twins can suggest personalized care, connect with other organ models, and even be used in virtual drug trials. This will improve patient safety, reduce healthcare costs, and make expert care available even to people in remote areas.

REFERENCES

[1] Baillargeon, B., Rebelo, N., Fox, D. D., Taylor, R. L., & Kuhl, E. (2014). The living heart project: A robust and integrative simulator for human heart function. European Journal of Mechanics - A/Solids, 48, 38–47. https://doi.org/10.1016/j.euromechsol.2014.04.001

[2] Bashir, A., Pagano, D., & Taggart, D. P. (2019). Role of digital simulation in planning cardiovascular surgery. Interactive Cardio-Vascular and Thoracic Surgery, 28(6), 985–992. https://doi.org/10.1093/icvts/ivz030

[3] Corral-Acero, J., Margara, F., Marciniak, M., et al. (2020). The 'Digital Twin' to enable the vision of precision cardiology. European Heart Journal, 41(48), 4556–4564. https://doi.org/10.1093/eurheartj/ehaa159

[4] Grieves, M. (2014). Digital twin: Manufacturing excellence through virtual factory replication. White Paper, Florida Institute of Technology.

[5] Tray nova, N. A., Chang, K. C., & Zhao, J. (2021). Personalized virtual-heart technology for guiding the treatment of atrial fibrillation. Nature Biomedical Engineering, 5(4), 398–407. https://doi.org/10.1038/s41551-021-00709-6

[6] Visconti, M., & Henney, A. (2021). In silico clinical trials: Next horizon in personalized medicine. Wiley Interdisciplinary Reviews: Systems Biology and Medicine, 13(2), e1512. https://doi.org/10.1002/wsbm.1512

[7] World Health Organization. (2023). Cardiovascular diseases (CVDs). Retrieved from https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases