CPS Frontiers: Compositional, Approximate, and Quantitative Reasoning for Medical CPSs

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CyberCardia

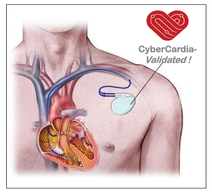
Stony Brook University

PROJECT SUMMARY

The CyberCardia project will lead to significant advances in the state of the art for system verification and cardiac therapies based on the use of formal methods and closed-loop control and verification. The animating vision for the work is to enable the development of a true *in silico* design methodology for medical devices that can be used to speed the development of new devices and to provide greater assurance that their behavior matches designer intentions, and to pass regulatory muster more quickly so that they can be used on patients needing their care.

The acceleration in medical-device innovation achievable as a result of the CyberCardia research will also have long-term and sustained societal benefits, as better diagnostic and therapeutic technologies enter into the practice of medicine more quickly.

VISION



- Closed-loop ***CyberCardia-V&V*** of devices
- With Patient-Specific settings
- **Steamlined** regulatory process
- **Shorter** Time-To-Market
- **Fewer** Device Recalls

***Open-loop* V&V also critically important!**

CHALLENGES

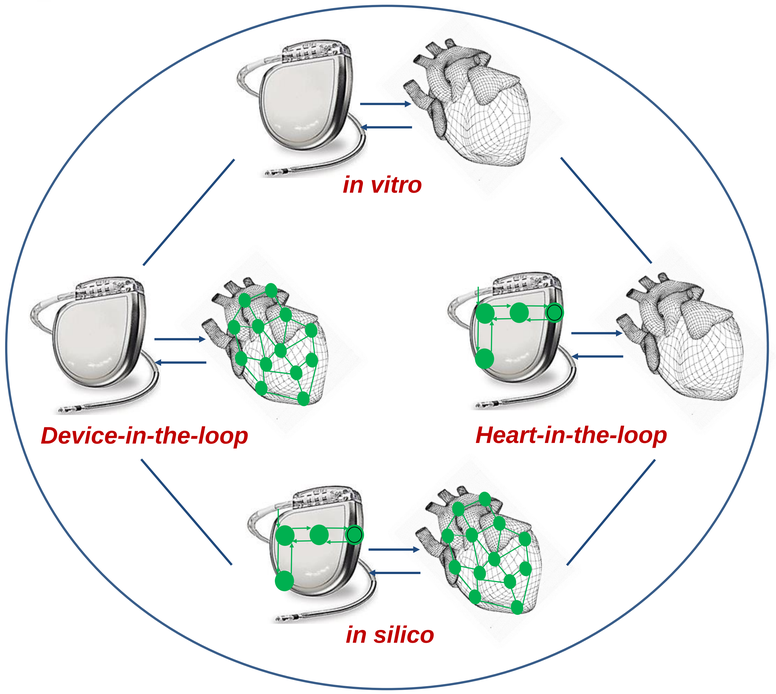
- Closed-loop verification of ICDs
- Patient-specific device programming
- Accurate heart & device modeling

SOLUTIONS

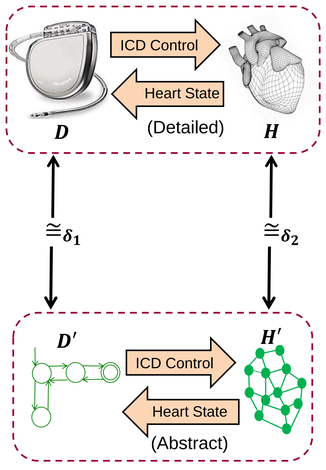
- Compositional, quantitative and approximate reasoning
- Wavelet-domain analysis of device algorithms
- Finite-element method for accurate heart modeling

CLOSED-LOOP V&V

- Virtualize (*in silico*) patient's **heart** and/or **device**
- Perform **verification** in each of 4 resulting scenarios
- Each with its own attendant **benefits!**



COMPOSITIONAL & APPROXIMATE REASONING



$D \times H$: Difficult to verify

Detailed feedback-composed closed-loop model of device (D) & heart (H)

$\cong_{\alpha_1\delta_1+\alpha_2\delta_2}$

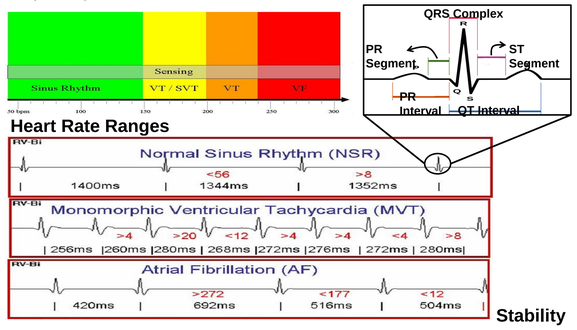
$\alpha_1, \alpha_2 \geq 1$

$D' \times H'$: Easier to verify

Abstract feedback-composed closed-loop model of device (D') & heart (H')

WAVELET-DOMAIN SPECIFICATION

- Discriminating ST and SVT signals is a crucial step of V&V
- *Continuous Wavelet Transform* will be used to specify VT and SVT



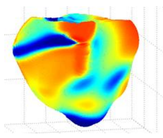
Using temporal and frequency-domain aspects of electrograms for specifying VT-SVT discrimination.

ACCURATE HEART MODELING

Sharp boundary method for tissue modeling including defibrillation

Method already optimized to handle

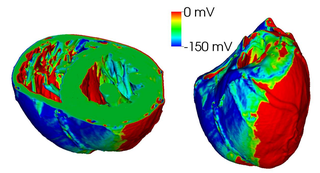
- Irregular domains



Simulated VF in rabbit ventricles

Method to study LEAP and filaments/virtual electrodes interaction

- Low-energy defibrillating shock



Shock-induced electrical signals in rabbit heart

SCIENTIFIC IMPACT

- Model-based clinical trials
- Quantitative verification of medical devices
- Patient-specific therapy guidance and device configuration
- Patient heart model in electronic health record

BROADER IMPACTS

- Project intended to lead to faster, more principled approaches to design of cardiac devices, and to yield methodologies for improving regulatory approval of new devices.
- Will also yield collection of tools & techniques applicable to design of other types of devices (e.g. *artificial pancreas*).
- Project advisory board will help ensure impact beyond the US and beyond academe.
- Undergraduate Workshop on Dynamics of Excitable Systems, RIT, January 8-14

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