Medical Cyber Physical Systems (MCPS)

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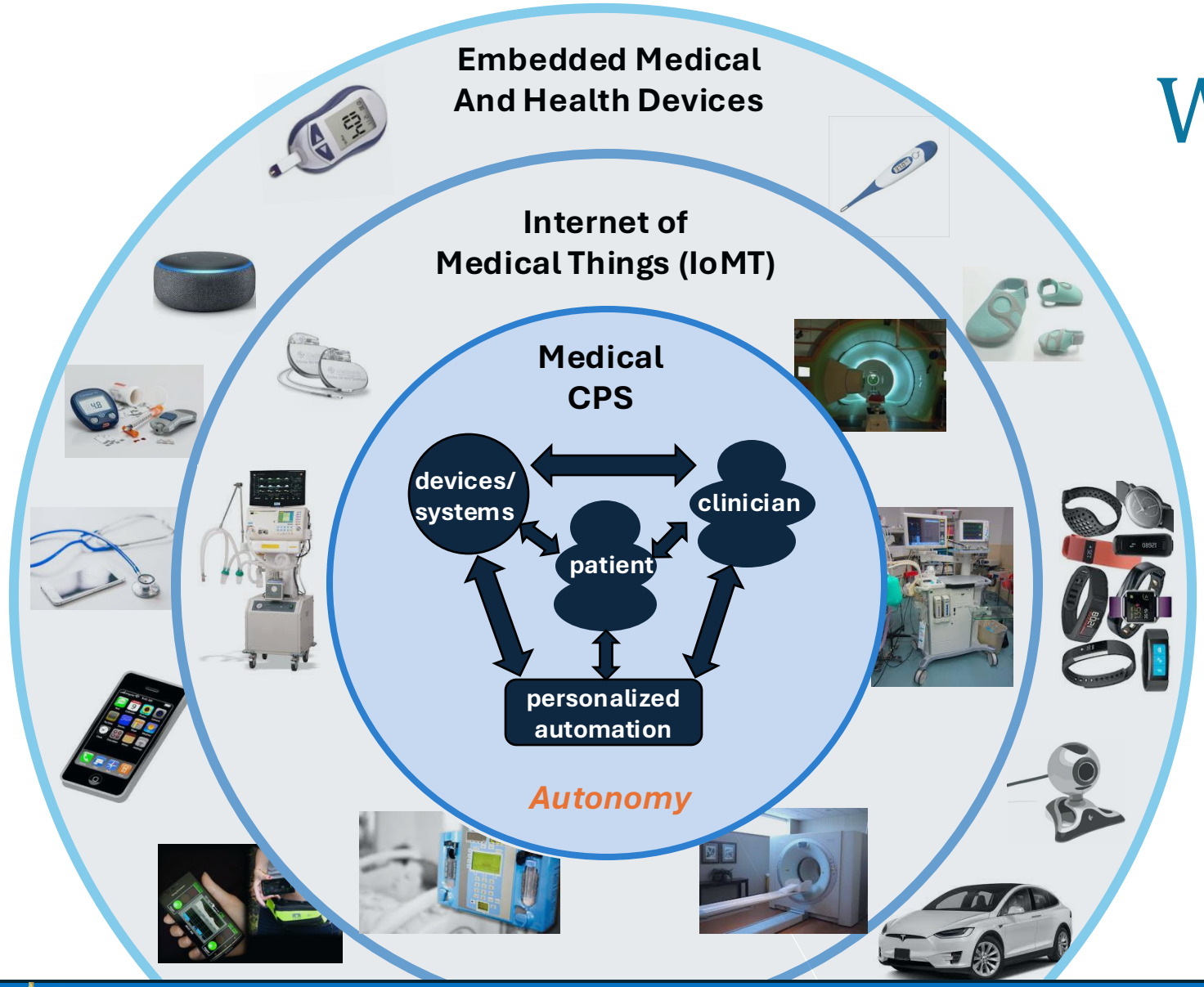
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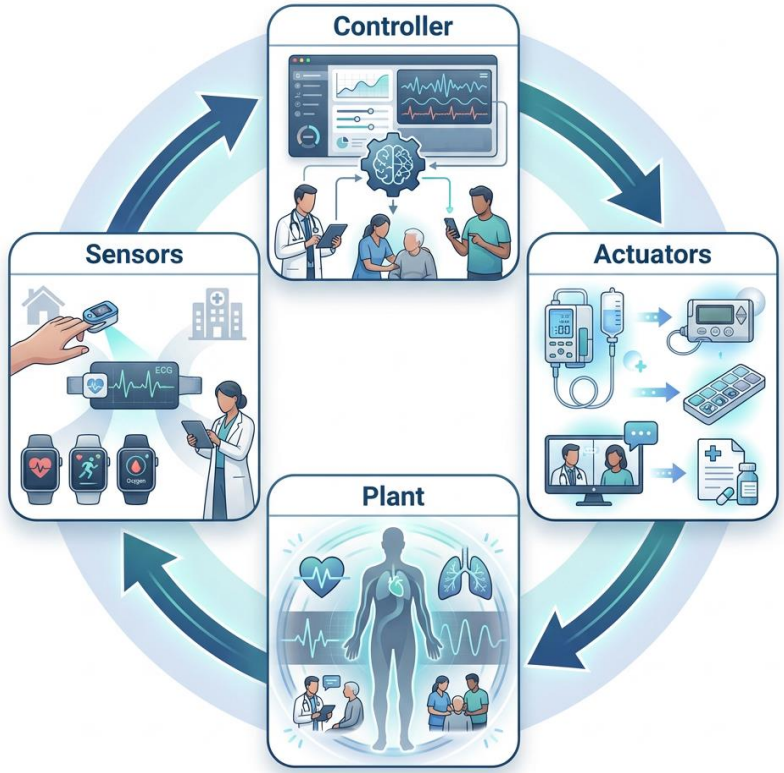
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What is a MCPS?





*The **feedback loop** differentiates an **MCPS** from the IoMT and Devices*

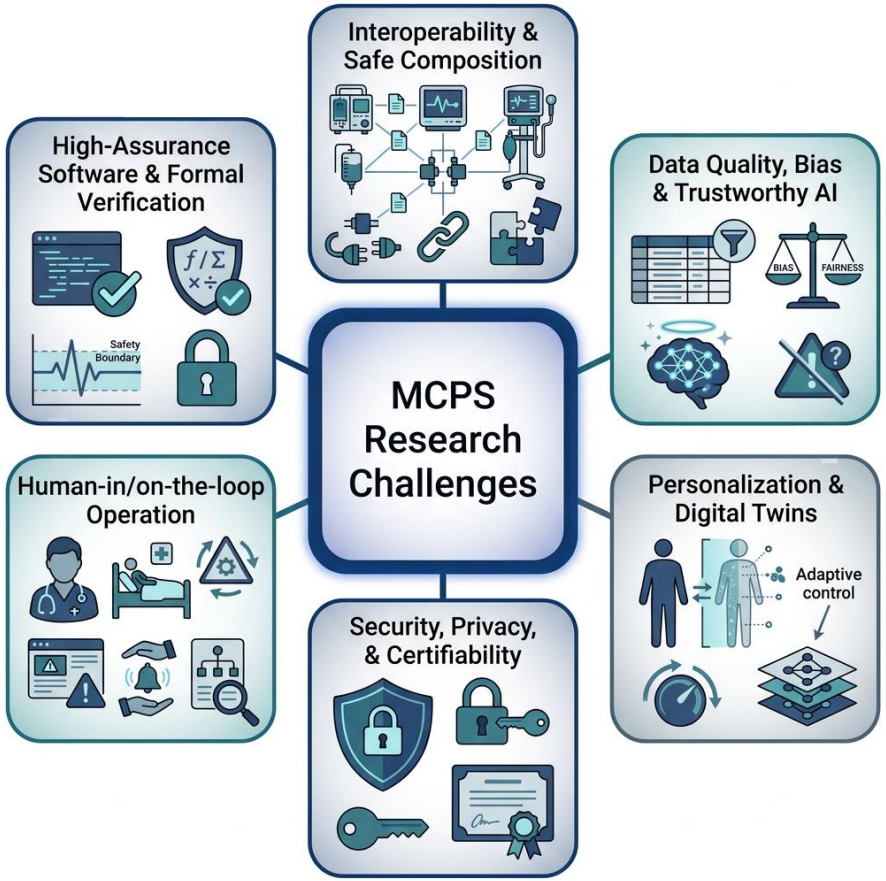
Research Challenges in MCPS

What makes MCPS research unique is how medical/health applications constrain the solution space.

The MCPS "plant" isn't built – it's a person.

You can't always put a sensor/actuator where you need it.

Every person is different – rarely does a one-size fits all solution exist.



Experimentation is resource intensive, you never have "enough" data.

Support, interoperability, and security of (legacy) systems.

Often operate in complex environments requiring human machine collaboration.

Evolution of MCPS: A Community History

2004 – present

Inception and the Beginnings

High Confidence Medical Devices, Software, and Systems workshop series (2004)

Medical Device Plug-and-Play (MD PnP) Interoperability workshop (co-sponsored by NSF)

Emergence as a Research Agenda

MCPS quickly became an active domain at **International Conference on Cyber-Physical Systems** (ICCPS) 2010

Medical CPS Workshop series at CPS week became a community forum

Expansion to NSF Smart and Connected Health

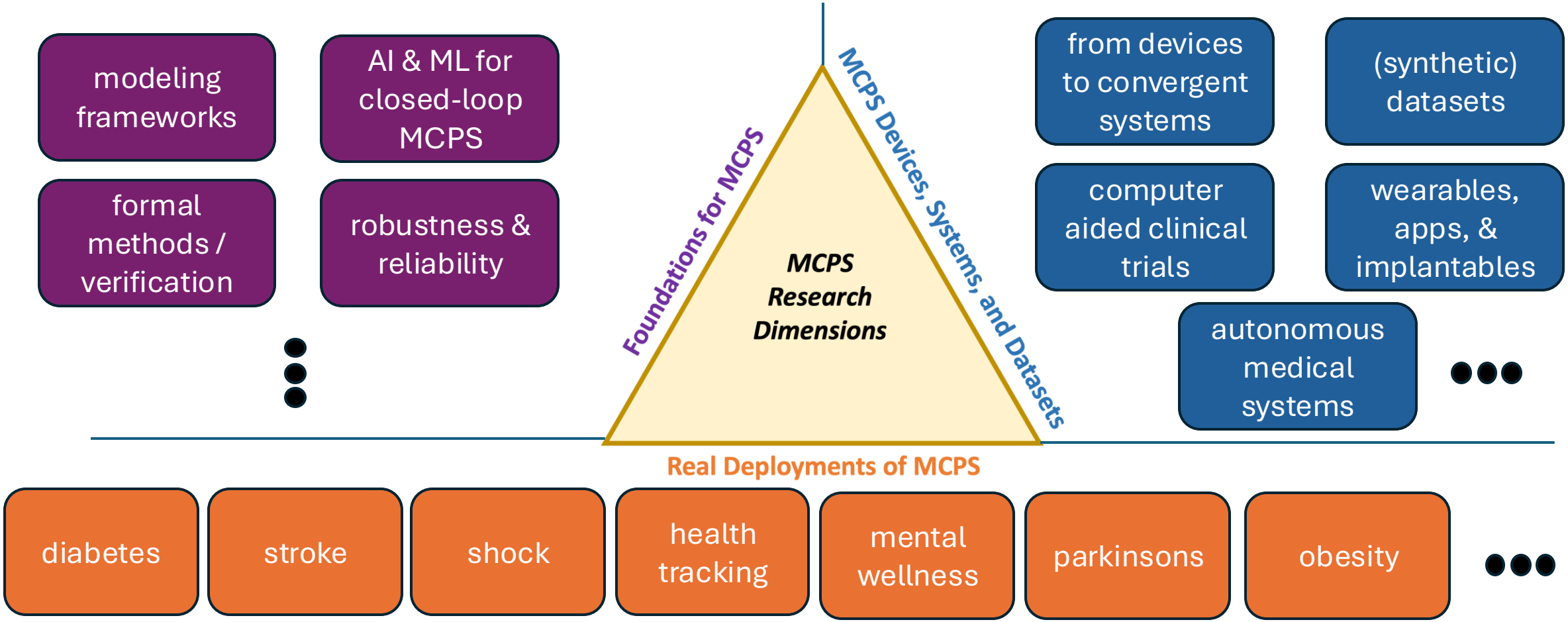
Expansion and Maturity

Wireless Health (2010-2016)

IEEE/ACM Conference on Connected Health: Applications, Systems, and Engineering (CHASE)

ACM Transactions on Computing for Healthcare

Contributions of MCPS Research

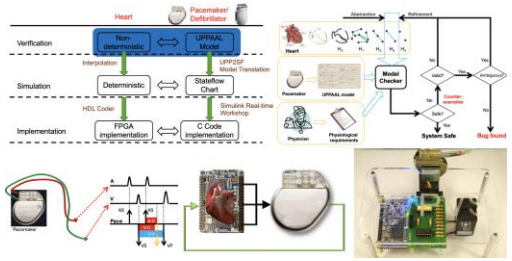


Foundations of MCPS

Rethinking "classical" CPS techniques to meet the unique demands and constraints of the medical domain.

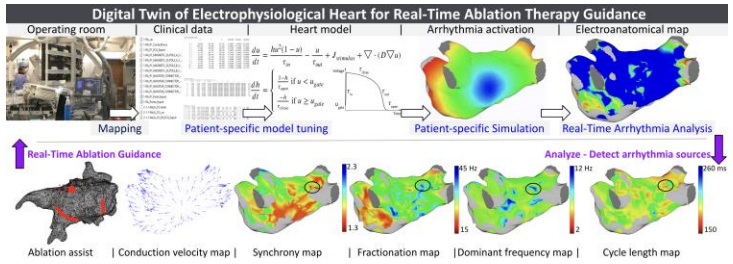
Research Highlights

Cyber–Physical Modeling of Implantable Cardiac Medical Devices. (Mangharam et al.)



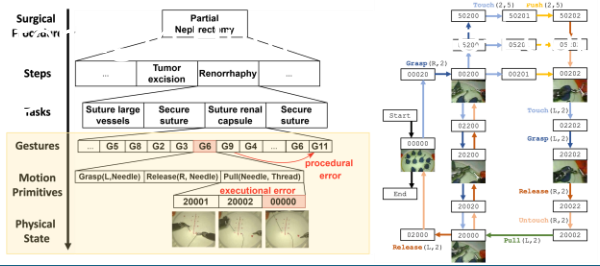
- *Developed a Virtual Heart Model*
- *UPP2SF (bridging UPPAAL w/ Stateflow/Simulink)*
- *Developed a WCET w.r.t. physiological events*

Patient-Specific Heart Models for Atrial Fibrillation Ablation (Mangharam et al.)



- *Developed a fast patient-specific computational heart model for Atrial Fibrillation*
- *Potential for Ablation localization*

Operational-Context Modeling and Monitoring in Human-in-the-Loop MCPS (Alemzadeh et al.)



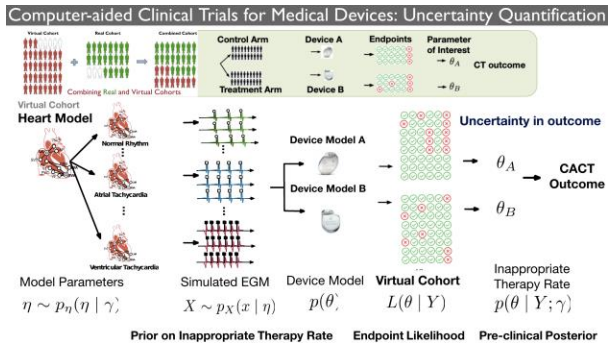
- Established operational context as a key contextual factor inferred through real-time multi-modal observations of human activities in MCPS

MCPS Devices, Systems, and Datasets

Building the MCPS infrastructure consisting of devices, systems/platforms, datasets, and capabilities.

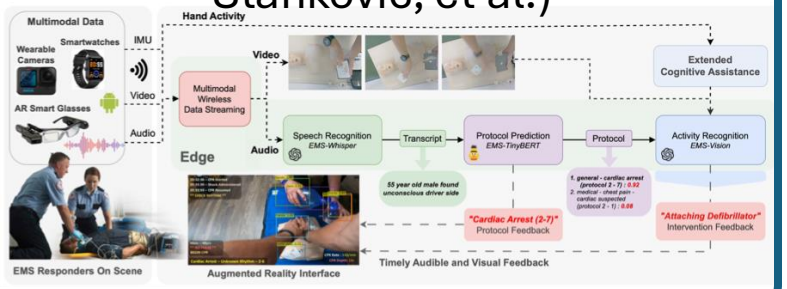
Research Highlights

Computer Aided Clinical Trials (Mangharam et al.)



- *Computer Aided Clinical Trial (CACT) Framework*
- *Demonstrated that a clinical trial would fail prior to patient enrollment.*

Real-Time Edge-Deployable Cognitive-Assistants for Emergency Medical Services (Alemzadeh, Stankovic, et al.)



- *Demonstrated that integrated, real-time, edge-deployable cognitive assistance is feasible for safety-critical clinical workflows*

VoiceCare: Wearables for Medical CPS (Stankovic et al.)



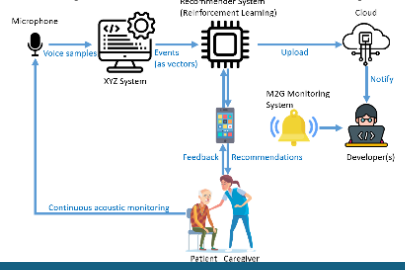
- *Demonstrated consumer wearables can host integrated, feedback-driven health assistants rather than single-function utilities*

Real Deployments of MCPS

Target populations benefit only when MCPS technologies are utilized in real life.

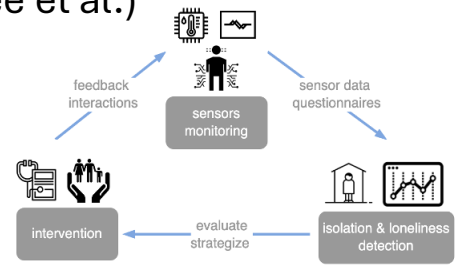
Research Highlights

PCR: A Patient Caregiver Relationship System for Alzheimer's Patients (Stankovic et al.)



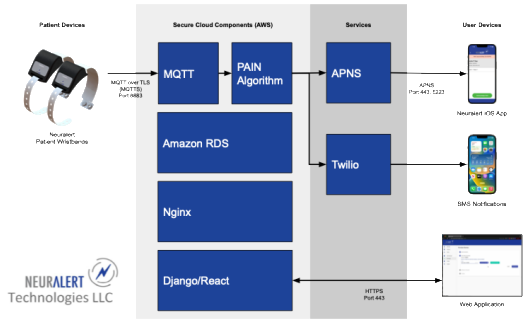
- *PCR shown to reduce stress and improve caregiver awareness*
- *D*eployed affect/conflict inference methods and personalized recommendations

iCareLoop: Sensor Data-driven Detection of Gerontological Social Isolation and Loneliness (Lee et al.)



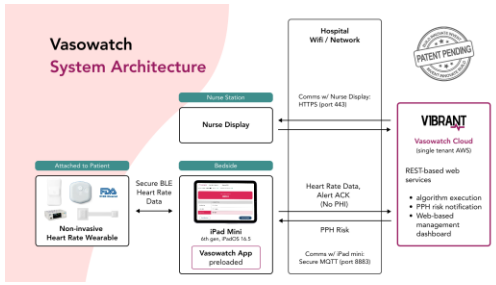
- *Joint work with JST*
- integrated sensing infrastructure for real-world monitoring of social isolation
- *Personalized interventions*

Automated Stroke Detection (Weimer, et al.)



- *Licensed to Neuralert*
- *Class 2 DeNovo MCPS*
- *In a Phase 2 Clinical Trial*
- *R*eplicable methodology for market-constrained clinical scoping
- Open-source medical device

Postpartum Risk Prediction System (Weimer, et al.)



- *Licensed to Vasowatch*
- *Class 2 DeNovo SaMD*
- Deploying SaMD where procurement uniformity cannot be assumed

Future Opportunities

MCPS goes beyond IoMT to ensure safe and effective behavior of the entire human–machine feedback system.

- AI in Healthcare / Wellbeing (high accuracy != readiness)
- Interoperability is a systems-safety problem, not just a comms standards issue.
- Human-machine collaboration w/ increased MCPS autonomy.
- Going beyond the lab/prototype/publication and transition to practice.
- Scalable V&V for AI+MCPS under uncertain and patient-specific physiological conditions
- Data quality, bias, and fairness in (AI-enabled) MCPS, especially for underrepresented populations
- Digital Twins for MCPS: Leveraging models and synthetic data to accelerate Phase 2 clinical trials
- Cyber Security of MCPS: Automated vulnerability identification and patching.

Big Problems in MCPS 2.0

	Potential directions:
What if we could shorten MCPS clinical trials from a decade to less than 2 years?	*Agentic-aided clinical trials*
What if an FDA-authorized clinical agentic AI could provide safe and effective care?	*Design of oversight agents for agentic clinical AI*
What if MCPS could be developed without pilot data?	*Foundations for MCPS design with synthetic data*
What if MCPS development was standardized?	*Performance-aware compiled MCPS*