Medical Cyber-Physical Systems: IoMT Applications and Challenges

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IoMT Research

Medical Device Interoperability
“How to collect/exchange the RIGHT data?“
- VitalCore: platform for medical device dashboard, anomaly detector, clinical alert apps.
- Raproto: Open-source, rapid prototyping platform for data collection via smartwatches
- Secure/tamper-proof logging

Clinical Decision Support
“How to interpret data for clinicians?“
- Suppressing events: smart alarms/alerts
- Detecting events: T1D meal ingestion
- Estimating/modeling state: T1D patient behavior
- Predicting outcomes: ACL Retear

Device Coordination / Closed-Loop
“How to automatically adjust clinical care”
- Mechanical ventilator weaning
- Fall prediction
- Motion detector using PulseOx

(MCPS) IoMT + SaMD
Challenges

1. IoMT/MCPS should be implemented in such a manner to reduce clinician load, not add to it.

2. Because of the reliance on high-quality data the first and often the most time-consuming step in many research endeavors is to build a data collection system.

3. Medical applications require high quality data from reliable, human-safe devices. Further, they present data storage issues and need ample processing and analysis to create useful applications.
Infrastructure: VitalCore

Analytics & Support Dashboard for Medical Device Integration

- 3000+ Integrated Medical Devices
- 36 HL7 & Application Servers
- 13 Facilities
- 7 Vendor Network

And growing...
Infrastructure: Raproto

Open-source, rapid prototyping platform for data collection via smartwatches
Applications: SmartAlarms

- Medical device alarms are non-informative
  - between 80% and 99% of all alarms are false
- Clinicians have developed alarm fatigue and may not respond to alarms
  - A top 10 health technology hazard since 2007
- Solution: Smart alarm suppression
  - Maximally suppress alarms non-informative alarms without suppressing actionable alarms
- Initially consider low SpO2 alarms
  - “Reducing Pulse Oximetry False Alarms Without Missing Life-Critical Events” (CHASE 2018)
  - ECRI 2019 #7 Health Tech Hazard: Improper Customization of Physiologic Monitor Alarm Settings May Result in Missed Alarms
Human-in-the-loop MCPS/IoMT

• Clinicians and/or patients operate and coordinate medical devices
• Analysis of safety and effectiveness needs to take operator behavior into consideration
  • How much the operator trusts the system
  • When and how operator interferes with automation
• Case study: patient-operated insulin pump
  • Smart pump suggest doses
    • Patients input carb intake
    • Patients can accept or adjust dose
  • How does behavior affect treatment?
RT-ACL: Identification of High-Risk Youth Patients and their Most Significant Risk Factors to Reduce Anterior Cruciate Ligament Reinjury Risk

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Clinical Decision Support

Aim: Develop a decision support system that is easy-to-use and is trusted by clinicians to aid in decision making for ventilation weaning

Based on votes from the expert created features and labeling functions. A risk stratification is applied that features an increasing retear rate as patients move through the bins.

Binning

Group patients by how likely they are to retear

Feedback System

Our approach: Leverage expert knowledge to intelligently design features that a predictive of risk. Combine these features using machine learning algorithms. Classify patient risk of retear as high medium or Low.

Risk Factor Evaluation

Training Dataset

441 Patients

Dataset: Analyzed Clinical Notes

Category # Missing Example
Demographics 6 5% Age, DOB
Injury Information 2 2% Data, Spirit Played
Family History 2 43% Relative with ACL Tear?
Surgery Information 20 9% Type of Reconstruction
Recovery Information 4 14% Date of Return to Activity
Re-tape Information 7 59% Time to Repeat ACL Tear
Rehab Information 213 79% Triple Hop LSI

Risk Factor Table

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>High, Medium, Low</th>
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<tbody>
<tr>
<td>Age at Injury</td>
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<tr>
<td>Injury Type</td>
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<tr>
<td>Activity Level</td>
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<tr>
<td>BMI</td>
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<td>Vertical Hop</td>
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<tr>
<td>Hamstrings/Quads</td>
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</tbody>
</table>

Conclusion

- The RT-ACL system identifies high-risk patients and determines their most significant risk factors to reduce ACL reinjury risk: High risk patients are 4.6x as likely to retear as low risk patients
- Evaluation on 441 youth patients, 8-21 years of age that underwent an ACL reconstruction at the Children’s Hospital of Philadelphia
- Next Steps:
  - Multi-year Clinical Validation at Children’s Hospital of Philadelphia
  - Generalized System Development
  - Integration into the EHR

Motivation

- 200,000 ACL Tears Annually in the US
- 1 in 60 Youth Athletes
- $2 Billion Annually in Medical Costs

Aim: Identify patients at high risk for ACL Retear

- Motivation

- Research Overview

- Data Collection

- Clinical Decision Support
Levels of Autonomy

Increasingly human-performed tasks
- Caregiver(s) performs the task

Increasingly machine-performed tasks
- Caregiver(s) is involved in task and technology aids and enhances effectiveness
- Caregiver(s) initiates a task and has discrete control over technology that executes it
- Caregiver(s) defines and initiates a task & technology executes the task with caregiver supervision
- Technology decides course of action and executes it with caregiver supervision
- Technology decides course of action and executes it without supervision

No autonomy
Technology Assistance
Task Autonomy
Conditional Autonomy
High Autonomy
Full Autonomy
Conclusion

• We are pushing towards a vision of the future in which technology autonomously provides comprehensive medical care.

• As we strive towards this reality, we have developed the IoMT and MCPS, but we still have many more challenges to surpass.