Resiliency in Cyber-physical Systems for Robot-assisted Surgery

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Safety Incidents in Robotic Surgery

• More than 1.75 million robotic procedures since 2000
• Various surgical specialties:
  – Gynecology, Urology, General, Cardiothoracic, Head and Neck

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Safety Incidents in Robotic Surgery

- Over 10,600 adverse events reported to the FDA
  - On average, one adverse event per 100 procedures
  - When an adverse event happens, there is a 24% risk of:
    - Injuries and deaths
    - Longer procedure times for troubleshooting problems
    - Conversion to non-robotic methods
    - Rescheduling

Safety Challenges

• Accidents are under-reported and not well studied
  – Causal analysis of accidents by considering humans in the loop
  – Improved error logging and monitoring mechanisms

• Monitoring and recovery mechanisms are passive
  – Assessing system resiliency against safety hazards
  – Considering HW/SW interactions, physical system, and human operators interactions

• Surgical teams are not well trained for dealing with adverse events
  – Simulation-based training by creating safety hazard scenarios in virtual environments
Our Research

Analyzing Past Failures and Safety Incidents

- Tools for automated analysis of incident reports
- Systems-theoretic accident models and hazard analysis

Assessing Resilience to Safety Hazards

- Software fault-injection to emulate realistic failures
- Simulators to virtually recreate hazard scenarios

Resilient Robotic Surgical Systems

Designing Resilient Surgical Systems & Simulators for Training

- Safety monitors for early detection/mitigation of safety hazards
- Training modules to expose surgeons to realistic hazard scenarios
Surgical Simulator
Safety Assessment and Training

Raven II Surgical System

User Inputs:
- Position
- Orientation
- Foot pedal

Robotic Control
Software and Hardware

Motor control commands

Motor encoder feedback

Instruments

Robotic Arms

DC Motors

Console Output
Surgical Simulator
Safety Assessment and Training

User Inputs:
- Position
- Orientation
- Foot pedal

Raven II Surgical System

Control Software Modules
- Network Thread
- Control Thread
- Console Thread

Control Hardware
- PLC Safety Processor
- Interface Boards
- Motor Controllers

Console Output
Surgical Simulator
Safety Assessment and Training

Haptic Device

User Inputs:
- Position
- Orientation
- Foot pedal

Pre-collected Trajectories

Network Thread
Control Thread
Console Thread

Control Software Modules

Simulated Tool-Tissue Dynamics
Simulated Mechanical Models
3D Visualization Software

Joint positions

Raven II Surgical Simulator

Console output
Graphics output

Virtual Environment
Simulation of Safety Hazards

Safety Assessment

Safety Training
Future Directions

**Analyzing Past Failures and Safety Incidents**
- Tools for automated analysis of incident reports
- Systems-theoretic accident models and hazard analysis

**Assessing Resilience to Safety Hazards**
- Software fault-injection to emulate realistic failures
- Simulators to virtually recreate hazard scenarios

**Designing Resilient Surgical Systems & Simulators for Training**
- Safety monitors for early detection/mitigation of safety hazards
- Training modules to expose surgeons to realistic hazard scenarios