A Framework for Validation and Monitoring of Robotic Surgery Systems

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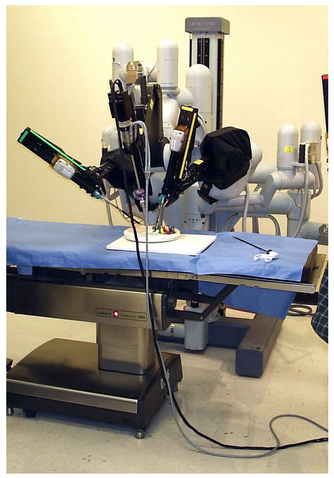
1. Robotic Surgery Systems

- Cyber-physical systems using robotic systems to aid surgical procedures
- Small incision, less blood loss, less pain, shorter recovery time, minimize side effects

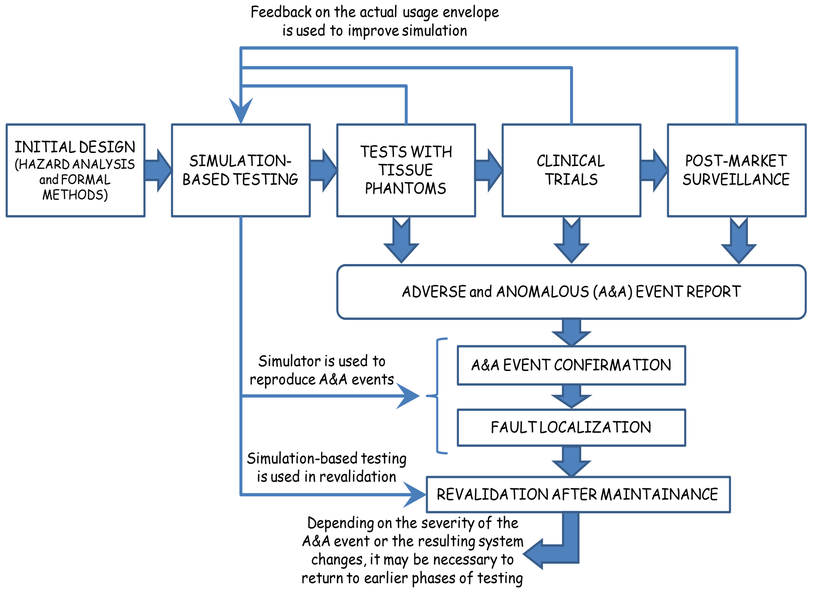


2. Adverse and Anomalous Events

[D]uring a da Vinci's beating heart double vessel coronary artery bypass graft procedure at the hospital, ***there was an unexplained movement*** on the system arm [which] caused the feet at the distal end of the endowrist stabilizer instrument to tip downward ***resulting in damage to the myocardium*** of the patient's left ventricle. (MAUDE report, FDA 2008)

- Unexpected events that potentially injure patients
  - Inadequate haptic control, violations of a motion or force limits, system crashes and hangs, software bugs causing unexpected behavior

3. Phased Validation Approach



Acknowledgements

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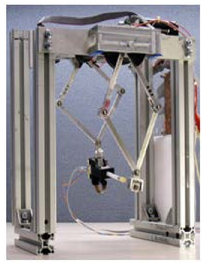
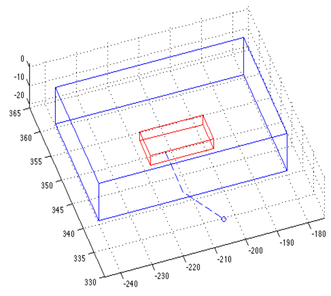
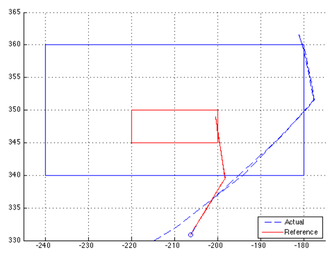
4. Testbed and Simulation Environment

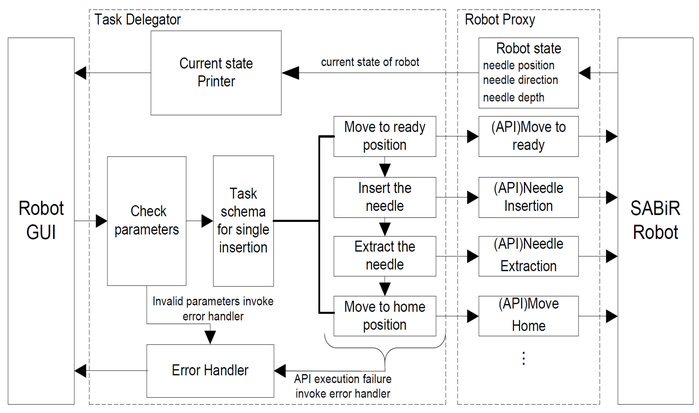
Small Animal Biopsy Robot (SABiR)





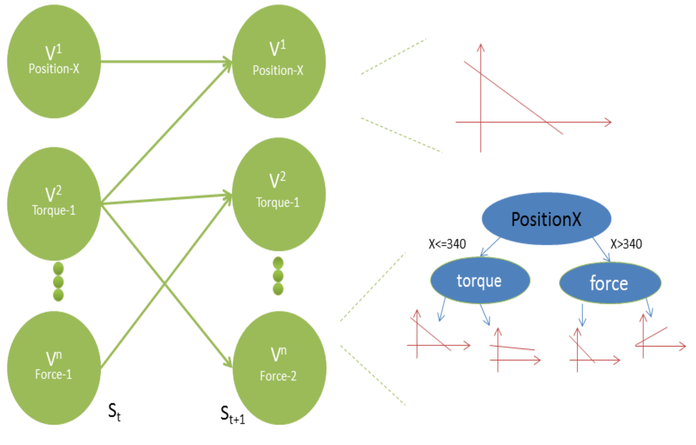


5. Software Architecture and Data Collection



6. Modeling Joint Hardware--Software State

- We model the time-evolution of the joint software/hardware state space of the system using dynamic Bayesian networks (DBNs).
- The testbed system is modeled with 30 hardware and 87 software variables.
- Hardware variables represent observed sensor data, software variables represent intermediate controller computations.



7. Empirical Evaluation

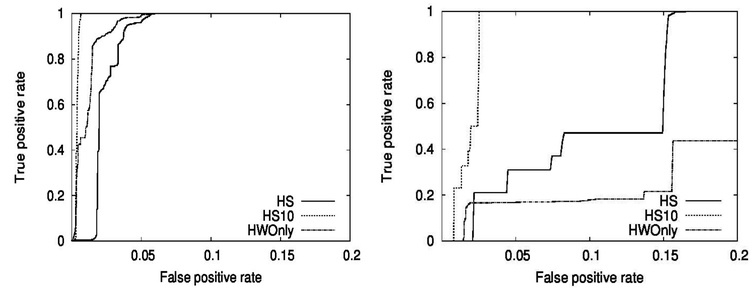
We evaluate 3 DBNs on 3 A&A events and plot ROC graphs.

DBNs:

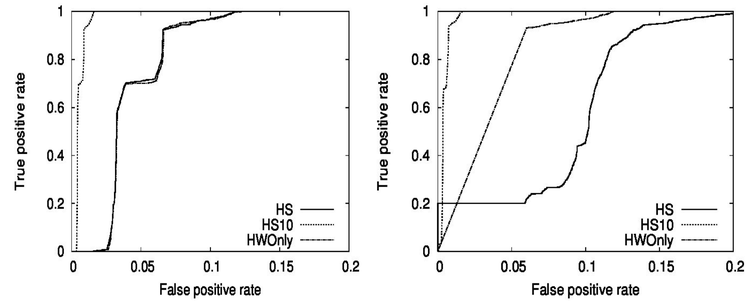
- HS: standard joint hardware/software model
- HS10: joint hardware-software model looking ahead 10 steps
- HWOnly: hardware variables only.

A&A Events:

- Encoder Failure: A&A event caused by hardware component failure
- Out-Of-Workspace: A&A event caused by software bug (missing boundary condition check)
- Sweep: A&A event caused by inadequate control or imperfect target geometry estimate or unexpected target motion



ROC graphs for detecting out-of-workspace and sweep A&A events.



ROC graphs predicting sweep A&A events, 0.5s (left) and 1s (right) before the event.

8. Current Research Directions

- Hardware validation of the developed methods and algorithms
- Constructing a low-dimensional usage envelope of the system using the learned DBNs
- Using the learned DBNs and causal inference to localize faulty controller code.

References

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