Reconfigurable Fabric

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Flexible Electronics

- Components built on a thin flexible material
- Provide opportunity to weave computation, storage, and communication into the fabric of the very clothing that we wear
- Biomedical implications
  - Computational devices in close proximity to the human body
  - Sensors and actuators enable new levels of interaction with the body
    - Drug delivery or modulation
Challenges

- Underlying technological differences
  - less mature than silicon-based electronics
  - computation-communication cost tradeoffs
    - organic interconnect has high resistance and capacitance
- Not just a traditional system with flexible form factor!
  - need new architectures
  - need new design tools
Further Challenges

- Different application challenges
  - environmental dynamics
  - physical coupling
  - resource constraints
  - infrastructure support
  - robustness requirements

- Requires radical innovation to realize this vision outside of the laboratory!
Reconfigurable Fabric Vest

- RFabVest
  - Medical vest for sensor-driven personalized trans-dermal drug-delivery
    - medical treatment
    - hazardous environments
  - Low-latency, fine-grained adaption of drug dosage based on continual physiological and possibly environmental measurements

- Sensors
  - interior and exterior

- Actuators
  - drug delivery system
Transdermal Drug Delivery

- Non-invasive
- Diffusion-controlled
- Augmented by electroosmosis
- Already used for
  - cardiac drugs (nitroglycerine, clonidine, etc)
  - hormones (estradiol, progesterone, etc)
- Benefits
  - higher drug concentration
  - elimination of gastrointestinal complications
  - elimination of infections from needles or pumps
  - patient compliance
Fault Tolerant Approach

- **RFabVest must have high availability**
  - tolerate tears and punctures
    - especially in hazardous environments
  - tolerate device failures

- **Redundancy!**
  - Replicated functionality
    - sensors and actuators
  - Distributed control
    - no single point of failure
  - Redundant or reroutable interconnect
Additional Benefits of Decentralization

- Sensing and Actuation are distributed across fabric
  - improved detection and remediation
- Control must also be distributed
  - tolerate communication constraints
  - close proximity to sensors and actuators
- Ergonomic considerations
  - electronics should be lightweight and low-profile
High Level Issues

- Reconfigurable Fabric
- E-Buttons
- Reconfiguration in the presence of device malfunction or damage
- E-Button Coordination
- Related Work
- Conclusions
Reconfigurable Fabric

- Large, flexible backplane
- Arbitrarily shaped (i.e. vest or shirt)
- Integrated wiring
  - perhaps with simple switches, latches, etc
  - redundant interconnect
- Complexity of integrated electronics is limited
  - More complex devices can be attached to fabric
  - Well-defined attachment points for external electronics
Organic Electronics

- Flexible, rugged, lightweight electronic circuit
  - fabricated at lower temperatures
  - potentially lower cost to manufacture
- UCLA has already demonstrated
  - transistors, diodes, LEDs, memory
- Reconfigurable Fabric
  - Organic electronic devices deposited on flexible polymeric substrates
  - Combination of inkjet printing and self-assembly method
E-Buttons

- Software-reconfigurable elements
- Attached to the Reconfigurable Fabric
- Sensor Buttons
- Control Buttons
- Actuator Buttons
- Other buttons?
  - communication, memory, signal processing
- Redundant E-Button placement
Architectural Overview

Sensor Buttons

Fabric Network

Low-pass Filter & Data Fusion

Control Buttons

Network

Drug 1

Drug 2

Drug 3

Drug 4

Drug 5

Actuator Buttons

Temp

A-D

Drug 1

Drug 2

Fabric Network

Single Physiological Parameter

Additional Physiological Parameters

Control

Temp

A-D

Temp

A-D

Temp

A-D

Temp

A-D

Sensor Buttons

Control Buttons

Actuator Buttons
RFab must configure itself based on
- initially available resources
- ongoing damage monitoring

2 alternatives
- passive wiring
  - connections are redundant
  - multihop packet routers
- software-controlled, electrical signal routers
  - switches and latches on fabric
  - controlled by distributed reconfiguration management service
Interconnect Reconfiguration
Interconnect Reconfiguration
Interconnect Reconfiguration
2-Way-Diffusion for Control
- useful in “detection and tracking” systems
- processing “in the network”
- initial broad distribution of data
- then gradients for efficient and effective data communication are reinforced

Control Groups
- loosely coupled clusters of sensors and actuators
- 2-way diffusion will build control groups
- groups will refresh periodically to allow for discovery of topological changes in RFabVest
Adaptive Fidelity
- self-organize to meet current system demand
- want maximal actuator coverage
- want predictability and reliability

Must ensure correct dosage is applied
- ONLY when required!
Wireless Sensor Networks

- **Analogous Features**
  - communication constraints are severe
  - systems are tightly coupled to physical world
    - must adapt to unforeseen environmental dynamics
  - self-organizing (i.e. no human intervention)

- **Key Differences**
  - node deployment is not ad hoc
  - interconnect is not wireless media
  - drug delivery requires reliable and predictable behavior
Power Considerations

- Need to balance
  - Fault tolerance and system response time
  - Energy consumption requirements

- Redundant sensors may be put in sleep mode
  - a given control group can be powered down
  - but communication costs might outweigh benefit
    - communication is costly

- Duty cycle scheme
  - control groups can be periodically woken up
  - shutdown time related to required QoS
Control Button Design

- Range from simple FSMs to more complex embedded processors
  - area, timing, energy, and performance
- Software reconfigurable to meet application needs
  - essential to meet needs of different medical applications
  - minimize energy consumption
  - reduced manufacturing cost
  - Software Parameterized Blocks (SPB)
    - Basic structure is fixed
    - Minimize reconfiguration time
Related work

- The Smart Shirt from Sensatex
  - [http://www.sensatex.com/technology.htm](http://www.sensatex.com/technology.htm)
  - wearable health monitoring device that integrates a number of sensory devices onto the Wearable Motherboard from Georgia Tech ([http://www.gtwm.gatech.edu/](http://www.gtwm.gatech.edu/)).
    - no actuation
    - no dynamic reconfiguration in the presence of rips or tears
    - centralized control

- Other projects:
  - [www-2.cs.cmu.edu/afs/cs.cmu.edu/project/vuman/www/home.html](http://www-2.cs.cmu.edu/afs/cs.cmu.edu/project/vuman/www/home.html)
  - [wearables.gatech.edu/](http://wearables.gatech.edu/)
  - [www.iis.fhg.de/pwn/technology/body_com/index.html](http://www.iis.fhg.de/pwn/technology/body_com/index.html)
Emerging technology of flexible electronics promises to transform biomedical practice and research

Seamless and fault tolerant integration of
- communicating computation and storage resources
- physiological and environmental sensors
- biomedical actuators
- all in close proximity to the human body

RFab Vest is a driver application for new technologies and architectures in the field of flexible electronics
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