

# Reconfigurable Fabric Vest for Fatal Heart Disease Prevention

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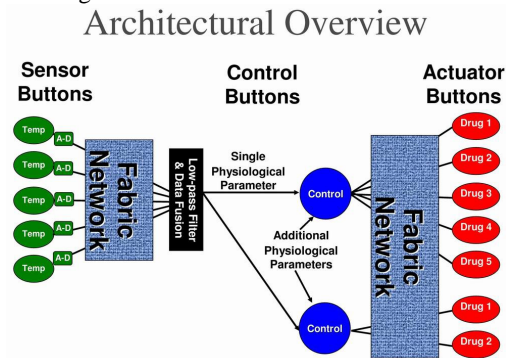
**Abstract.** In recent years, exciting technological advances have been made in development of flexible electronics. These technologies offer the opportunity to weave computation, communication and storage into the fabric of the every clothing that we wear, therefore, creating intelligent fabric. The implications of seamlessly integrating a large number of communicating computation and storage resources, mated with sensors and actuators, in close proximity to the human body are quite exciting. This paper present Reconfigurable Fabric-Vest (*RFab-Vest*) designed and implemented at UCLA for a medical application. Such a vest would have sensors for physiological readings, and software-controlled, electrically-actuated trans-dermal drug delivery elements. Furthermore, computational elements are embedded in the vest for collecting data from sensors, processing them and driving actuation elements. Since the *RFab-Vest* will be used for medical, life-critical applications, the single most critical requirement of such a vest is an extremely high level of robustness and fault tolerance. Meantime, the key technological constraint for these mobile systems is their power consumption. Our target application for the *RFab-Vest* is the detection of possibly fatal heart problems, specifically unstable angina pectoris or ischemia. We illustrate the design stages of *RFab-Vest*. Moreover, we measure the robustness of our system with existence of various faults. Finally we present a summary on the power consumption of several configurations of the *RFab-Vest* as well as the computational capability of our processing units for the specific application that we implemented.

## 1 Introduction

The emerging technology of flexible electronics, where electronics components such as transistors and wires are built on a thin flexible material, offers the opportunity to weave computation, storage, and communication into the fabric of the very clothing that we wear. The characteristics of the flexible electronics technology and the novel applications enabled by it require innovation at the system-level and technology-level [1]. The natural applications of these systems have environmental dynamics, physical coupling, resource constraints, infrastructure support, and robustness requirements that are distinct from those faced by traditional systems.

## 2 Driver Application

Although the goal of the RFab project is to investigate system architecture and design methodology concepts for electronic textiles, successful systems research of this nature requires that one not only develop these concepts, but also validate them in context of real technology constraints and application requirements. Therefore, we use pervasive patient monitoring and sensor-driven personalized trans-dermal drug delivery as our driver application. One possibility of leveraging electronic textile technology in the context of such an application is to create a flexible garment (i.e., vest) that the patient can wear, which has sensing, computation, communication, and actuation elements embedded in it. We are developing such a prototype vest called the RFab-Vest illustrated in Figure 1.



**Fig. 1.** System Architecture of RFab-Vest

One of target applications of RFab-Vest is the detection of possibly fatal heart problems, specifically unstable angina pectoris. Angina Pectoris is a fatal medical condition with more than 7 million sufferers in the U.S. alone. With the RFab-Vest the patient can have a personalized tuning for the system by his/her physician and can continue with the normal life activities with the vest. Drug delivery algorithms running on the vest, finely tuned by the patients physician, can be used prevent any fatal results.

## 3 Design of RFab-Vest

### 3.1 Interconnection Topology

The interconnection medium for our proposed system is a mesh of wire segments. The mesh interconnection topology is a wire-frame that has a regular structure, each vertex being connected to exactly four other vertices.

### 3.2 Computational Units and Switches

The dot motes developed at the University of California, Berkeley offer a tiny, low cost computation platform for embedded applications. It comprises a programmable ATmega128 microcontroller [2] from Atmel.

The dot nodes are connected to UART lines through programmable switches to create the distributed computation fabric drawn in Figure 2.

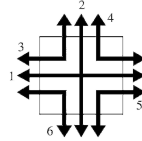


Fig. 2. Switch Model

All three terminals on each side are connected to a horizontal or a vertical wire segment. Six types of connection may be established with this switch. Two connections are straight connections whereas the other are bent connections.

### 3.3 Sensing Components and Actuators

An electrocardiogram (ECG / EKG) is an electrical recording device of the heart signals and is used in the investigation of heart diseases including Ischemia. The ECG monitoring system, that we use, utilizes ten electrodes. Digitized samples are sent to the dot-nodes for Ischemia detection process through UART protocol.

Nitroglycerin is used to prevent Ischemia (Angina). It works by relaxing the blood vessels to the heart, so the blood flow and oxygen supply to the heart is increased. Various routes of administration are proposed such as sublingual tablets, extended-release capsule, skin patches (transdermal), spray and ointment. Active transdermal technologies include iontophoresis (which uses low voltage electrical current to drive charged drugs through the skin). Transdermal iontophoresis becomes an excellent candidate for our application since it is controlled by electrical signals [3]. Such a drug delivery unit is shown in Figure 3.

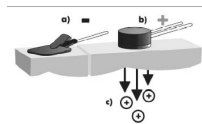


Fig. 3. Electrode for Transdermal Iontophoresis System

Nitroglycerin may lose its effectiveness over time, so physicians generally schedule nitrate-free breaks to prevent tolerance. A valid concern exists that nitrate-free periods might increase the risk for angina and adverse heart events. With on-line monitoring RFab-Vest, we avoid excessive amount of drug administration and eliminate its risks.

### 3.4 Ischemia Detection and Drug Delivery Method

As the heart undergoes depolarization and repolarization, the electrical currents that are generated spread not only within the heart, but also throughout the body. This electrical activity generated by the heart can be measured by an array of ECG electrodes placed on the body surface. A typical ECG signal is shown in Figure 4.

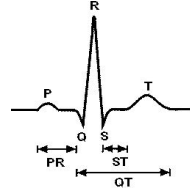


Fig. 4. A typical ECG Signal

Our ischemia detection algorithm incorporates a collection of initial tuning sessions to extract the normal heart pattern of the patient [4]. For diagnosis, common ECG patterns of the heart signal are used such as: heart rate, PR interval, QRS duration, QT interval duration, ST interval...etc [5][6]. In addition, a collection of abnormal ECG patterns associated with the ischemic conditions are stored. Normal ECG patterns of the patient along with the standard indications and abnormal patterns of ischemia are incorporated as a basis for the rest of the automated analysis that is performed by the reconfigurable vest as shown in Figure 5.

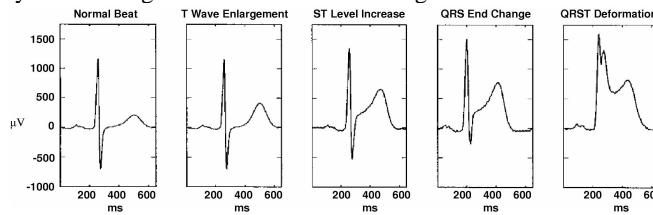


Fig. 5. Normal and Abnormal ECG Signals

The algorithm implemented for ischemia detection is illustrated in Figure 6.

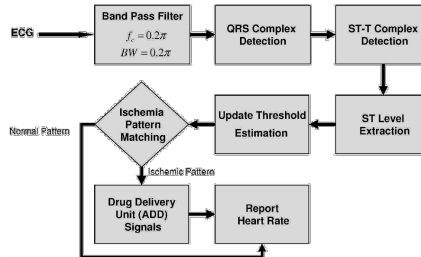


Fig. 6. Ischemia Detection Operations

#### 4 Reconfiguration in RFab-Vest

As discussed earlier, the interconnection medium of RFab-Vest is a mesh of wire segments. We employ four dot-motes as computational units placed at the corners of a square in our interconnection network as shown in Figure 7. Every dot-mote is accompanied with a switch which is described in Section 3.2. In this prototype, we use a mesh of size 4x4. The center square of wire segments are associated with inter-mote communication and will be referred as inner square in this paper. The outer

square of wire segments (mesh of size 4x4) is responsible for carrying ECG and drug delivery signals. The switches, controlled by dot-motes, connect ECG, drug delivery or inter-mote communication lines to the motes. There exist two pairs of wires in inner square to improve the reliability of inter-mote communication. In case if a pair of wires fails, switches can swap to the other pair and reconfigure the circuit.

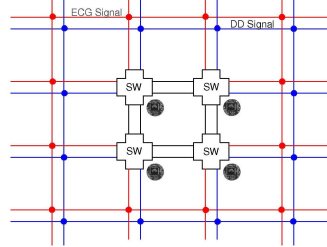


Fig. 7. Network Topology

## 5 Experimental Analysis

All the experiments are carried out with real ECG signals. We used ECG signals from European ST-T Database [7]. In the first set of experiments, we measured the latency of fault detection and circuit reconfiguration for various types of faults as shown in Table 1. V/H wire faults refer to vertical/horizontal partitions of the broadcast medium.



Fig. 8. RFab-Vest Prototype

Fault Type	Fault Detection Time (msec)	Detection + Reconfiguration Time (msec)
V/H Wire Fault	58	63
Corner Wire Fault	59	67
ECG Wire Fault	8	9
Drug Delivery Wire Fault	4	5
Mote Fault	92	N/A

Table 1. Fault Detection/ Reconfiguration Time

The next set of experiments are performed on power consumption versus reliability trade-offs of the RFab-Vest. If we decrease the number of dot-motes on the RFab-

Vest, we reduce the power consumption while the reliability of the system degrades. A summary on the maximum number of faults which can be tolerated while the system is still functional is presented in Table 2.

Number of Dot-Motes	Power Consumption (mW)	Number of Failed Motes Tolerated	Worst-case Number of Failed Wires Tolerated
4	980	3	3
2	470	1	1
1	230	0	1

**Table 2.** Power Consumption/Reliability of Rfab-Vest

Finally, in Table 3 we present a brief summary on the processing time required for ischemia detection on each channel of ECG device. As shown, the processing time increases largely with complex ECG signals.

Signal Complexity	Sample (/Channel) Processing Time ( $\mu$ sec)	Sample Rate (Hz)	Maximum Number of Channels
Average	250	250	8
Highest	420	250	4

**Table 3.** Computational Capability of Dot-Motes

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