CustoMed: A Customizable and Mobile System for Medical Monitoring and Analysis

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Abstract

We propose a new architecture called CustoMed that will reduce the customization and reconfiguration time for medical systems that use reconfigurable embedded systems. This architecture is a network enabled system that supports various wearable sensors and contains on-board general computing capabilities for executing individually tailored event detection, alerts, and network communication with various medical informatics services. In most medical applications, the reliability and robustness is the key, even in cases where the device is exposed to extreme noise. Therefore, we perform continuous radio channel characterization and adaptively coordinate communication among various system components. Furthermore, the customization of such system with a large number of "med nodes" is extremely fast even by non-engineering staff. Finally, the power consumption rate of such system is a major concern considering that the system must be wearable, light-weight and low-profile and has very limited energy resources. We perform various experiments and measure the power consumption of the system. The experimental results show the effectiveness of our system.

1. Introduction

The implications of seamlessly integrating a large number of communicating computation and storage resources, mated with sensors, in close proximity to the human body are quite exciting. For example, one can imagine biomedical applications where biometric and ambient sensors are woven into the garment of a patient or a person in a hazardous environment to trigger or modulate the delivery of a drug. 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. This combination requires one to go beyond thinking of these systems as traditional systems in a different flexible form factor. Instead, a rethinking of the architecture and the design methodology for all layers of these systems is required.

An innovative system such as our CustoMed for biomedical monitoring requires that the spatially distributed components on its surface be able to communicate and coordinate to achieve the desired sensing and actuation function. Sensing will take advantage of the spatial dispersion over the human body surface to improve detection efficiency, effectiveness and robustness. Such collaboration requires flexible communication among the elements. While the resource constraints imply that the communication must be done in a highly efficient manner, the distributed control nature of the applications requires that the communication be highly predictable (latency) and reliable. The ultimate goal of this research is to develop the communication, coordination and control primitives with which a wide variety of applications will be enabled, and to demonstrate their effectiveness compared to other approaches, using a biomedical application as a motivator.

2. System Description

Our proposed CustoMed is a fascinating and critical class of distributed embedded systems.The main attribute of CustoMed is its fast and easy customizability capability based on patients' needs. Firstly, the customization may be at the device level. The choice of the device, the placement of the device on the body, and the interaction level of the device with the environment will be tailored to the individual and his/her needs. Secondly, the software downloaded onto the devices can be customizable. Depending on the gender, age, medical condition, and other variables, the software downloaded onto the devices differs. The idea of customization has not been emphasized before, but is an important concern, if the system is made to be robust enough to handle many different needs, as well as unexpected needs that may arise.

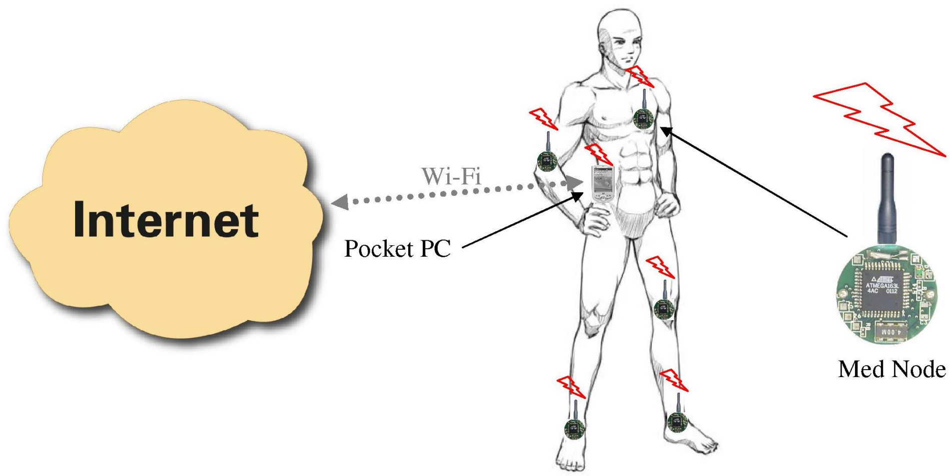

Figure 1: System Components

CustoMed can be easily custom-built for patients by non engineering-staff. The system will be quickly assembled from basic parts and configured for use. The vision is that in the doctor's office in about five minutes, the appropriate devices and the correct number of them will be assembled and affixed to the patient. Other system take months or even years to built, and hence lack the adaptability the system we propose. The physician will also pick from a wide range of code to download onto the devices. We developed such a tool which enables physicians to pick a specific variation of a code for a particular application and download it to the system components of CustoMed as shown in Figure 2. Furthermore, it works with the environment made available to the patient. For example, in case of an emergency, the sensors can alert the security system in the house. In less urgent case, an email can be sent across the Internet or a home appliance can be turned off or on.

The main component of our system is called "med nodes" which incorporate sensing, processing and communications (both wired and wireless). The processors of "med nodes" support variety of analog and digital sensors and are programmable to process the collected data from sensors. Figure 1 illustrates our CustoMed architecture connected to internet through a Pocket PC.

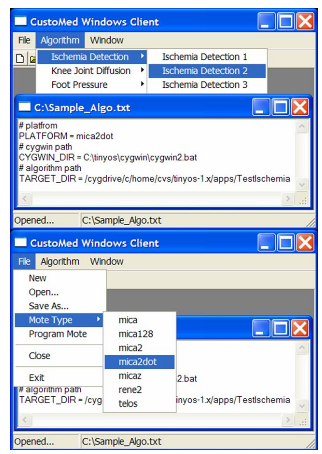

Figure 2: CustoMed GUI on a Personal Computer

3. Related Work

Several "wearable" technologies exist to continually monitor patient's vital signs, utilizing low cost, well-established disposable sensors such as blood oxygen finger clips and electrocardiogram electrodes.

The Smart Shirt from Sensatex [3] is a wearable health monitoring device that integrates a number of sensory devices onto the Wearable Motherboard from Georgia Tech [9]. The Wearable Motherboard is woven into an undershirt in the Smart Shirt design. Their interconnect is a flexible data bus that can support a wide array of sensory devices. These sensors can then communicate via the data bus to a monitoring device located at the base of the shirt. The monitoring device is integrated into a single processing unit that also contains a transceiver. The SmartShirt design features plastic optical fiber that can be used to detect punctures - however, they do not have any means of dealing with these punctures other than reporting them via the transceiver. In the event that their single processing unit (and transceiver) is damaged or the control lines leading to the device are torn, the Smart Shirt is virtually inoperable. In our design, we distribute control to multiple processing elements and can accommodate multiple communication buttons. This ensures that a puncture to our vest will not result in total system failure. This fault tolerance is essential in the demanding and/or hazardous environments targeted by this research. Firefighters, policemen, soldiers, astronauts, athletes, and others working in hazardous environments need robust material that can sustain damage and yet still reliably provide service. Moreover, our design supports an alert system which could provide immediate medical attention to individuals in emergency medical situations. Several other technologies have been introduced by MIT called MIThril [5], e-Textile from Carnegie Mellon University [7] and Wearable e-Textile from Virginia Tech [8]. Furthermore, the Lifeguard project being conducted at Stanford University is a physiological monitoring system comprised of physiological sensors (ECG/Respiration electrodes, Pulse Oximeter, Blood Pressure Monitor, Temperature probe), a wearable device with built-in accelerometers (CPOD), and a base station (Pocket PC). The CPOD acquires and logs the physiological parameters measured by the sensors [2]. The Assisted Cognition Project conducted at the University of Washingtons Department of Computer Science is exploring the use of AI systems to support and enhance the independence and quality of life of Alzheimers patients. Assisted Cognition systems use ubiquitous computing and artificial intelligence technology to replace some of the memory and problem-solving abilities that have been lost by an Alzheimers patient [6]. Nevertheless, none of the above projects/systems supports the concept of being custom-built in minutes and reconfiguration in the extent that CustoMed does.

4. System Components

CustoMed is composed of the following devices:

4.1. Sensors

We employ various types of sensors for continual physiological measurements as well as environmental measurements to identify wearer's physiological conditions and disorders and the case where people operating in hazardous environments. We have available to us pressure sensors, galvanic skin response sensors, flex sensors, and piezoelectric film sensors.

- Flex Sensors: The flex sensor changes resistance when bent. It will only change resistance in one direction. An unflexed sensor has a resistance of about 10,000 ohms. As the flex sensor is bent, the resistance increases to $30 - 40K\Omega$ at 90 degrees. They can be used to measure the angular motion of various parts of body such as knees and neck.
- Pressure Sensors: These sensors are ideal for measuring forces without disturbing the dynamics of a test. They can be used to measure both static and dynamic forces. They are thin enough to enable non-intrusive measurement. The resistance of the sensor decreases as force is applied. Measurement of pressure under the foot is of particular interest to the clinician and researcher, particularly in the fields of diabetes, orthopaedics, sports science and rheumatology. Hence pressure sensors could be placed in shoes to perform such measurements.
- Piezoelectric Film Sensors: Piezoelectric thin film sensors generate analog voltage signals in response to applied dynamic forces. They can be used to monitor if a patient being attacked or abused by other patients.
- Galvanic Skin Response (GSR) Sensors: The galvanic skin response (GSR) also referred to as the electrodermal response (EDR), measures electrical skin conductance from the fingers or palms that is associated with sweat gland activity. It is commonly used in psychophysiology experiments to infer emotional state and cortical arousal. The GSR is commonly used in Biofeedback experiments.
- Temperature Sensors: The polymer based bulk heterojunction solar cells have demonstrated the ability to act as temperature sensor. These high performance photodetectors combined with organic-thin film transistors can be used to realize sensors that can be fabricated on flexible substrates including fabric. Such devices possess a combination of electrical performance with superior properties such as light weight, low cost of fabrication, and flexibility [4].

4.2. Med Nodes

The most important component of our system is the "med nodes". "Med nodes" are stand-alone components equipped with processing units and batteries. They support various types of sensors for physiological reading from human body. These blocks enable the system to be flexible, however their basic structure remains fixed almost all the time and thus the reconfiguration time is no longer a severe limitation. Furthermore, customization of such system with a large number of "med nodes" is extremely fast. The "med nodes" can possess several parameters such that they can be complex enough to suit a range of applications. They can as well be more basic that can perform multiple operations. Furthermore, they support variety of analog and digital sensors such as flex sensors, piezo-electric sensors, pressure sensors, etc. Also the block is left software programmable which can be customized for various applications and sensors. On-chip memory blocks are also available for data storage. The processors of "med nodes" are dot-motes developed at University of California, Berkeley and manufactured by Crossbow [1]. A "med node" along with a flex sensor is shown in Figure 3.

4.3. Pocket PC

A pocket PC is responsible for collecting data from "med nodes" and classifying them. It dispatches the critical events detected by "med nodes" or the pocket PC, itself, to the

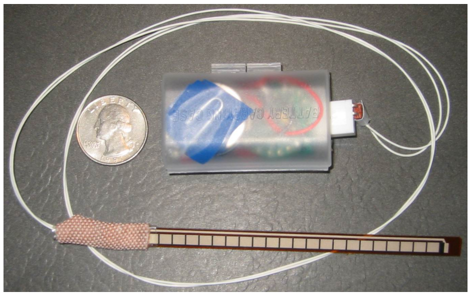

Figure 3: A Med Node along with a Flex Sensor

internet. Moreover, it coordinates and controls the overall functionality of the system.

5. Driver Applications

The design and development of the system framework is meant to be versatile enough to be applied to many different medical applications. The requirements of the system, specifically with the ability to quickly and easily make a custom-made system per patient, were deeply affected by this vision. The following are sample applications that have inspired the overall system requirements and the initial idea.

- Post-knee surgery tracking of patients:
  Structuring of imaging data from the musculoskeletal system will be accomplished utilizing novel MR pulse sequences to support canonical imaging values from tissue independent of acquisition techniques. Two ”med nodes” are placed on knees and two on the ankles. The ”med nodes” on the knees are equipped with flex sensors while ”med nodes” on the ankles utilizes pressure sensors. ”Med nodes” on the knees are responsible for tracking the angular motion of the knees and transmitting the collected data to the pocket PC. ”Med nodes” on the ankles, however, measure the forces and pressures under the foot as well as the load distribution. In addition, we place another ”med node” on the neck to measure the angular motion of the back/neck.

- Used to aid Alzheimer's patients:
  The rise of Alzheimers disease is one of the greatest health crises facing the industrialized world. Today, approximately four million Americans suffer from Alzheimers disease; by 2050, the number is expected to rise to 15 million people. CustoMed can make huge differences in the quality of life of Alzheimer's patients. It would be appropriate of the ”walking well” Alzheimer's patients, who are patients that are fully mobile. Galvanic skin response sensors, which detect arousal and/or agitation by measuring skin conductance, can be placed on the patients' body. Perhaps they can be placed in their socks or in the nap of theirs neck, two places, where there is large amount of perspiration. When agitation is sensed, proper verbal cues can be issues to the patient, to reorient them or calm them down. Also, in case of emergency CustoMed can email physicians and/or family members. CustoMed can extend the time span when patients are independent, and hence improves the quality of their life and reduce the cost incurred. CustoMed can prove to be very useful in assisted living homes, also, where the ratio of the staff to patients is about one to ten. In such situations, being hit or abuse has been a problem. Pressure sensors placed on the patients can determine a hit, but even more importantly the detection of agitation, before any harm has been done can be used to protect the patients and the staff. Perhaps, during times of agitation the staff's pagers can be cued.

6. Experimental Analysis

All the experiments were carried with transceivers operating at $433MHz$. All ”med nodes” were equipped with a $3V$ Duracell DL2450 batteries except the ”med node” placed at location 5 (with three batteries) since it is connected to the Pocket PC and must remain on continuously. We conducted our experiments with various transmission power settings in ”med nodes”. The transmission power setting can be easily changed in dot-motes throurgh ChipCon CC1000 chip. The ”med nodes” are placed on body as shown in Figure 4.

We used specific sensors for both post-knee surgery tracking of patients and Alzheimer applications for experimental analysis. For the first application, we placed ”med nodes” equipped with flex sensors at locations 1, 6 and 7 and pressure sensors at locations 8 and 9 according to Figure 4. ”Med node” placed at 5 was responsible for collecting data from other ”med nodes” and transmit it to Pocket PC through UART (Universal Asynchronous Receiver/Transmitter). Other ”med nodes” were used as hops when needed. In the Alzheimer application, all ”med nodes” were equipped with piezoelectric sensor and three of them were picked to transmit their data to ”med node” 5 and pocket PC. The candidates for data collection were randomly selected every three minutes to cover the whole body. At the time three were active collecting data, other ”med nodes” could be used as hops if needed. Table 1 shows the maximum number of ”med nodes” functioning simultaneously either for collecting data or forwarding packets. Table 2 illustrates the lifetime of CustoMed with various transmission power settings.

As shown in Table 2, the best power lifetime is gained with transmission power setting $= 20.1mW$ for post-knee

Transmission Power Setting	20.1 mW	22.8 mW	26.1 mW	31.2 mW	80.1 mW
Post-knee Surgery Tracking	7	6	6	5	5
Alzheimer	N/A	6	4	3	3

Table 1: Maximum Number of Med Nodes Utilized Simultaneously During the Monitoring

Transmission Power Setting	20.1 mW	22.8 mW	26.1 mW	31.2 mW	80.1 mW
Post-knee Surgery Tracking	36 hrs	34 hrs	32 hrs	29 hrs	16 hrs
Alzheimer	N/A	51 hrs	72 hrs	78 hrs	48 hrs

Table 2: Lifetime of CustoMed with Various Transmission Power Settings

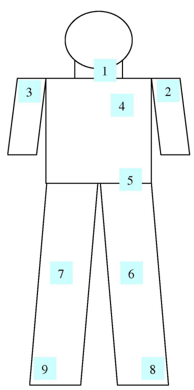

Figure 4: Med Nodes Placement Configuration

surgery tracking application while in Alzheimer application, the best lifetime is achieved with $31.2mW$ transmission power setting.

7. Conclusions and Future Work

In this paper, we presented CustoMed, a medical monitoring system which can be easily custom-built for various medical applications by physicians or non-technical staff. We illustrated a power optimization technique for such architecture which dynamically minimizes the power consumption rate with respect to the environmental noise. Our future goal is to focus on less computationally intensive algorithms for power optimization and consider automatic adjustment of transmission power setting. In addition, other power optimization techniques such as shutting down "med nodes" can reduce the energy usage and is of our great interest.

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