The Berkeley Tricorder: Wireless Health Monitoring

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ABSTRACT

The advancement of precision micropower amplifiers, microcontrollers, and MEMs devices have allowed for a paradigm shift from traditionally large and costly health monitoring equipment only found in hospitals or care centers to smaller, wireless, low powered portable devices that can provide continuous monitoring for a number of applications. Along these lines, we have developed a small wireless health monitoring device, named The Berkeley Tricorder, capable of monitoring a wide range of health-related signals, and have vetted it in a number of human trials. We will present a number of different real-time visualization tools that have been developed, and discuss some relevant applications for the Tricorder as a platform. Real time wireless telemetry from the device will be demonstrated.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: Life And Medical Sciences—*Health*; B.0 [**Hardware**]: General

General Terms

Design

1. DISCUSSION

The Tricorder (Fig. 1) differs from most other wireless health monitoring devices in that it incorporates a large number of sensing modalities on a single small device (Tab. 1). This allows for a number of advantages such as requiring only a single circuit board, a single battery, and no need for inter-device communication – simplifying the end user experience. Bluetooth is used for remote telemetry given the requirements for high bandwidth (1 Mbit), standardized communications protocols (i.e. serial streaming and dial up networking), it's prevalence in consumer endpoints for visualization and data relay (i.e. cell phones, laptops), and the ability to interface to a large number of Bluetooth-enabled medical devices (i.e. weight scales and blood glucose monitors). Support for microSD cards allows for long term data storage on multi-Gigabyte SD cards. Data transfer and battery recharging is provided through a mini USB connector.

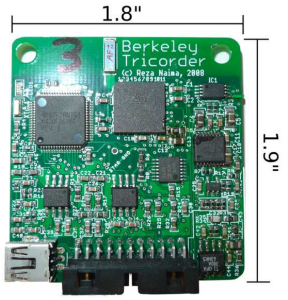

Figure 1: The Berkeley Tricorder

Multiple means of affixing the Tricorder to the subject have been evaluated:

- A pouch worn around the neck contains the Tricorder and affixes to the user with Silver-SilverChloride (Ag-AgCl) electrodes.
- A pouch worn around the wrist containing the Tricorder used with metal EMG button electrodes.
- An elastic belt which utilizes dry rubber electrodes manufactured by Respironics (Model 16510-1, Murrysville, PA). The Tricorder and battery are placed inside the strap, and the belt is worn around the chest by means of Velcro (Fig. 2 left). A reflective pulse-ox sensor manufactured by Nellcor (Max-Fast, Nellcor/Tyco, Pleasanton, CA) is placed on the forehead to minimize SpO_2 motion artifacts for ambulatory subjects.
- A compression shirt with conductive fabric strips on the inside (Fig. 2 right).

A number of real time visualization applications have been written that communicate over Bluetooth. These include a C# application for mobile PC cell phones, a PC-based java application, an iPhone (Fig. 3) and an iPad application, and multiple Android-based applications. In addition, an Android-based application has been developed which performs feature extraction from the dataset and transmits the data to a remote server over the cellular network.

The Tricorder has been successfully used in four sets of human trials, and is planned on being used in a number of

Wireless Health '10, October 5-7, 2010, San Diego, USA

Modality	Sampling Rate	Bits/Sample	Comment
Electrocardiograph (ECG)	256Hz	12	2-Stage HPF; RFI Filer
Electromyograph (EMG)	256Hz	12	1-Stage HPF; RFI Filter
Respiration (Bioimpedance)	256Hz	12 Phase; 12 Mag.	4-Electrode; 350μA @ 50kHz
Acceleration (3-Axis)	256Hz	8/Axis	Hardware fall detection
Blood Oxygenation	256Hz	15	Full photoplethysmograph
Galvanic Skin Response (GSR)	256Hz	12	
Skin Temperature		12	*Not Yet Validated*

Table 1: Device Parameter Summary

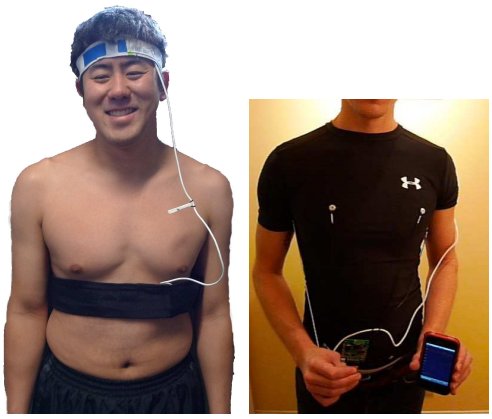

Figure 2: Left:Chest belt containing Tricorder and electrodes, reflective forehead pulse-ox sensor. Right:Compression shirt with conductive fabric on the inside, data visualization on iPhone.

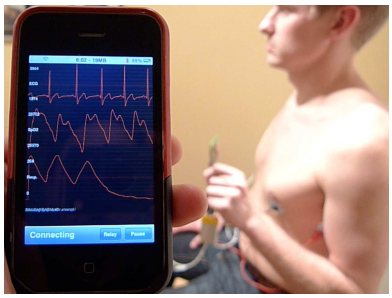

Figure 3: iPhone Bluetooth application. Traces from top: ECG, Red SpO_2, Respiration Volume

future studies. The first two studies evaluated the ability of the Tricorder to record ambulatory data using the chest belt over a period of 24 hours[4]. One study evaluated the activities of daily living by measuring EMG and motion on the wrist while collecting additional motion data from a commercial Bluetooth-enabled accelerometer manufactured by SparkFun (WiTilt 2.5, Boulder, CO). Finally, a study was performed by our collaborators who investigated using the Tricorder as a sports training aid[2]. Future planned studies include using the Tricorder to measure stress by means of EMG and GSR, to measure variations in water compartmentalization using it's bioimpedance spectrometer and the cole-cole models[1], and to help find triggers of Crohn's disease outbreaks.

The Berkley Tricorder is presented as platform which can enable a wide range of research and commercial applications. Our initial goal was to coninuously monitor the elderly and at-risk populations for early signs of problems. These include health related monitoring[3], detection of acute events such as a fall or cardiac ischemia, and management of stress through monitoring GSR and EMG. Furthermore, the data from the accelerometer can be used to deduce daily activity.

Additionally, the Tricorder is well suited for performing ambulatory diagnosis of asymptomatic conditions. For example, it's additional data streams can be used to augment ECG data that a traditional holter monitor provides to give a more complete picture of the health state of the patient leading to an arrhythmia.

The compact form factor and the shirt interface can provide feedback to help train athletes, or track the vitals of emergency responders such as firefighters. Some initial work has already been performed to evaluate the Tricorder with the belt strap in monitoring badminton players[2].

Finally, the Tricorder can provide low cost medical diagnostic tools to remote regions of developing countries where it is difficult to deliver healthcare. Given the prevalence of cellular networks in rural areas of developing countries, real-time vitals telemetry can be provided to physicians in urban centers in order to help with diagnosis and care of patients.

We have presented a brief summary of the Berkeley Tricorder, and associated tools. It has been vetted in a number of human studies with more planned. As a platform, the Tricorder is capable of enabling a wide range of research and commercial applications. It's modular design allows for rapid redesigns to optimize it's application - such as increasing the number of ECG channels or adding a GSM cell modem (currently under development).

A demonstration video can found at *http://tiny.cc/tricorder*.

2. REFERENCES

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