Web-based Sensor Streaming Wearable for Respiratory Monitoring Applications.

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Abstract— This paper presents a system for remote monitoring of respiration of individuals that can detect respiration rate, mode of breathing and identify coughing events. It comprises a series of polymer fabric-sensors incorporated into a sports vest, a wearable data acquisition platform and a novel rich internet application (RIA) which together enable remote real-time monitoring of untethered wearable systems for respiratory rehabilitation. This system will, for the first time, allow therapists to monitor and guide the respiratory efforts of patients in real-time through a web browser. Changes in abdomen expansion and contraction associated with respiration are detected by the fabric sensors and transmitted wirelessly via a Bluetooth-based solution to a standard computer. The respiratory signals are visualized locally through the RIA and subsequently published to a sensor streaming cloud-based server. A web-based signal streaming protocol makes the signals available as real-time streams to authorized subscribers over standard browsers. We demonstrate real-time streaming of a six-sensor shirt rendered remotely at 40 samples/s per sensor with perceptually acceptable latency (<0.5s) over realistic network conditions.

I. Introduction

Biosignal monitoring in the home is an increasingly important component of e-health systems. Real-time monitoring is required for specific applications such as tele-rehabilitation wherein guidance and supervision is remotely administered by a health-care expert. The benefits of such approaches are primarily those of cost, convenience and patient comfort[1]. These systems ideally require low time lag, high-speed data streaming during operation. This level of performance up to now has required dedicated networked applications which are over-expensive to develop considering the unexploited functionality and increasing sophistication of web browser technologies. Furthermore, for many patients such custom applications are difficult to use and inconsistent home connectivity problems can mean that communication can be unreliable. The result is poor patient compliance and system abandonment.

We present a prototype respiratory monitoring system for which we assumed basic patient computer literacy (i.e. the basic ability to use a web browser). Respiratory monitoring is of particular interest for monitoring patients with chronic respiratory conditions for which breathing technique and event detection are an important component of their treatment[2]. Respiratory monitoring requires multiple sensors sampled at relatively high rates presented to a therapist often situated many kilometers away. Our solution uses piezo-resistive sensors integrated into a sports vest which communicates over a short range radio link to standard home PC[3] (Fig. 1).

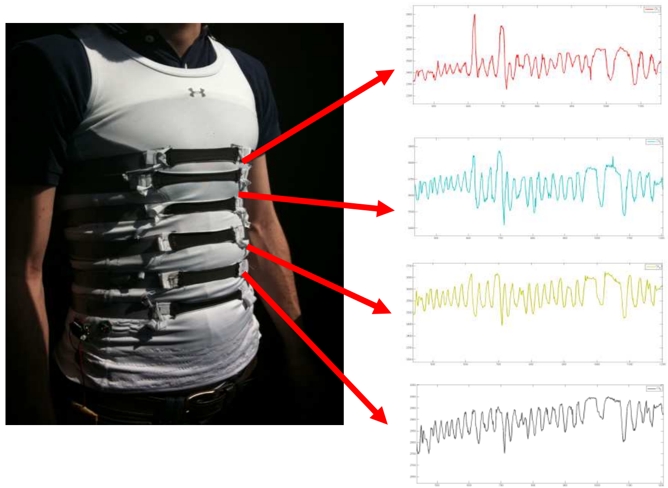

Figure 1. Respiratory shirt showing streams from several sensors.

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Using a pre-installed bridging application and a web browser the data can be visualized (Fig. 2) and streamed to a central web-based signal streaming server[4] for real-time distribution to authorized users. Users subscribing to the respiratory signals need only a web browser and the appropriate URL to see live data streams from patients. Fig. 3 shows an architectural overview of the system.

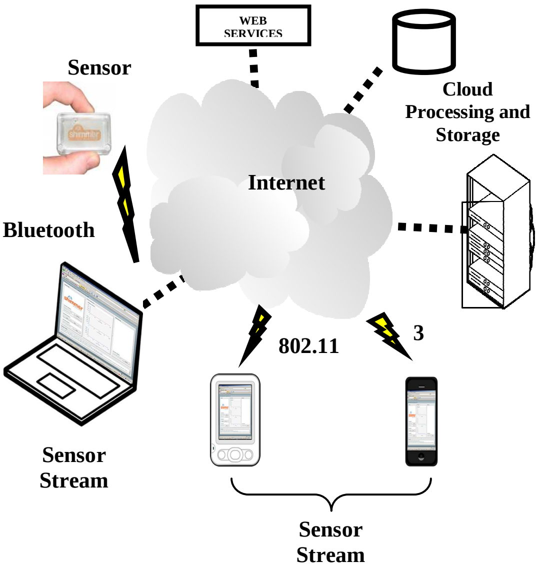

Figure 2. Overview of web streaming solution for respiratory signal distribution.

II. METHODS

A prototype vest with piezoresistive sensors (Fig. 1) has been developed to detect body movements related to breathing. The vest is capable of measuring the frequency of respiration and can also distinguish between deep and shallow breathing through the use of multiple sensors. Another advantage of using multiple sensors is in the detection of anomalies in the respiration cycle such as coughing episodes.

The vest incorporates six sensors aligned along the front panel. The sensor locations are chosen to maximise the relevant information that each sensor can give from various positions along the torso. In this way it is possible to monitor the about movement of the thoracic abdominal cavity and identify which muscle groups are active.

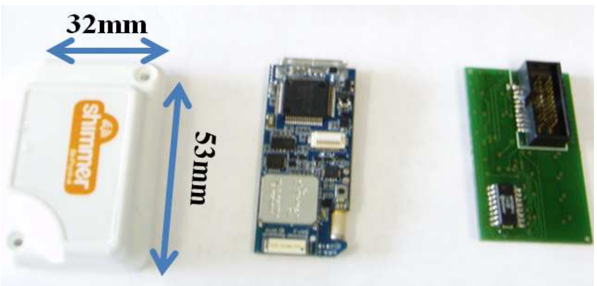

Figure 3. Left to right, casing, the main board and expansion board

The Shimmer platform has a total of eleven ADC inputs six of which are used to connect the piezoresistive sensors. The other five channels may be used in the future to measure temperature, humidity or other sensed parameters related to personal health. The data from the sensors is sent wirelessly to a laptop via Bluetooth. The data can then be processed and analyzed in real-time. Fig. 4 shows an example of a signal received by the Shimmer platform. Channel 1 (Ch 1) corresponds to the sensor on top of the chest and channel 4 (Ch 4) over the navel. Both cases show similar temporal characteristics but the difference in amplitude suggests that greater movement is occurring in the chest region rather than the abdomen.

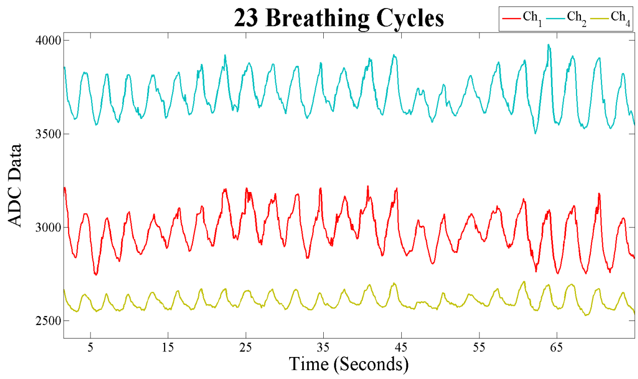

Figure 4. Example of data received from shimmer platform during a breathing exercise.

The signal streaming capability is achieved with the VS3 signal streaming system (Vivid Spectrum Technologies, Ireland). VS3 comprises VSX, VSView and Bloom. Bloom is a small piece of bridging software designed to web-enable non-IP enabled sensor technologies. In this case the wireless sensor system (Shimmer Research Ltd., Ireland) was bridged using Bloom to provide seamless integration with VSX and VSView.

Bloom runs as a background service and is not visible to the user once configured. VSView is a rich web library containing functions useful for browser-based manipulation, pooling, management and viewing of sensor data. In this instance VSView was extended to provide the necessary interface for the prototype application shown in Fig. 2. Client-side filtering operations especially digital filtering are available for RIA designers from this library. Finally the stream aggregation and management system is achieved through an instance of VSX running on an appropriate server technology (Amazon EC2 for example). VSX is a set of extensible server-based software components which act as a backend for matching sensor streams with subscribing clients as well as manipulating incoming streams for further processing and archiving. VSX can be run on cloud or dedicated server systems. In addition VSX supports the encryption standards necessary for patient related data transfer.

III. RESULTS

To test the system we connected the respiratory shirt to a cloud hosted server solution. Using the Shimmer platform (Fig. 3), we are able to transmit and reconstruct acquired signals sensors at 40 samples per second across a representative network environment (Bluetooth, Wifi, DSL (0.5Mb/s upload, commercial ISP backbone) with acceptable responsiveness and sub second latency.

The web browser application shown in Fig. 5 displays the breathing signals acquired by the vest in real-time. This information can be accessed by a medical professional as the patient performs their breathing exercises. This has applications for various respiratory illnesses and allows the clinicians to observe their patients physical state remotely.

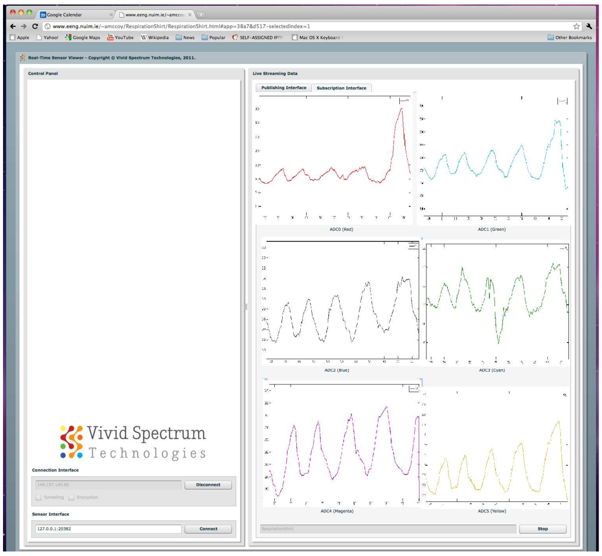

Figure 5. Rich Internet Application showing output from top breathing sensor over 5 second window

The breathing patterns shown by these graphs can also highlight any anomalies that occur during respiration. Figure 6 shows an example of coughing events between breaths. A change in the expected periodic cycle of breathing occurs due to the irregular movements during a cough. This technology will be useful in identifying the frequency of coughing for various respiratory pathologies. This could help identify any deterioration in the patient's condition.

The signal streaming performance was compared with the machine-to-machine communication capabilities offered by a leading industrial provider – in this case, Labview Web Services (National Instruments, USA). A single wireless sensor was used for streaming in this case and network traces were collected using Wireshark. The Labview Web Services client allowed signal samples to be rendered on a remote browser at a rate of 2 samples per second – much less than the 40 sample per second rate available with VSX.

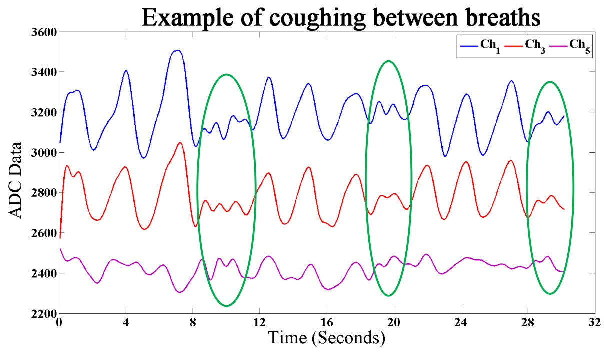

Figure 6. Breathing signals acquired by sensors positioned at top, middle and over the navel. Highlighted regions are during coughing events.

IV. CONCLUSIONS

In this paper a rich internet application for signal streaming has been presented suitable for real time tele-rehabilitation purposes. The application combines smart textiles, web streaming technologies and wireless, untethered patient connectivity to yield a practical solution for respiratory monitoring in a home environment. Validation of the sensors will involve comparison with a gold standard $V0_2$ max machine or spirometer. The effects of temperature also need to be investigated to ensure wearability and ruggedness of the sensors.

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