Poster: Smart KT Tape - A Bendable Wearable System for Muscle Fatigue Sensing

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Abstract

We see a major hurdle, as well as a window of opportunity, in wearable sensing system design - making the system soft and bendable for skin surface sensing. In this abstract, we present our design and exploration of a FPCB-based wearable system for muscle fatigue sensing, referred to as the Smart KT Tape.

1 Motivation

Building muscle strength and endurance is among the most effective ways to prevent injuries [3]. The dilemma is that muscle building requires excessive muscle use, which puts the subjects at rick of injuries. The biology of muscle use suggests that as time goes by, fatigue builds up and the force behind the muscle movements declines. This makes it difficult to resist the strain and tension required to maintain movements, and eventually leads to injuries. Sensing of muscle fatigue is therefore crucial in preventing injuries while keeping the population fit. Existing solutions are shown capable of inferring muscle fatigue using mobile, miniature EMG or motion sensor [5, 2]. They are, however, still bulky and stiff. This hinders body movements and therefore compromises the usability.

To this end, we find opportunities in a unique form of wearable – Smart KT Tapes. KT tape is also known as the kinesio elastic therapeutic tape. It is more often used by the professional athletes but is gaining popularity among the recreational users. Users typically seek the taping treatment when muscle injuries have grown noticeable. This coincides with the need to measure muscle fatigue, making the tape-form wearable system natural to the intended users, and therefore better usability.

2 Design Rationale

The challenge of realizing the Smart KT Tape for muscle fatigue inference lies in the system design. The main design considerations are: (1) Usability: To fit on skin surfaces of arbitrary curvature, the hardware needs to be soft and bendable. (2) Inference Accuracy: Surface EMG signal is noisy and particularly so when there is little muscle contraction. This means additional sensor that is capable of estimating body movement is essential. (3) Sampling Granularity: The 20-500 Hz frequency band is necessary to infer muscle fatigue. The EMG sensor signal therefore needs to be sampled at a frequency multiple times higher than 500 Hz.

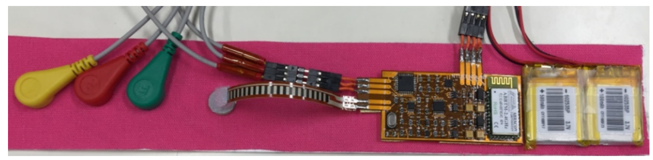

Figure 1. Hardware Prototype

These design considerations call for a soft, flexible circuit board (FPCB) solution composed of an EMG sensor, motion sensors, a short-range radio, and a microcontroller with fine-grained clocking. To infer muscle fatigue, all sensor signals collected on board the Smart KT Tape are transmitted to a computation platform, e.g., a mobile phone. The motion sensor data are first processed to identify active periods of body movements, which are used next to select the parts of EMG signal relevant to muscle fatigue calculation.

3 Hardware Implementation

Smart KT Tape's hardware architecture is similar to most wireless sensing systems. On board are the essential components: MCU, the Bluetooth module, and the power adaptor. In addition to the main sensor – EMG, we choose to include two motion sensors in the design, i.e., accelerometer and flex sensor. These motion sensors are used to identify active periods of movement, which are necessary to extract EMG signal where muscles are actually in use.

To implement a soft board, we place and wire components albeit the design guidelines for FPCB [1]. The main feature is the 2-layer circuit design, as opposed to the popular 4-layer design where components and wiring can go in parallel in 4 layers and therefore cutting down the board size. The reason for such a design is to prevent breaking or crossing of the circuits with frequent bending. The second feature is that all chipsets are placed on the top layer while the bottom layer is used only for wiring purpose. This allows better signal

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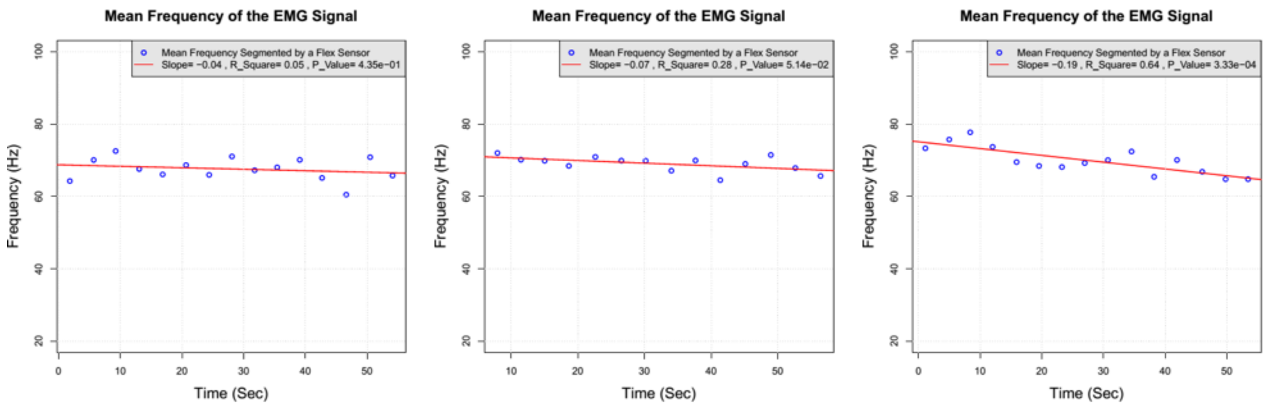

Figure 2. Muscle Fatigue Index: Light, Medium and Heavy Weight Cases

quality and better bendability as well.

Figure 1 shows the hardware prototype. The board size is 6.7 cm by 3.8 cm. It is ultra slim and the height is a mere 0.05 cm. One particular experience to share is the choice of connectors. In an earlier design, we use a hard pin connector to interface the main board to the peripherals. This is proven naïve. The board area where the connector lays breaks in the trial runs. It turns out that the connectors are pulled and bended repeatedly as the test participants perform the instructed body movements. We replace the hard connector with a soft one in the final design. The current prototype has sustained the experiments with intensive exercise.

4 Software Implementation

To infer muscle fatigue robustly from the EMG signal, we explore a motion-sensor-assisted approach to capture the time windows the muscle is active in use. To begin with, a high pass filter is applied on the EMG signal to filter out the low frequency component and ensure the 20-500 Hz frequency component is preserved. The accelerometer and flex sensor data are treated similarly. A low-pass filter at cut-off frequency 5Hz is applied on both motion sensor signals to keep just the component in human motion range. The motion signals are then used to identify movement cycles. This is done by applying the peak detection algorithm [4] on the motion signals. Generally, a pair of peaks indicate the beginning and the end of a movement cycle. Note though for movements that are not repetative, the peak detection algorithm might need to be adjusted. This is a subject of investigation in the future. Subsequently, the EMG signal within the movement cycles is extracted. Finally, the mean frequency calculation is applied on the resulting signal, which is what defined as the muscle fatigue index. A declining trend in the mean frequency indicates a rising level of muscle fatigue.

5 Preliminary Result

A small number of participants are invited to the prototype trial. Each participant is instructed to lift a dumbbell of specific weight. Within the participant's capability, 3 weights, 1 kg apart, are selected. They are labelled as the light, medium and heavy weight experiment respectively. In each experiment, the participant lifts the weight repeatedly at a constant speed for about a minute. **Figure 2** shows the mean frequency of the EMG signal from one of the participants. The dots (blue) on the plots indicate the mean frequency calculated per lift. The straight line (red) is the linear fit of the mean frequency samples. One can observe from the slope of the linear fit that the declining trend is mild in the light weight (slope = -0.04), more noticeable in the medium weight (slope = -0.07), and the most pronounced in the heavy weight case (slope = -0.19). This demonstrates the promise of the Smart KT Tape for muscle fatigue sensing.

Based on the experience wearing the prototype, each participant is asked to assess, on the scale of 1 to 5 (5 being the best), the comfort level of using KT tape in 3 different forms: no sensor, hard board sensor, and bendable board sensor. The average scores are 4.56, 3.93, and 2.63 respectively. The p-value is 3.23e-16, suggesting that the difference is significant and the bendable design enhances the usability effectively.

6 Work in Progress

We are yet to experiment the system in a full-scale user study. In that, the Smart KT Tape will be compared to a reference design using the conventional, hard board EMG sensor. The intension is also to explore the trade-off between sensing accuracy and usability tuning the key design knobs, including the use of flex sensor vs. accelerometer and the choice of parameters in movement cycle detection algorithm.

7 Acknowledgments

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