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# Myoelectric Pattern Measurement on a Forearm via Conductive Fabric

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**Abstract:** We propose a wearable two-dimensional (2D) Electromyography (EMG) measurement system put on a forearm by applying a conductive-fabric-based bus connection scheme. This scheme enables the user's natural motion during EMG pattern measurement without impairing the comfort by excluding individual signal wires. Reliable power supply and signal transfer over a single bus are achieved simultaneously by adopting multi-band on-off-keying and frequency modulation techniques.

**Keywords:** man-machine interface, two-dimensional (2D) Electromyography (EMG), conductive fabric

## 1. INTRODUCTION

Electromyography (EMG) is widely used in many applications, such as physical rehabilitation, gait analysis and injury prevention. It can also be used as man-machine interfaces by recognizing hand postures or movements. The myoelectric signals can be measured by applying electrodes to the skin surface. In typical cases, only one or a few pairs of electrodes are placed onto specific points of user's forearm. However, in many applications, there are potential demands for a dense two-dimensional (2D) EMG pattern [1] measured by a large number of distributed electrodes in order to distinguish several EMG patterns corresponding to different hand motions, for example.

A considerable problem in 2D EMG measurement is an increasing of wires. These wires will lead to a more complicated device structure and also a restriction of hand movements. In addition, the contact between electrodes and the skin easily becomes unstable because of the inextensibility of these wires.

In order to eliminate one-to-one wiring in a 2D EMG measuring system [5], we propose a new myoelectric pattern measurement using a conductive fabric based bus connection scheme.

The conductive fabric based approach is especially suitable for providing sensing or actuating capabilities on user's body surface while eliminating a number of individual wires. A particular implementation of this scheme is to utilize three fabric layers: the top and the bottom conductor fabrics and an insulator fabric between them. The two conductive layers work as a signal bus shared by all devices mounted on the fabric. Successful DC power supply and serial communication on the bus were realized in TextileNet proposed by Akita *et al.* [2]. Based on this concept, we establish the practical sheet medium and the signal transmission scheme for a large number of sensors sharing a single conductive layer.

† Ya Zhu is the presenter of this paper.

In our proposal, we arrange EMG electrodes onto a conductive fabric. A reference electrode for EMG sensing is placed at a distance from the array.

The overall image of our system is shown in Fig. 1. The EMG signal is captured at each electrode, amplified immediately, and sent to a central node in an appropriate time slot. Simultaneous power and signal transfer is supported [3].

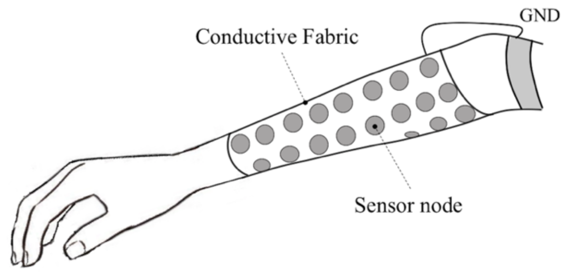


Fig. 1 Overall image of our measurement system.

The system enables users to wear the system comfortably and also move their hands and fingers naturally by applying stretchable conductive fabric with less wire. The potential applications of the device are as follows:

1. Users can interact with their smart home devices or video games by inputting gesture commands.
2. Operating telepresence robots or artificial limbs.
3. Recording myoelectric data during daily exercises or sports for further analysis.

## 2. SYSTEM DESIGN

### 2.1 Conductive Fabric Scheme and Tack Connector

The fabric medium used in this work has a non-conductive fabric sheet with conductive threads sewn on both sides of it [3] as shown in Fig. 2. The conductive threads on the top and the bottom should be isolated from each other so that these two isolated threads form a signal bus used for power supply and signal transmission. This scheme can retain the stretchability, flexibility, thinness and texture of the original base fabric, which enables users to wear the measurement system comfortably just as putting on a cloth. We arrange the conductive threads as a square mesh pattern while any other geometric layouts could be arranged as creative artworks.

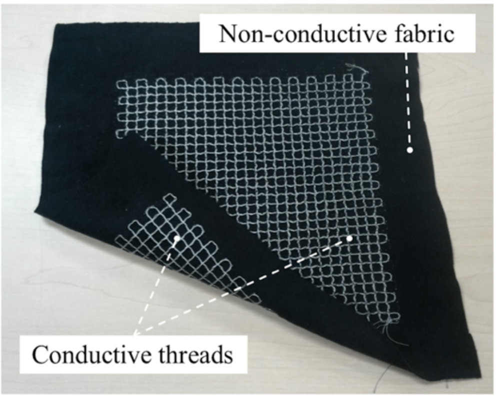


Fig. 2 The conductive fabric used in our work.

Also, a special sensor node like a small brooch with electrode, amplifier and filters integrated on it is used in our system as shown in Fig. 3. The main body of this node consists of a tack and a clutch. The needle of the tack is stuck through the fabric from one side and the clutch is attached on the other side. Owing to this design, the physical mounting of these nodes becomes quite easy by just sticking nodes onto the conductive fabric without any other electrical connections. Then, the electronic components integrated on it can be powered and also the captured myoelectric signal can be transmitted via the bus.

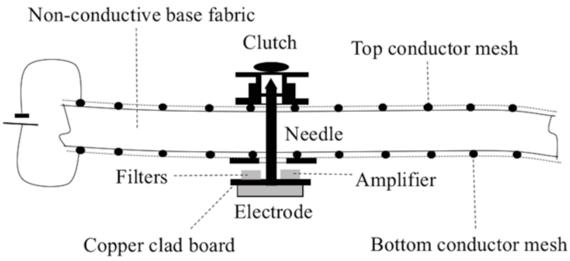


Fig. 3 A sensor node with electrode, amplifier and filters integrated on it is stuck through the conductive fabric.

### 2.2 Communication between devices

We use master-slave model for communication between devices mounted on the conductive fabric, i.e., the master initiates every signal transmission. Every connector can be seen as a "slave" owning its unique address. And one "master" with microcontroller integrated in it can address these slaves in any specific order and receive myoelectric data from them. There is only one bus used for communication between the one master and multiple slaves. A concise schematic is shown in Fig. 4.

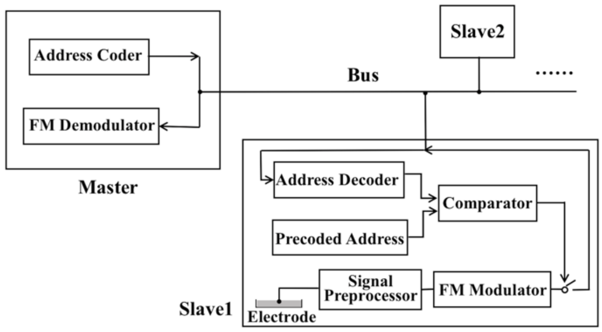


Fig. 4 Master-slave model for communication.

### A. Master Circuit

The master circuit generates addressing signals for specifying the ID of a sensor that should respond. The $n$ bit ID is transmitted as a combination of $n$ frequency components, as shown in Fig. 5. By switching on/off states of $n$ frequency components, $2^n$ slave addresses can be handled. For example, to communicate with "slave 0011", the master turns $f_3$ and $f_4$ components on. Fig. 5 shows an example of 4-bit addressing.

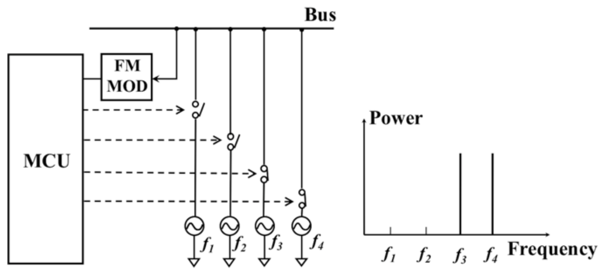


Fig. 5 Four bit addressing scheme with four frequencies.

### B. Slave Circuit

Every slave owns its unique ID precoded in its circuit. The addressing signal received via the bus is compared with the precoded address, and the only device that is addressed by the signal begins data transmission as shown in Fig. 4. The addressed slave begins to send a myoelectric signal sampled at that moment. The signal picked up from the electrode is amplified and filtered as shown in Fig. 6. Due to the high impedance between the skin and the electrode, an instrumentation amplifier (Analog Devices AD8553) is applied to process a stable gain range up to 1000 with low noise. Noise components contained in the captured signal, out of the range from 20 to 500 Hz [4], are removed by a band pass filter. A carrier signal at a much higher frequency band around 10 MHz is frequency modulated (FM) with the output of the filter and the modulated signal is sent to the master via the bus.

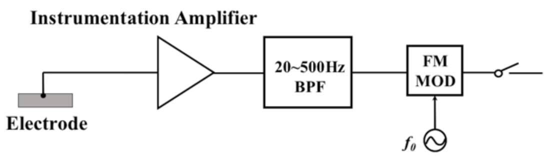


Fig. 6 Myoelectric signal preprocessing circuit

The advantages of this communication method is the easiness of the implementation. A compact hand-made circuit can be realized since a limited number of frequency bands are used, precise clock and timing control are unnecessary, and high-speed computation is not required in the sensor. Nevertheless, it is possible to readout 64 sensor's data of 6-bit ID in 1 ms since high signal-to-noise ratio FM signal transmission is possible.

## 3. TEST EXPERIMENT

To verify the effectiveness of our master-slave signal transmission scheme, we did an experiment to test two-channel on-off control of two slaves.

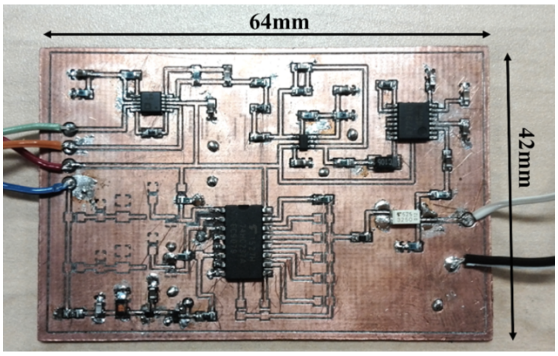


Fig. 7 The hand-made sensor circuit

A hand-made sensor circuit as the slave with all amplifiers, filters, decoder and FM module integrated on it was developed as shown in Fig. 7. And the disposable Ag/AgCl solid gel electrodes (Vitrode M-150) were used. The two-channel sensor circuits with four recording electrodes for differential amplification and a common ground electrode is shown in Fig. 8. The overall voltage gain is 415 and the bandwidth of the band pass filter is 20-500 Hz. And the two channels shared one bus for signal transmission.

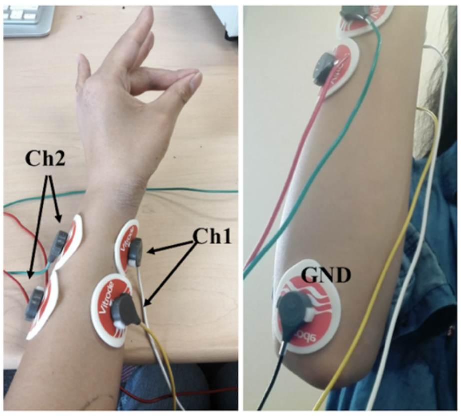


Fig. 8 Experiment task and positions of the electrodes

In the master circuit, we used the Waveform Generator (KEYSIGHT 33600A series) as the address coder to generate two different frequencies, 23 MHz, and 53 MHz, for addressing 2-bit sensor ID. Also, a universal software radio peripheral (Ettus Research USRP N210) was used for FM demodulating.

In the test experiment, the subject (female, 26 yeas old) should use her thumb to press her middle finger within 1 second at a time as shown in Fig. 8. The two different signal patterns of the two channels when the subject was performing such a motion were recorded beforehand. The two EMG signal patterns of ch1 and ch2 are shown in Fig. 9. Then the subject repeated performing this motion and once the subject finished one time, the master switched the channel. When the master turned the 23 MHz component on and kept the 53 MHz component off, ch1 was addressed and began to send a myoelectric signal sampled at that moment. Conversely, ch2 would be addressed when the master turned the 53 MHz component on and kept the 23 MHz component off.

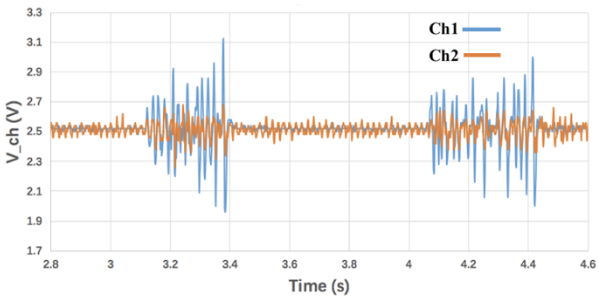


Fig. 9 The two EMG signal patterns of ch1 and ch2

The modulated myoelectric signals received by the master were demodulated and the result is shown in Fig. 10. The result shows that the two-channel on-off control was effective and the demodulated signal patterns were similar to their original EMG signals.

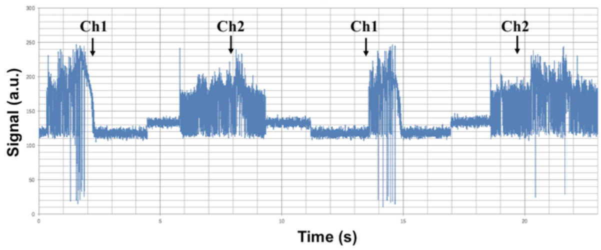


Fig. 10 Two-channel on-off control and myoelectric signal demodulation

In addition, in this test experiments, we switched the channels manually, by changing the frequency of function generator signal, with the switching rate lower than 0.2 Hz. It was just for a preliminary experiment to demonstrate the operation of the circuit. In an actual measurement system, high-speed switching rate, much higher than 500 Hz, will enable simultaneous multi-channel measurement. We did not yet test the signal transmission through a fabric medium, but the only bus used for signal transmission in the test experiment is equivalent to the fabric medium. Wires between the electrodes and the circuit shown in Fig. 8 will be eliminated in the finalized version of the system by attaching the electrode directly to the slave circuit board.

## 4. CONCLUSION AND FUTURE WORK

We proposed a new wearable 2D EMG measurement system put on a forearm via a conductive fabric. This conductive fabric is composed of one base fabric with conductive threads sewn on both sides of it. The two isolated conductive threads are used to supply power and signal transmission bus for special sensor nodes and controllers. Then, multiple sensor nodes for measuring myoelectric pattern are stuck through the conductive fabric. Master-slave model is used for communication between these nodes and a main controller. Every node has a unique address precoded in its circuit. The main controller addresses one of these nodes at a time by sending multiple frequency combinations. The controller addresses these nodes in a cyclic order to obtain the changing myoelectric patterns. Only one bus is necessary for such a communication.

The test experiment verified the effectiveness of our master-slave signal transmission mode in the condition of two-channel on-off control of two slaves.

In our proposal, less wire is used and the attribute of the original base fabric can be retained, which enables users to wear the measurement system comfortably and move their hands and fingers naturally. Even if there are always some modulation errors in FM module, the observation of changing myoelectric patterns will not be seriously affected.

We have developed a small hand-made sensor circuit and we will make it more compact in the next few months. Furthermore, we also plan to design a compact master circuit with power supply, clock generator, and demodulator integrated on it. Also, we will test the high-speed on-off control of signal transmissions under the circumstance of more than two channels.

## ACKNOWLEGEMENT

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