# Delivering key signals to the machine: seeking the electric signal that muscles emanate

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**Abstract**. Due to the limitation of electric power generation in the human body, present human-machine interfaces have not been successful because of the nature of standard electronics circuit designs, which do not consider the specifications of signals that resulted from the skin. In general, the outcomes and applications of human-machine interfaces are limited to custom-designed subsystems, such as neuroprosthesis. We seek to model the bio dynamical of sub skin into equivalent mathematical definitions, descriptions, and theorems. Within the human skin, there are networks of nerves that permit the skin to function as a multi dimension transducer. We investigate the nature of structural skin. Apart from multiple networks of nerves, there are other segments within the skin such as minute muscles. We identify the segments that are active when there is an electromyography activity. When the nervous system is firing signals, the muscle is being stimulated. We evaluate the phenomena of biodynamic of the muscles that is concerned with the electromyography activity of the nervous system. In effect, we design a relationship between the human somatosensory and synthetic systems sensory as the union of a complete set of the new domain of the functional system. This classifies electromyogram waveforms linked to intent thought of an operator. The system will become the basis for delivering key signals to machine such that the machine is under operator's intent, hence slavery.

## 1. Introduction
Due to the limitation of electric power generation in the human body, present human-machine interfaces have not been successful because of the nature of standard electronics circuit designs, which do not consider the specifications of signals that resulted from the skin. In general, the outcomes and applications of human-machine interfaces are limited to custom-designed subsystems, such as neuroprosthesis.

People who apply prosthesis commonly claimed they felt a lack of feedback for the replacement limbs that requires great effort and concentration for them to execute a routine task. This is the effect of the absence of a direct neural interface that provides a comprehensive sensory feedback. The advances of modern science help more people those who used the prosthesis to replace their lost limbs due to birth defects, diseases or accidents. Intracortical micro stimulation percepts may be implemented to a somatosensory prosthesis where a much more detailed feedback could be obtained as compared to vibrotactile motors and sensory substitution devices that convey unrefined sensations [1].

## 2. Background

Stimulation of electric pulse that is localized in human skin is known as somatosensory evoked potential. It is a result of an electric response of the central nervous system to an electrical stimulation of peripheral nerve, for example, in the median nerve at the wrist or the posterior tibial nerve at the ankle [2]. Somatosensory input allows an upper-limb neuroprosthesis be connected with a brain-machine interface [3]. This brought out the somatosensory percepts for object manipulation process.

The nervous system mechanism can generate significant information towards electric physiological diagnosis and intraoperative monitoring [4,5]. In addition; micro stimulation can be used to activate localized populations of neural elements. However, predicting and subsequently controlling nervous responses to simultaneous current injection through multiple electrodes is a complex process. The computed electric field in the 3-D space surrounding the stimulating electrodes could overcome this drawback [6]. Furthermore, improving sensory and motor outcomes in chronic stroke patient and healthy subject through neuro rehabilitative treatments may be done by temporal functional deafferentation [7].

The body responds to the sub threshold stimulus when subjected to somatosensory stimulations to the tibialis anterior tendon while measuring the brain waves [8]. Therefore, a brain - computer interface may help individuals with disability to control assistive devices and reanimate paralytic limbs. The electrocorticography signals recorded from the sensorimotor cortex could be used for real-time device control in paralyzed individuals. Consequently, brain-computer interface introduces a direct link for transmitting communication between brain and artificial mechanism [9–11]. As a result; a controllable interface for assistive device could raise the quality of life for the disability [12,13].

One of the best approaches to interface with human body could be done through the invasive device [14]. For example, the combination of the hand-wrist splints, volitional and electrically stimulated muscle contraction could induce the corticospinal plasticity [15]. It is suggested that myoelectrically controlled functional electric stimulation clinically produces greater improvement similar to the physiotherapy session uses mock stimulation [16]. On the other hand, reading the data generated from an EMG-controlled stimulation system will have limitations such as the reliability of surface EMG (sEMG) recorded for a long period of time. In addition, the trustworthiness data of sEMG usage are the issue, when it comes to the sample size [15,17].

This paper explains the idea of developing a relationship between human and machine such that a human may instruct a machine to execute pre-thought activities via somatosensory activities generated in the brain. We are attempting natural interaction of a human to machine through a non-invasive approach, hoping to create the ability for a human operator to merge with manufacturing machinery in running a production process.

## 3. Approach

We seek to model the bio dynamical of sub skin into equivalent mathematical definitions, descriptions, and theorems. Within the human skin, there are networks of nerves that permit the skin to function as a multi dimension's transducer. We investigate the nature of structural skin. Apart from multiple networks of nerves, there are other segments within the skin such as minute muscles. We identify the segments that are active when there is an electromyography activity. When the nervous system is firing signals, the muscle is being stimulated.

### 3.1. Active segment

The experiment was noninvasive in nature where we performed sEMG. The probes or electrodes are attached onto the skin surface using standard patches to read voltage excitations on muscle stimulation. The reference coordinates to place the electrodes is explained in Figure 1. It shows a grid that estimates the location to place each of the electrodes. For example, a set of probes that is with red, blue, and black cables may be placed at (d,C)-red, (d,D)-blue, and (e,A)-black, respectively. The black-cabled electrode functions well when it is placed on a bony area. So, (e,A) is the best position on the grid.
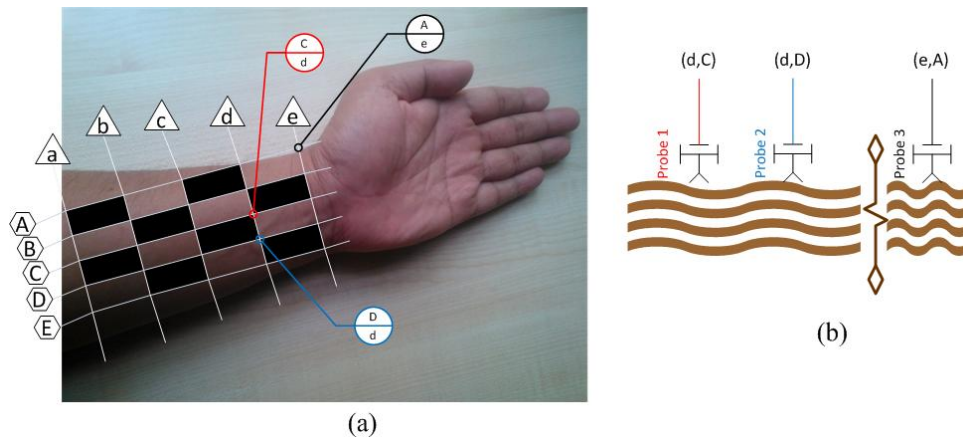
(a)

(b)

**Figure 1.** (a) A grid that depicts the probable location where each of the probes may be attached. For example, there is a vertical axis ⟨a⟩ and a horizontal axis [A] (b) The skin surfaces where all the nodes should be put. Probe 3, however, does not have the luxury of selecting a location. Its current location on the grid is fixed.

Table 1 lists the proposed locations for the electrodes. It explains the locations on the arm based on the anatomical landmarks [18]. The named locations, however, are shown based on the grid system mentioned in the preceding that corresponds to the landmarks.

**Table 1.** Active locations for electrode attachment.

| № | Landmark | Estimated grid location |
|---|----------|-------------------------|
| 1 | Brachioradialis | (a,A) |
| 2 | Flexor carpum radialis | (b,C) |
| 3 | Flexor carpum ulnaris | (c,E) |
| 4 | Smaller forearm extensors | inv(a,C) [a] |

[a]At the back of the arm where the "inv" is a short form for "inverse".

*3.1.1. Model 1.* Let the grid, G has a horizontal axis with triangle scale notation for a through e, and a vertical axis with polygon scale notation for A through E such that $G = \{g \in G : g(\rho,\sigma)\}$ where $g(\rho,\sigma)$ is sub trees in the grid and $\rho$ and $\sigma$ represent vertex and edge, respectively that holds the information of the axes.

Let $\Xi$ represents the abscissa where are definedts .the axis is defined as $\Xi = \{A,B,C,D,E\}$. Also, let $\Psi$ represents the ordinate where are definedts .the axis is defined as $\Psi = \{a,b,c,d,e\}$. There exist a number of possible points that the electrodes may be placed with a number of possible combinations of coordinates. We have the following equation that explicitly defines the phenomenon.

$$\mathbf{X} = \{\chi \in X \subset \mathbf{G} : [\Psi \times \Xi] \,|\, \exists P \text{ may be fixed to some locations}\} \qquad (1)$$

The sensor module has a set of three electrodes coded by colors, block A, and block B. Figure 2 depicts a generalized block diagram of the electronic system depicted in Figure 3. The probes 1, 2, and 3 are coded as red, blue, and black, respectively. Its present state is at (d,C), (d,D), and (e,A). Block A receives raw signals and amplifies them. Block B receives the amplified raw signals and rectifies them.

*3.1.2. Model 2.* Let P represents the probes or the electrodes. We have $P = \{p_1, p_2, p_3\}$. There are at most three electrodes. Let block A represents an amplifier circuit and block B a rectifier circuit. The generalized output function of the transducer system is:

$$\mathbf{O}(s) = \mathbf{P}(s) \cdot \mathbf{A}(s) \cdot \mathbf{B}(s) \tag{2}$$

Suppose there is a number of a combination of a set of probes to be localized within the grid, which is defined in equation (1). Each set of probes is represented by a sub tree and is related to a transducer system. Therefore, the root of the sub tree is the block B. We have for $G$:

$$\left. \begin{array}{l} \rho = \{A, B, p_1, p_2, p_3\} \\ \sigma = \{(A,B),(A,p_1),(A,p_2),(A,p_3)\} \end{array} \right\} \tag{3}$$
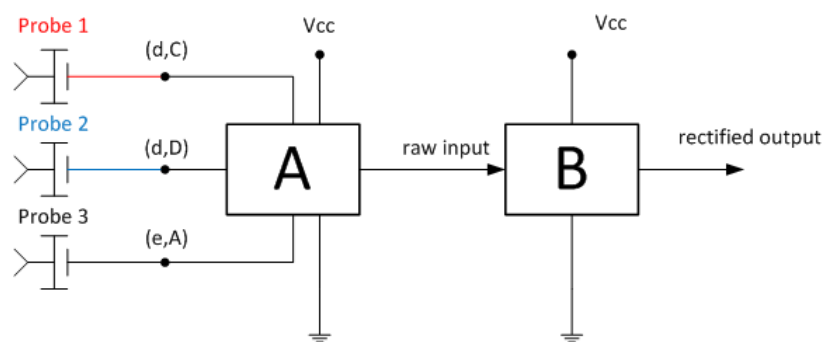


**Figure 2.** The transducer has three electrodes, circuit in block A, and circuit in block B. Block A receives signals from the muscles and produces raw outputs that are being amplified. Block B receives the amplified raw signals and produces rectified outputs.
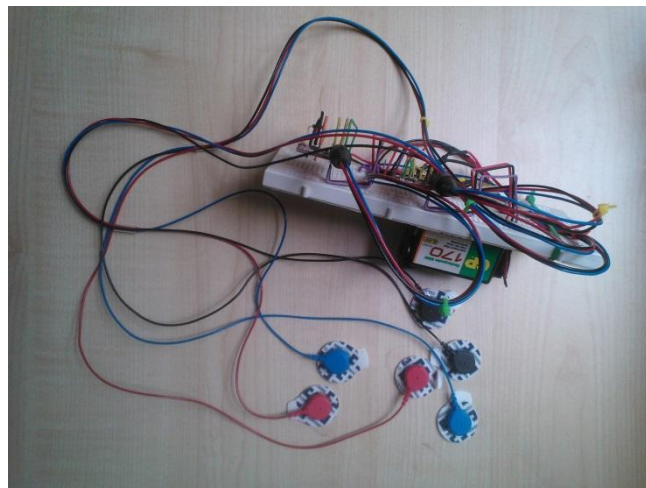


**Figure 3.** A transducer system prototype showing two sets of electrodes, circuit installed onto a breadboard powered by two units of 9-volt battery. This is a prototype-0.

*3.1.3. Model 3.* Figure 3 exhibits a pilot test on the transducer system where a set of electrodes was placed on a segment of the subject's left hand. The subject would have "intent to grab something." The muscle around that segment was stimulated, and an amount of potentials was read on the instrument.

Upon muscle stimulation, an amount of potential is transferred through the electrodes. These raw signals are being amplified and transfer to another process, which rectifies them. These useful signals are now ready to realize a human and a machine signal interface. The machine module will have a processor that accepts a certain signal protocol from the transducer system.

Let $\Pi$ represents the machine processor protocol. We have the following equation that defines the human-machine signal interface protocol.

$$\Pi(s) = \begin{cases} 1, \forall \mathbf{O}(s) \text{ reaches threshold} \\ 0, \text{ otherwise} \end{cases} \tag{4}$$



**Figure 4.** A pilot test of the transducer system was performed on the subject left hand. An oscilloscope and a multimeter were used to observe the evoked potentials. The instrument used were Tetronix TBS 1062 oscilloscope and Tenma 72-8170 multimeter.

## 4. Preliminary results

Ten male subjects participated in this study. The age ranges from 20-year-old to 27-year-old, all of whom have had no trauma. The experimental setup consisted of a Prototype-1 transducer system shown in Figure 5(b), a digital Parallax USB oscilloscope. The subjects were asked to supply the information that led to the body-mass index (BMI) shown in Table 2. The idea behind finding the BMI was to learn the degree of obesity that could have somehow affected the signal transmission from the skin to the electrodes due to fat layer thickness.

The forearm length was measured and assumed symmetry for both arms. Once registered, the subject was assigned an identification number. Based on the proposed landmarks on the forearm mentioned in Table 1, a number of grid location was identified and was suspected to be the locations where the electrodes should be placed, and the electromyograph could be read. There were three distinct muscles chosen, the flexor carpi radialis, the extensor digitorum superficialis, and the carpi radialis longus. The mean, median, and standard deviation for each of the grid locations are shown in Table 2, respectively. For the mean arm length of 24.90 cm, a grid location for flexor carpi radialis is somewhere at mean position (9.92 cm, 8.62 cm) where the origin is at the intersection of the vertical axis ⟨e⟩ and horizontal axis [e].

**Table 2.** Identified grid locations on forehand.

| Subject | BMI | Arm length, $L$ ($cm$) | Identified grid location $\{x, y: cm\}$ | | |
|---------|-----|------|------|------|------|
| | | | On flexor carpi radialis | On extensor digitorum superficialis | On extensor carpi radialis longus |
| 1 | 19.72 | 27.0 | 10.8, 7.2 | 13.5, 2.3 | 13.5, 8.1 |
| 2 | 21.88 | 25.5 | 9.8, 8.0 | 12.3, 2.5 | 12.3, 9.0 |
| 3 | 23.29 | 26.0 | 10.4, 4.8 | 13.0, 2.5 | 13.0, 9.0 |
| 4 | 21.30 | 24.0 | 9.6, 7.2 | 12.2, 2.5 | 12.0, 8.1 |
| 5 | 27.70 | 28.5 | 11.4, 10.0 | 14.3, 3.1 | 14.3, 11.3 |
| 6 | 26.37 | 24.0 | 9.6, 9.6 | 12.0, 3.0 | 12.0, 10.8 |
| 7 | 25.00 | 23.0 | 9.2, 8.4 | 9.2, 2.6 | 11.5, 9.5 |
| 8 | 22.30 | 25.0 | 10.0, 10.2 | 12.5, 3.2 | 12.5, 11.5 |
| 9 | 26.00 | 23.0 | 9.2, 10.8 | 11.5, 3.4 | 13.5, 12.2 |
| 10 | 19.80 | 23.0 | 9.2, 10.0 | 11.5, 3.1 | 11.5, 11.3 |
| Mean | - | 24.90 | 9.92, 8.62 | 12.20, 2.82 | 12.61, 10.08 |
| Median | - | 24.50 | 9.70, 9.00 | 12.25, 2.80 | 12.40, 10.15 |
| Std. deviation | - | 1.77 | 0.71, 1.76 | 1.30, 0.36 | 0.89, 1.43 |

Figure 5 shows how the measurement was made on the forehand. This electrode positioning was based on the specific muscles identified earlier. The muscles involved in this procedure were the carpi radialis and brachioradialis. In this procedure, the second transducer prototype was used. Table 3 lists the settings, readouts, and oscilloscope's display for the three subjects chosen from the list seen in Table 2. The subjects were asked to move one or two of the fingers in a relax state while the measurement was made. In Table 3, subject-1 produced an output function corresponds to 70 mV, subject-2 140 mV, and subject-3 70 mV.
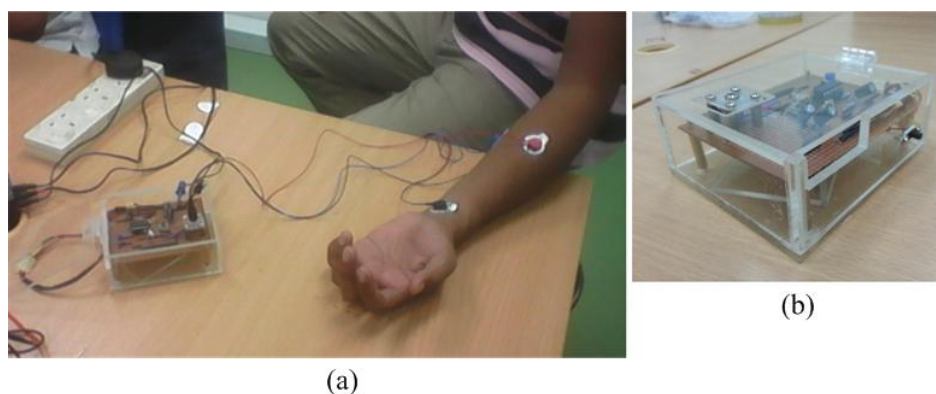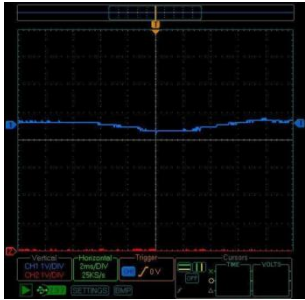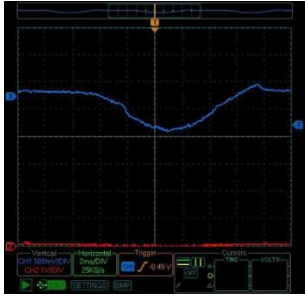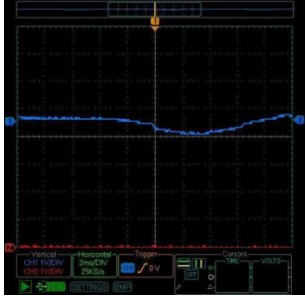


(a)

(b)

**Figure 5.** (a) A test conducted where the electrodes were attached to the subject's left arm on carpi radialis (red electrode) and on brachioradialis (blue), while the black electrode functions as the frame ground. The electromyograph was measured using the transducer system and the Parallax USB oscilloscope. (b) This is the second prototype transducer system based on Prototype-0 with some modifications.

**Table 3.** Readings obtained from the subjects on relax state.

| Subject | Settings and readouts | | Oscilloscope display (flexor carpi radialis) |
|---|---|---|---|
| 1 | Vertical:<br>Horizontal:<br>Max. voltage:<br>Min voltage:<br>Pk-Pk voltage:<br>Mean voltage:<br>RMS voltage:<br>Period:<br>Frequency:<br><br>$\therefore O(s) \mapsto 70mV$ | 1 V<br>2 ms<br>150 mV<br>-310 mV<br>470 mV<br>-70 mV<br>70 mV<br>5.44 ms<br>183 Hz |  |
| 2 | Vertical:<br>Horizontal:<br>Max. voltage:<br>Min voltage:<br>Pk-Pk voltage:<br>Mean voltage:<br>RMS voltage:<br>Period:<br>Frequency:<br><br>$\therefore O(s) \mapsto 140mV$ | 500 mV<br>2 ms<br>200 mV<br>-650 mV<br>850 mV<br>-140 mV<br>140 mV<br>4.76 ms<br>210 Hz |  |
| 3 | Vertical:<br>Horizontal:<br>Max. voltage:<br>Min voltage:<br>Pk-Pk voltage:<br>Mean voltage:<br>RMS voltage:<br>Period:<br>Frequency:<br><br>$\therefore O(s) \mapsto 70mV$ | 1 V<br>2 ms<br>150 mV<br>-470 mV<br>620 mV<br>-70 mV<br>70 mV<br>2.92 ms<br>342 Hz |  |

## 5. Conclusion

In result, we propose a relationship between the human and synthetic systems, sensory as the pairing of a complete circle of the new field of the functional scheme that classifies electromyogram waveforms linked to intent thought of an operator. The system will become the basis for delivering key signals to machine such that the machine is under operator's intent, hence machine slavery.

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