Man to Machine, Applications in Electromyography

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1. Introduction

The study of electrical signals due to muscle activation has been evolving since Francesco Redi found electrical generation in the muscles of the electric ray fish in 1666 (Fishman, Wilkins, 2011), Dubois discovered electrical activation in voluntary muscles in 1849 (Blanc, Dimanico, 2010), and Mari coined the term Electromyography in 1922 (Raz, et al., 2006). Evolving over the following decades, electromyography has found widespread use in clinical settings as well as extensive use in ergonomic assessment and biomechanics research laboratories.

As with many technologies, the discovery of electromyography occurred long before inexpensive and robust hardware was developed to utilize the vast amount of information available from myoelectric signals. Until recently, existing technology could not support efficient generation of repeatable robust signals for even highly sophisticated research laboratories, let alone the widespread availability of affordable, robust hardware required to propagate electromyography through the research communities. New high-speed computation tools make real-time analysis feasible. With the emergence of low cost hardware, high speed wireless communication technology, and low cost, high speed computing/signal processing equipment, Electromyography is becoming available to a whole new set of experimenter. With these advances making electromyography a feasible option in many situations, we see the emergence of a key period in the evolution of the technology. Surface electromyography (sEMG) provides a convenient and relatively non-invasive avenue for determining muscle activation, particularly as highly portable devices become available. Of course with the benefits of wider availability, we must consider the risks inherent in this spread, as the practitioners involved move from electromyography specialists, to technologists in other fields, using electromyography either part time, or only occasionally. Electromyography is a detailed art, and can easily lead to erroneous conclusions if not practiced carefully. With new applications, particularly where electromyography is employed as a means for humans to control electromechanical systems, care must be taken to insure that these systems are developed with robust safety systems, and improper assumptions about electromyography do not cause harm, injury, or even death.

2. Background

Recognized as a potentially powerful tool EMG was first used in measuring human movement at the turn of the 20th century (Medved, 2001). As use spread, techniques for

recording, processing, and interpreting EMG signals varied widely. With a lack of standardization, various styles developed and the discipline became an art as much as it was a science (De Luca, 1997).Efforts have been underway to standardize the EMG process, with considerable efforts in the past decade to implement standards which 1) formalize scientific understanding of the concepts behind EMG (De Luca, 1997), 2) allow interpretation and repetition of previously published results (Hermens, et al., 2000) , and 3) provide standards going forward for generating as well as publishing EMG data (Hermens, et al., 2000). In the following sections, three major efforts to standardize the EMG recording, processing, interpreting, and publishing procedures are discussed

2.1 What is electromyography?

Muscle cells are surrounded by a selectively permeable membrane with a resting electrical potential of 70 to 90 millivolts. The outside of the cell is positive relative to the inside. Motoneurons carry impulses from the central nervous system to the muscle cells called the nerve action potential (NAP). All muscle cells (or fibers) innervated by one motoneuron are called a motor unit, and are stimulated simultaneously when the motoneuron fires. The muscle fibers of one motor unit are not bundled within a muscle. Rather they are spread throughout the muscle with a relatively uniform distribution. When a series of NAP's reach the cells of a muscle unit they cause a release of chemical transmitters which depolarize the cell to a threshold value, initiating an action potential as the cell wall permeability changes. This depolarization causes a brief contraction, or twitch, of the muscle cell (and all other cells in that motor unit) and comprises the basis of muscle movement. The depolarization that travels along the muscle fiber and can be detected on the surface of the muscle as a small electrical potential called the muscle action potential (MAP). Each muscle is comprised of many muscle motor units, which are comprised of many cells, and are connected to many motoneurons, thus a seemingly simple muscle contraction will correspond to a complex overall MAP waveform. An electrode properly positioned with respect to the muscle can record these MAP waveforms. The sensing and recording of these electrical waveforms is called electromyography (EMG). Though a motor unit is either on or off, based on whether or not it is being stimulated by a NAP, an increase in muscle tension beyond that caused by a single NAP can occur either from multiple NAPs stimulating the same motor unit, or from recruitment of additional motor units. Fortunately, both phenomena cause an increase in overall MAP waveform amplitude, corresponding to an increased EMG signal (Chaffin, Andersson, 1999). Properly recorded and processed EMG signal is known to correlate to muscle activation level, and in some cases can be used to determine muscle tension (De Luca, 1997). EMG recordings can be done through two basic methods; 1) Intramuscular, where needle based electrodes are inserted through the skin into the muscle of interest, or 2) Surface, where flat electrodes are adhered to the skin surface above the muscle of interest. Intramuscular EMG is the preferred method when measuring small muscles, particularly those surrounded by large muscles which may prevent accurate recording of the signal of interest or when attempting to measure only a few motor units. Surface EMG is preferred when studying large muscles, especially those near the surface and with few large muscles nearby. An added advantage of surface EMG is that the electrodes are adhered to the skin surface, thus piercing of the skin is not required.

2.2 EMG, proper signal detection and processing

In the Journal of Applied Biomechanics, De Luca details the factors affecting EMG signal and proper procedure for detecting and processing the signal (De Luca, 1997). These

discussions are followed by a summary of recommendations in the use of EMG. In most biomechanics applications, EMG is used in three areas, 1) to identify the initiation of muscle activity, 2) as a surrogate for estimating muscle tension (force), and 3) as a method for estimating muscle fatigue. In this discussion we cover applications involving filtered and processed EMG signals, thus initiation and fatigue will serve only as tertiary topics of discussion, with the focus of this chapter on muscle activation level. In detecting and recording an EMG signal with maximum fidelity and minimum noise, one must consider a number of factors.

- Electrode configuration. This includes shape and area, material, and inter-electrode distance (IED) which determines the number of motor units being detected. Also to be considered are location of the electrodes on the muscle, laterally and longitudinally. This effects the amplitude and frequency of the signal detected as well as the level of cross-talk from other nearby muscle groups. An appropriate IED should be chosen which is small enough to minimize crosstalk, yet large enough to minimize risk of shunting (electrical contact between electrodes, in effect making them one larger electrode and reducing signal amplitude and signal to noise ratio).

- Intrinsic (muscle) factors. This includes the number of active motor units at any time, fiber type of the muscle, blood flow to the muscle, fiber diameter, and the depth of active muscle fibers. These considerations can affect amplitude and frequency characteristics of muscle response. Also of consideration are the amount and type of tissue between the muscle surface and the electrode. Signal may experience considerable spatial filtering due to interstitial tissue.

- Intermediate factors. These effects include electromechanical properties of the electrodes, and their ability to act as band-pass filters or integrators, and the tendency to record cross-talk from other muscles. Also of concern is the conduction velocity of action potentials and spatial filtering effects of relative electrode-muscle fiber position, as these tend to affect amplitude and frequency characteristics of an EMG signal. This is particularly important when considering anisometric EMG, as EMG signal varies as muscle fibers change in length.

- Deterministic factors. This includes the number of active and detected motor units, motor unit force twitch, fiber interaction, firing rate, characteristics of the action potentials, and recruitment characteristics.

- Other interstitial tissue properties. It can be understood that the movement of subcutaneous tissues including muscle and fat can cause signals erroneously. These signals should be considered in EMG data as a source of artifact error.

The recorded EMG signal can be used to determine muscle activation level in many situations and even to determine muscle force in some cases. These relationships are not automatic however, and care must be taken to design the experiment correctly and to draw only appropriate conclusions from the data. For the isometric case, the amplitude of the EMG signal is understood to increase with muscle force. This qualitative relationship however can not be extrapolated to a force magnitude for one subject or especially as a force comparison or magnitude measurement from subject to subject. In order to make force predictions or make comparison between subjects, EMG signals must be normalized to some applied force. This is usually done normalizing to maximum contraction of the muscle (MVC 100%) or to a reference voluntary exertion (RVE). Additionally, every time an electrode is moved (between sessions or simply due to electrode dislodging) normalization

must be repeated. When electrodes are placed, no matter how carefully, they cover a slightly different set of motor units. As the muscle units under study and the spatial filtering characteristics will change with the new electrode placement, they will yield a slightly or even substantially different signal. Also, if the joint angle changes, the location of the electrodes relative to the muscle belly change. In comparing signals between subjects, the amount of subcutaneous fatty tissue can vary substantially and becomes a major concern. De Luca warns that all of these issues become magnified, and new issues arise when dynamic EMG is considered.

Several recommendations are given and are listed in an abridged form below.

- The preferred electrode configuration (general, not muscle specific) consists of two parallel bars, 1cm by 1-2 mm wide placed 1 cm apart, which record at a bandwidth 20-500 Hz.
- Locate the electrodes on the midline of the muscle belly.
- Use the RMS value of the signal for measuring amplitude of the EMG signal.
- Measure activation time of all contractions.
- Check for crosstalk
- Quantitative comparisons between EMG signals are to be performed in static cases only, and require additional precautions and procedures.
- Instantaneous EMG signals should be treated as stochastic. To obtain a force-EMG relationship, signal should be filtered over a 1 second window, among other precautions.
- In constant force isometric contractions, motor units should not be near their threshold.
- Avoid measurement of anisometric contractions. Additional considerations are required.
- Normalize EMG at values less than 80% of maximum voluntary contraction (MVC), but calibrate between electrode placements and between subjects at MVC.

2.3 EMG, and SENIAM (surface EMG for a non-invasive assessment of muscles)

European group SENIAM has a specific objective of creating collaboration, developing recommendations on sensors, sensor placement, signal processing and modeling. From 1996 – 1999, a major effort was conducted to scan the literature for existing surface-electromyography (SEMG) work, contact these researchers for details and clarifications on their SEMG work, and develop recommendations for SEMG in the future (Hermens, et al., 2000). This effort yielded results showing the breadth of hardware and procedures used, as well as those that were most common.

Based on this research as well as parallel investigation into optimum properties (as opposed to the most commonly reported ones discussed above), SENIAM generated the following recommendations for SEMG.

- There is no recommendation regarding electrode shape, but the size of the electrode should not exceed 10 mm in the direction of the muscle fiber.
- IED should be 20 mm, but this should be reduced for small muscles.
- Pre-gelled Ag/AgCl electrodes are recommended.
- Skin at the sensor location is to be shaved if covered with hair and is to be cleaned with alcohol prior to adhering the sensors.
- SENIAM refers to their CD data for proper subject posture during sensor attachment for specific muscles. This is also the case with determining proper sensor location on specific muscles.

2.4 Standards for reporting EMG data, ISEK

The International Society of Electrophysiology and Kinesiology (ISEK) has endorsed standards for reporting EMG data, and have published them in the Journal of Electromyography and Kineseology (Merletti, 1999). Standards applicable to the experiments conducted here are summarized below.

- Electrode material, shape, and size should be reported.
- Skin and electrode preparation should be given, including abrasion, shaving, cleaning, and use of gel or paste.
- Electrode orientation and location over the muscle should be given.
- Detection details, including gain range used should be given.
- Filtering details, hardware and software, should be given, and amplifier filters should be in the range of high pass 5 Hz, and low pass 500 Hz.
- If rectification and smoothing occur in hardware prior to sampling and storing data, sampling rates can be reduced to 50 – 100 Hz.
- Description of the A/D card used should be given.
- If the Mean Average Value (MAV) of the rectified signal over time T is used, then T should be given.
- EMG values should be normalized about MVC, and conditions should be described.
- When normalizing, the following information should be provided: Training, rate of rise of force, velocity of shortening or lengthening and range of angles if not isometric, load in non-isometric contractions.
- Efforts should be taken to determine that crosstalk did not contaminate the signal. And care should be taken in areas with subcutaneous adipose tissue (body fat).

In reviewing the recommendations from these sources, and especially when comparing them to published experiments, one sees some ambiguity and even some conflicting recommendations. For the most part, however, the guidelines allow the design of well organized experiments, and data can be taken with considerable confidence as to standards and repeatability. In using these agreed upon methods, EMG based devices and applications can anticipate good, robust, and recognizable result. These relatively consistent results can be used to control an array of devices.

As discussed above, EMG data is not a reliable method of predicting forces during individual events within a short task, because EMG signals do not correlate with muscle forces on a real time basis, and individual event measurement is understood as stochastic data only. De Luca expressed concern over the repeatability of tests based on calibration around maximum voluntary contraction and the consistency of subjects applying a truly maximum contraction. Depending on the application, calibration based on maximum or reference contractions are of varying importance. In many applications, truly real-time event recognition may not be necessary, so filtering over a relatively long timeframe (hundreds of milliseconds) may be perfectly acceptable. In other applications, higher speed may be necessary, but accuracy of signal magnitude may be of low concern. In such applications, different approaches to interpreting myoelectric signals should be undertaken. For yet other applications, very little lag is permissible, and high signal fidelity is also required. For such applications, EMG may not currently be the optimum sensing tool. As with most design projects, clearly understanding the parameters and scope of the endeavor is key to developing a successful device or tool. So while standards are in place for interpreting myoelectric signals, proper care and design structure is required to insure the best possible results.

3. Chapter organization

Electromyography is being used in a myriad of evolutionary and revolutionary ways, both alone and in conjunction with other technologies. Along with the widespread availability of high speed, robust computing and sensing equipment at a relatively low cost, EMG is pushing the forefront of human machine interface. We discuss several of the interesting applications of EMG, including current and emerging areas of EMG use, as well as mixed-use applications in which EMG is used in conjunction with other technologies to yield a suite of sensors providing robust signals for the application at hand. Next, we cover possible future applications of EMG, and we discuss the relative merits and cautions of using EMG in various applications.

4. Methods of utilizing EMG in engineering devices

Electromyography can be used in many ways for various applications, with various techniques and concerns corresponding to each new application. This chapter covers five of the most common methods of employing EMG. Each technique has advantages and disadvantages to be explored or avoided based on the specific application.

Methods of using EMG in engineering applications:

Method 1. Sense and emulate/amplify. Here, Electromyography is used to sense the activity of a muscle and the myoelectric signal is processed in order to determine an activation magnitude as a function of time. This magnitude is then used to determine a target force, position, or motion of a worn mechanical device emulating, or actually worn over the same limb. In this method, the myoelectric signal is interpreted in order to determine a discrete magnitude, not a target threshold value. This method is used in controlling the HAL exoskeleton discussed later (Kasaoka, Sankai, 2001)
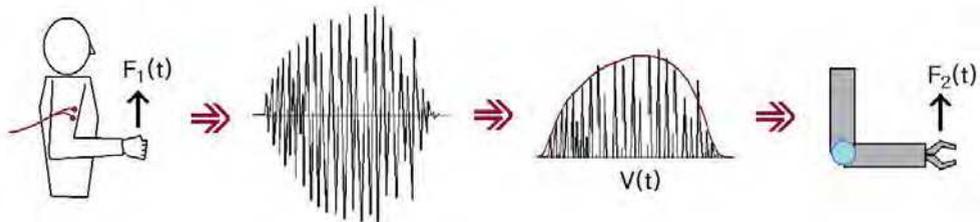

Fig. 1. Method 1 Schematic.

Method 2. Sense and interpret, proportional. Similar to method one, EMG is used to determine activation level of a muscle as a function of time. Rather than interpreting the signal in order to control a local device and directly emulate the limb being sensed, this method interprets the signal in order to provide input to another device, either locally or remotely. Signal strength is used to interpret a desired magnitude (such as speed, lift force, grip strength) For example, a prosthetic arm can not use EMG signals from the missing limb (an exception to this, using the emerging TMR techniques, will be discussed later in the chapter) but can be controlled by sensing the activity of other muscles. Likewise, myoelectric signals can be used as an input source for other devices, either locally or remotely. In this

method, as in method one, signal strength is interpreted to determine a magnitude which changes over time rather than a threshold value.
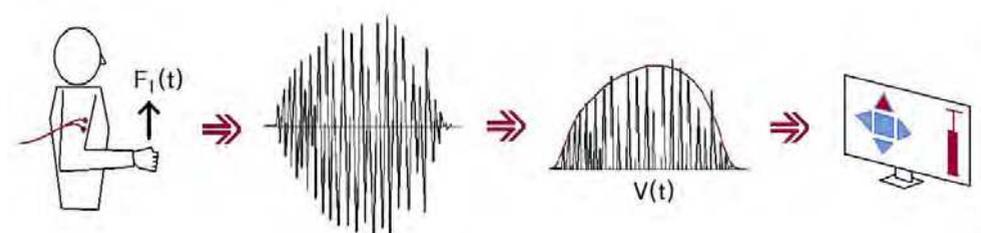

Fig. 2. Method 2 Schematic.

Method 3. Sense and interpret, threshold. A myoelectric signal is read, processed, and compared to a predetermined threshold value. When that value is reached, a condition is considered satisfied. Rather than interpreting a signal to determine a curvilinear magnitude with respect to time, this application is more similar to an on-off switch. EMG signal can be used to signal stop-go, open-close, or other two state situations. Other configurations such as three state situations or any number of two state situations are also possible. The matrix of possible states available is limited only by the number of EMG channels available, and user skill/endurance in operating the device. A simple two or three state device offers the advantage of being easier to operate and has a faster learning curve. This method is used in some prosthetic devices and is believed to cause less fatigue for users than the proportional control in method 2 when the system is designed properly with this goal in mind. This advantage is possible because with the threshold value technique, the controlling muscle is not required to maintain a consistent activation level to maintain the device state.
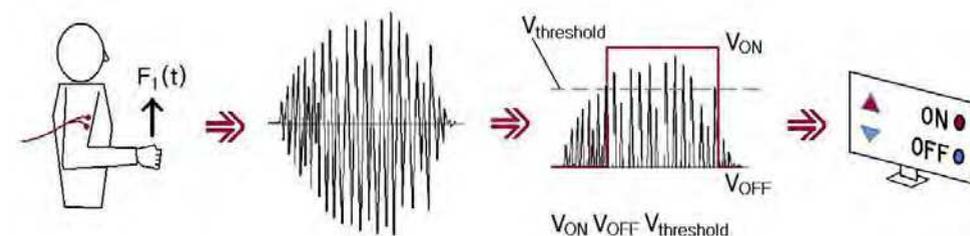

Fig. 3. Method 3 Schematic.

Method 4. Monitor to design. EMG signals are recorded and evaluated during the design and development phases of a device in order to optimize device effectiveness. After development is completed, the EMG tools are no longer used on the device. This use of EMG may be completely transparent to the end user or purchaser of the retail device. This method was used in the development of the Berkeley Lifting Exoskeleton device to evaluate the effectiveness of the device in reducing activation levels in the muscles of the lower back during lifting (Wehner, et al., 2009).
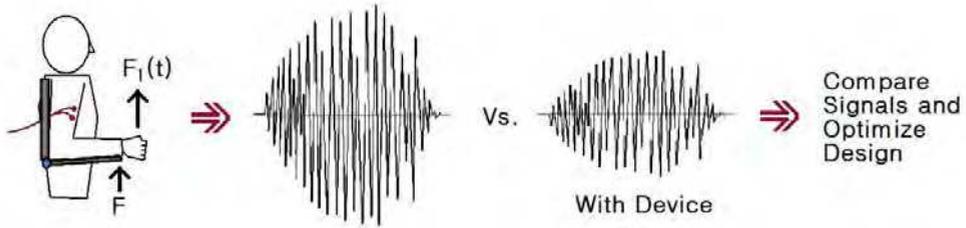
Fig. 4. Method 4 Schematic.

Method 5. Monitor to evaluate. EMG technology is used to study muscle activation levels and report on the effectiveness of a device after it has been designed, and possibly after it is already commercially available. In devices, procedures, or workplace layouts developed to reduce operator exertion or injury, this method can be used alone or with other tools such as surveys to gather data. In some of these cases, EMG was not used during the development of the device, and the developer may not even be aware of EMG technology or its use in evaluating the design. Ergonomic evaluations often fall under this method (Ulrey, Fathallah, 2011).
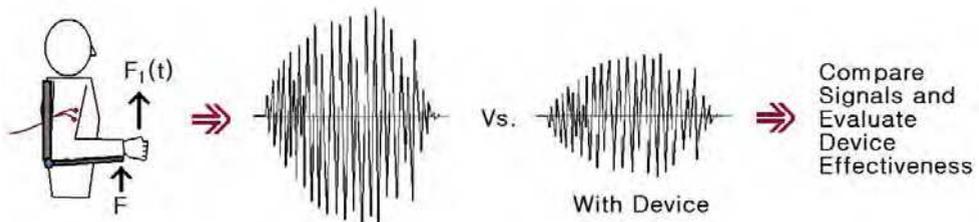

Fig. 5. Method 5 Schematic.

5. On-body devices (worn devices, human exoskeletons, and prosthetics)

Electromyography lends itself especially well to use in on-body devices, as the devices are by definition local to the user. In some applications, EMG provides a particularly intuitive and convenient interface, as the device is intended to perform an action very similar to the motion of the wearer. Because surface EMG is less invasive than some other options, it has natural advantages in non-clinical settings. EMG also has the advantage that the hardware required to record and process myoelectric signals can be relatively small and light, making it more convenient than other sensors which would be awkward or impossible to incorporate into mobile devices (MRI, fMRI). Because EMG electrodes are placed locally, it can anticipate a greater user acceptance than a full EEG sensor array, designed to cover the user's head. Social acceptance can be a considerable block to device use, so eliminating the requirement of wearing a sensor network on one's head can greatly affect a devices widespread success.

5.1 Human exoskeletons

Human exoskeletons have undergone rapid development recently, and are enjoying a surge in popularity. With the wide variety of applications for which human exoskeletons are utilized, use of EMG can fall under any of the five methods discussed earlier. For re-ambulation of patients with reduced ability due to illness or advanced age, method one can be the most suitable technology. To amplify the efforts of able bodied workers, providing additional strength, reach, or range of motion, method one may also be a valuable method and additional features can even be employed in which the wearer controls an additional device utilizing methods two or three. For paraplegic patients with no muscle signal to measure, or patients with other disorders causing spastic muscle behavior, method one would be an inappropriate and possibly dangerous choice. Many exoskeleton designs can utilize method four during the design optimization process or method five after development is complete. As with any application, the appropriate parameters must be set prior to deciding on a method.

The selection of muscle to measure and electrode placement is critical to effective use of EMG for exoskeleton and machine control, particularly if a worn device is intended to perform such complex tasks as interpreting a wearer's intent. A selection of muscles and sensor locations must maximize signal strength, and minimize noise/crosstalk. Additionally, the design must maximize sensitivity to desired signals, yet insure maximum specificity, and not read undesired signals as intended commands. In addition, the decision regarding sensor placement must consider variability in wearer physiology as well as gait variations. Body shapes and sizes vary and have a vastly varying amount of adipose tissue interfering with proper EMG sensing. Additionally, any electrode placement should not be overly invasive, cause discomfort, and can not obstruct proper use of the device. These often competing concerns make EMG sensor placement a difficult task. For example, perhaps the most readily measurable muscle contains high signal variability (false positives), and the most predictive muscle (both sensitivity and specificity) is either small, difficult to reach, or surrounded by larger muscles. Zhen, Songli, Yanan, and Jinwu discuss the relative merits of using sEMG signals of four ankle muscles for gait analysis and control (Zhen, Songli, 2007). The following is a discussion of some human exoskeleton projects, and their use of EMG.

5.1.1 Berkeley exoskeleton (BLEEX, Austin, HULC, etc)

The exoskeleton systems developed at the University of California at Berkeley are used for a variety of applications and come in both active and passive versions (application based). The Lifting Exoskeleton project employs a passive device, as it is used to reduce back forces in able bodied workers during lifting (Wehner, 2009). The Austin, medical exoskeleton, however, is active as it re-ambulates patients with no use of their lower extremities. Intended for paraplegic users, the Austin project would not be a suitable candidate for the direct use of EMG for control. Other exoskeletons, BLEEX, ExoClimber and HULC, are active exoskeleton systems, intended to amplify the movements and abilities of able-bodied users. While not using EMG for sensing or control, and not using EMG during development, method five is still a viable candidate for further experimentation, and can be incorporated with other techniques such as VO2 monitor and treadmill tests. Passive ExoHiker, shown below, uses active damping control based on stride, and swing/stance gait phase to support heavy weight, but actuation is performed by the able bodied wearer. This exoskeleton system does not use EMG for sensing or control, but could utilize method five during future

experiments. The Lifting Exoskeleton project used EMG by method four to monitor and evaluate the device during design, development, and testing (Wehner, 2009). The device was developed as a research platform, intended to generate data which will serve as a knowledge base for the development of an eventual low-cost passive device to reduce back forces. It was never anticipated that the final device would include EMG capability.

Fig. 6. Berkeley ExoHiker exoskeleton.

On the Lifting Exoskeleton project, a passive exoskeleton based device was developed to reduce back forces during lifting. During device development, a variety of techniques were used to optimize the design balancing effectiveness at reducing forces and user comfort. The device featured a spectrum of adjustable features including adjustable size of various features for wearers of varying height and body type. Additionally, the device featured adjustable overall restoring force, adjustable onset angle, and adjustable restoring moment profile, allowing wearers to vary the amount of restoring moment provided in various portions of the squat-lift cycle. Key techniques employed in optimizing the design were human subject comfort surveys, video motion tracking, force plate based lift analysis, and surface EMG, used during static squat postures and dynamic squat lifting. sEMG was used to track the activity of the lumbar erector spinae muscles during repeated lifting of objects with and without the assistance of the device. Use of these techniques facilitated tuning of the device using a variable stiffness spring profile, yielding a reduction of erector spinae muscle activity (as measured by EMG) of 27 to 52%. Tests were conducted in dynamic squat-lift scenarios as well as static squat-sustain postures. This allowed the utilization of

the benefits of static EMG (well understood muscle contraction correlation, averaging over long periods, minimal electrode-to-muscle relative motion), but also generated valuable data over more realistic dynamic tasks. Issues such as crosstalk, relative muscle movement, and inability to determine momentary muscle activation were considered individually during experiment design, as should be done by any EMG practitioner.
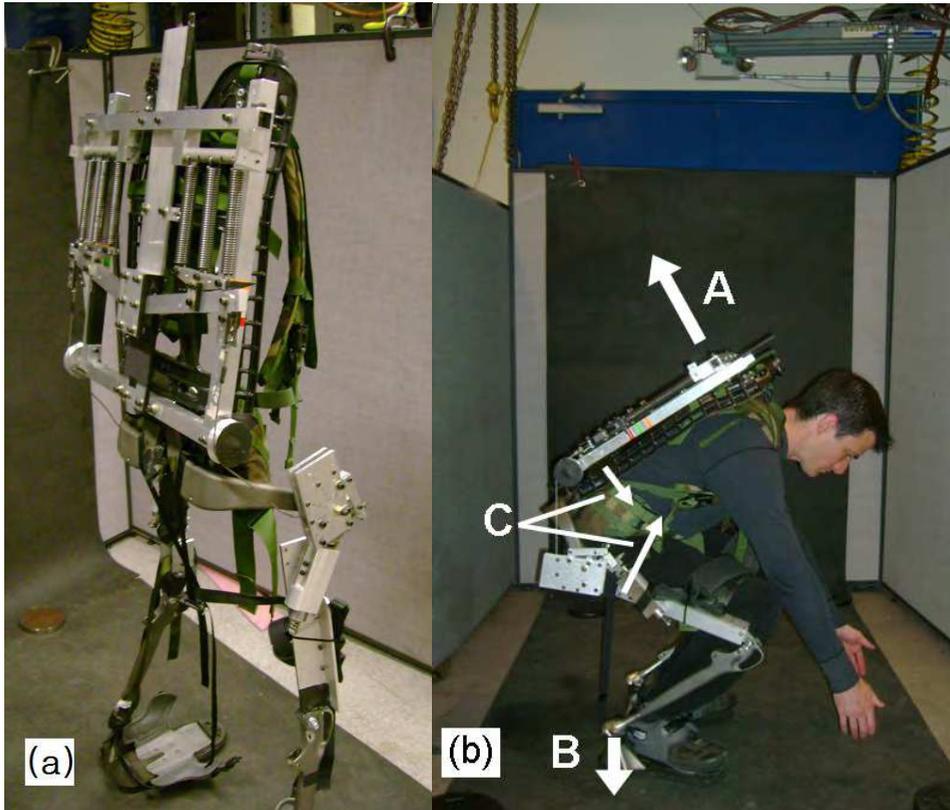

Fig. 7. Berkeley lifting exoskeleton. (a) device. (b) the device with a wearer in squat position. Forces illustrated.

5.1.2 HAL (hybrid assistive limb) exoskeleton by cyberdine

The HAL system by cyberdine (Kasaoka, Sankai, 2001) uses a number of innovative techniques in order to allow the device to function using EMG method one described above. Due to the inherent sensitivities, requirements, and considerations with EMG, specifically high noise rate, muscle movement relative to skin, and difficulty in determining momentary events (detailed in the background section), direct sensing-actuating can not be conducted with the confidence required of such a fault-intolerant application as bipedal walking. For this reason, HAL uses an assortment of techniques to anticipate user actions, adapt to each user's gait, and vary impedance in the knees of the HAL device. (Lee, Sankai, 2002). It is believed that the human limb moves most efficiently at its natural frequency, thus HAL uses

the natural frequency/pendulum model to determine initial settings for the device, modifying the dynamics based on user behavior and EMG signal based feedback (Lee, Sankai, 2003). These techniques utilize known characteristics of EMG signals, standard human gait and gait variation, using a recursive least square (RLS) technique to optimize HAL's gait and impedance realtime. These techniques allow a more natural gait, reduced energy consumption by the exoskeleton device, a robust sensing/actuation loop, and reduced energy expenditure by the user (Kawamoto, Suwoong, 2003). Further refinement, including correlation between a large amount of data from many gait studies by biomedical research groups has allowed the HAL project to develop a calibration algorithm, further developing the natural gait capabilities based solely on sensors onboard the exoskeleton system (Fleischer, Hommel, 2008), and based mainly on surface EMG signals.

5.1.3 Other exoskeletons

Though the above exoskeletons use EMG for design optimization and force amplification, several exoskeleton devices are not currently using these methods. The Sarcos/Raytheon exoskeleton (Sarcos, 2011) MIT exoskeleton (MIT, 2011) and the Berkeley BLEEX exoskeleton (BLEEX, 2011) use direct force control to sense/anticipate user intention. Use of EMG for gait control is an exceedingly difficult task, as seen by the HAL system. Despite not using EMG to directly control the motion the exoskeleton actuators, these exoskeleton systems can incorporate EMG into the development and refinement of their devices (methods 4 and 5). There is no indication if such efforts are currently underway.

5.2 Lift assist devices

Numerous knee-to-shoulder lift assist devices have been designed and are at various levels of development (We hner et al., 2009). Professor Fathallah at UC Davis has conducted extensive tests on these devices, and an additional two person device (Ulrey & Fathallah, 2011; Paskiewicz & Fathallah, 2007). Research tools include extensive use of sEMG, inclinometers, electrogoniometers, and a lumbar motion monitor were used. The worn devices evaluated are shown in figures 8, 9, and 10 below. Figure 11 shows a two-person device, GRIPSystem™. Device effectiveness varies between devices, but sEMG proves to be an effective method of evaluating relative muscle activation and is relatively easy to switch test setups between subjects. While numerous variables must be considered, sEMG provides a highly quantifiable measure of back muscle activation (magnitude and variability from lift to lift and from subject to subject) with and without the device. Other factors such as user comfort and satisfaction as well as device adaptability to various body shapes are critically important to a lift assist device. These factors are not, however, as readily quantifiable as EMG based muscle activation information. Comfort surveys can yield valuable data, but uncertainty is much greater than with EMG muscle activation data. Even if a device is ineffective or yields highly varied results, which can be shown in a quantifiable manner with EMG based experiments, making sEMG particularly useful in this suite of data options. In testing the BNDR system, investigators were able to witness and quantify the flexion relaxation (FR) phenomenon, where some subjects are able to relax the erector spinae muscles of the lower back during sustained static stoop postures, where other subjects maintain high back stresses. The device under study (BNDR) reduced erector spinae forces by 26% (p<.001) among non-FR subjects, while those experiencing FR had such low erector spinae activation that the device did not cause a significant change in activation. Without a
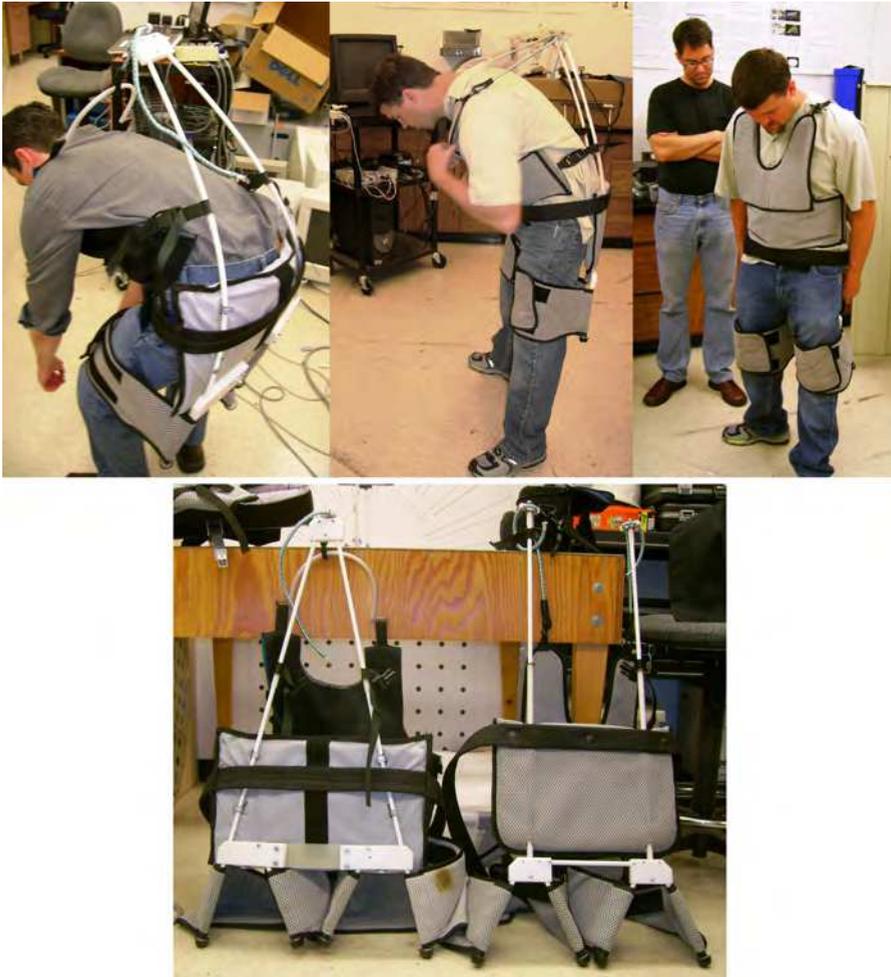
Fig. 8. Happy back, two versions. Top, in use. Bottom, both versions alone.

quantitative analysis tool such as EMG, this phenomenon would have been difficult to detect, let alone separate out the subjects experiencing FR. Device comfort and adjustability were major concerns (Ulrey, Fathallah, 2011). In a study of the GRIPSystem™, twelve subjects performed a variety of real-world lift scenarios, lifting 3 devices at various weights (weight adjusted with the addition of sandbags). EMG was used to monitor the activation levels of ten muscle groups (right and left erector spinae, latissimus dorsi, rectus abdominus, internal abdominal obliques, external abdominal obliques) with and without the use of the device. Erector spinae muscles of the low back saw reductions in low back muscle activation (erector spinae) of varying percentages, all yielding p values below 0.05. EMG allowed researchers to quantify the benefits of the device, but other concerns were evaluated through careful manual analysis. It was noted that the device couples the two workers and makes It more difficult to release an object. Thus, other safety concerns may

arise from such a device.In both the GRIPSystem™ and the BNDR study, EMG was the conduit to valuable information, but the researcher was still required to make the observations and decisions which lead to the true discoveries.

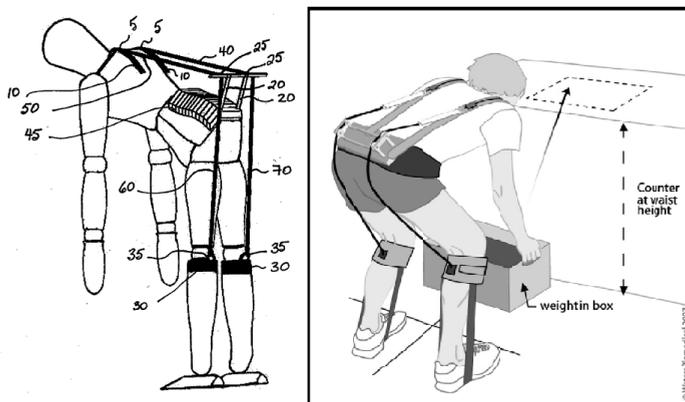Fig. 9. BNDR lift assist system.

Fig. 10. PLAD lift assist system.

6. Prosthetics, upper limb

Upper limb prosthetics (hand, elbow) have been available in some form for millennia. In recent decades, these prosthetics have developed from fairly rudimentary rigid devices to single degree of freedom (DOF) devices, controlled by movment of the shoulder inside of a mechanical harness. More recently, modern upper limb prosthetics have used EMG to control much more advanced devices, incorporating more complex motion into reduced

Fig. 11. GRIPSystem™.

order devices and multiple DOF devices more closely resembling actual hands and arms. EMG based prosthetic hands were first used in 1960 by Kobrinkski et al., and have been growing in popularity and capability ever since. In 1980, forty-three subjects were tested using Otto Bock EMG based as well as hook based hands. Results varied based on many factors, but overall observations included a desire for more durable fingers and finer control of the prosthetic's fingers (Northmore-Ball, et al., 1980). Since this time, of course, advances in materials science, controls, robotics, and other areas have permitted modern designs to greatly improve on the earlier models. In reviewing the five methods of using EMG in on-body devices, we can make several observations. Because prosthetics specifically deal with replacement of missing body parts, method one (amplifying existing motion) does not apply. An exception to this using emerging TMR technology is discussed below. Methods two and three (sense and interpret, proportional or threshold) are the most common use of EMG in prosthetics. Methods four and five (monitor to design or evaluate) can be used to evaluate/optimize designs, or determine metabolic cost of a design or configuration.

6.1 Proportional sensing versus threshold sensing

Upper extremity prosthetics present a considerably different set of challenges from lift assist devices and lower extremity/walking exoskeletons. Emulating a natural gait is not the goal, and precise measurement of muscle activation/muscle force is not necessarily a requirement or even a goal. One popular choice in EMG based upper limb prosthetic control is to use threshold sensing to achieve robust control of a reduced order (one or two DOF) prosthetic hand or hand/elbow system. Otto Bock has developed a full line of threshold based prosthetic hands (Ottobock, 2011a) using a myoelectric signal to activate a degree of freedom based on a threshold. Signal above a threshold initiates or ceases a command. Force

is exerted based on yes/no value (breaking a threshold) rather than proportional to the signal strength. A variety of signal-logic structures are possible, the most basic of which causes a gripper to open/close based on presence of one EMG signal. More complex possible logic structures include a combination of signals all acting as 'switches' to indicate various states such as Signal 1: open, signal 2: close, signal 3: make the DOF go limp, no signal: lock DOF at present location. Of course, the matrix of possible logic states is limited only by the number of EMG sensors available, the available DOF's, and of course the ability/endurance of the patient. Another option in prosthetic control is proportional sensing. In this method, the speed or force of a DOF is controlled by the magnitude of a signal. This presents all of the traditional difficulties of EMG (crosstalk, filtering, realtime issues), and presents new challenges of safety, accuracy/repeatability, and user fatigue. While potentially much more elegant, and possibly capable of providing more realistic emulation of natural hand movement, proportional sensing includes the fundamental issue of requiring a much higher level of continuous engagement from the user. Proportional sensing, by its nature requires continuous stimulation of the controlling muscle by the user. User fatigue quickly becomes a major concern. Recent advancements in computer science and machine learning are addressing this. Current work uses EMG with downsampling techniques to reduce the exertion/fatigue issues (Castellini & Smagt, 2009) and use of a linear-nonlinear projection method to more effectively control myoelectric prosthetic hands real-time (Chu, et al., 2006).

6.2 Current research and commercial prosthetic hands

Currently, Otto Bock provides a variety of EMG based prosthetic hands to the commercial market (Ottobock, 2011b) including high speed (300mm/s) and high force (160N compression) options. i-Limb provides a hand with five independently powered digits, but is controlled by only two EMG electrodes (Touch Bionics, 2011). Antfolk et al. discuss controlling the SmartHand prosthetic using sixteen myoelectric sensors on able bodied and amputee participants (Antfolk, et al., 2010). 86% accuracy was reported on this extremely complex sixteen DOF system (three per finger plus one for thumb-opposition). Despite these considerable advances, EMG control of prosthetic hands is still far from natural hand motion, and some feel that a great deal of improvement is possible (Massa, et al., 2002).

Currently, feedback is a major concern in upper limb prosthetics. Clearly, existing prosthetics can not 'feel' in the traditional sense. While much research is underway to provide haptic touch/force feedback, for position, feedback is still obtained by visual examination of the prosthetic. Touch/force research is currently underway using vibration as a feedback mechanism to indicate contact, or even force feedback (Cipriani, et al., 2008).

6.3 Targeted Muscle Reinnervation (TMR)

Research is also underway to use targeted muscle reinnervation (TMR), in which residual nerves of an amputated limb are connected to spare muscle fibers of a target nerve. EMG signals from these newly innervated muscle fibers are then used to drive a prosthetic device (Zhou et al., 2005a) (Zhou et al., 2005b). Using this technique, a patient performs the mental action of moving the phantom extremity. The rerouted nerves stimulate the newly innervated fibers, generating a myoelectric signal. This signal can be measured similar to traditional EMG measurement of the original muscle fibers, allowing patients to generate a

signal in a much more natural manner. With additional development, TMR could allow researchers to fundamentally rethink the control of prosthetics, and allow for innovative new designs. If successful, this promising technique would allow the use of EMG in prosthetics to move from Methods 2 and 3 to the highly preferable Method 1. Because TMR allows users to actuate prosthetics by "moving" their corresponding phantom muscles, prosthetics controlled by TMR based EMG signals have been shown to be much more intuitive. This new technique has been shown to yield a much shorter learning curve, and has allowed users to control far more sophisticated devices with a greatly increased number of DOF's. As this technology evolves, it will allow the development of considerably more realistic, higher order devices (Kuiken, et al., 2009). Emerging technology, targeted Sensory Reinervation (TSR) promises a complementary technique, providing a sense of touch to the missing limb. A segment of the skin over the TMR site is denervated and regenerating nerves from the TMR procedure reinnervate in this area. When this area is touched, the patient feels a touch sensation in the phantom limb Kuiken et al., 2007). These two emerging technique could allow the realistic closed loop control of multi DOF prosthetics.

7. Lower extremity prosthetics

Electromyography has been used extensively in upper limb prosthetics, and has enjoyed numerous advancements in myoelectric signal processing, as well as pattern recognition (PR) software algorithms. Rates as high as 97.4% EMG based recognition accuracy have been achieved (Chu, et al., 2007). While this is a major achievement in upper extremity control, in highly fault-intolerant tasks such as walking, a 2.6% error rate could prove disastrous. A great deal of effort has gone into EMG for lower extremity exoskeletons, and tremendous strides have been made in this extremely difficult task (see exoskeleton section for details). In EMG controlled prosthetic ankle/knee applications, where the limb is completely absent, patients would be required to control active prosthetics by enervating other muscles. This is considerably difficult in upper limb prosthetics, where real-time movement control (walking gait) is not required. For many applications, grasping can be completed at a modified pace, with position feedback being generated by observing the position of the prosthetic. This would provide overly cumbersome for EMG as a neural control system for lower limb prosthetics, and failures could be dangerous for the user. Due to the critical importance of real-time control and very fault-intolerant nature of walking, lower limb prosthetics are generally not EMG based, though recent research brings new hope about it's future viability. Even in research scenarios, there is a large variation between cycles, making PR difficult. Without the ability to sense or predict the user's intent, active control becomes difficult, because impedance and power must be varied in a feed-forward manner (Huang, et al., 2008). While several active prosthetic ankles and knees have been developed at a research level (Au, et al, 2009; Johansson, et al., 2005; Wilkenfeld, Herr, 2000). There has even been very preliminary work on the possibility of controlling an active ankle prosthetic using EMG, and it has shown promise over a neural network approach (Au, et al., 2006). For the most part, however, other techniques are largely used to control lower limb prosthetics. Despite not currently being suitable for methods one through three, methods four and five can be utilized in lower limb prosthetics development and evaluation. The Otto Bock C-Leg is a popular active lower extremity prosthetic, making it a prime candidate for EMG based gait research (Orendurff, et al., 2006).

8. Tele-operation and gesture based remote control

Just as EMG can be used to control on-body devices, it can be used to tele-operate remote devices from great distance or nearby. While tele-operation via EMG possesses the same restrictions and drawbacks of EMG control of worn devices, it can nevertheless be a powerful tool, and in certain situations the so-called drawbacks of EMG can be used as advantages. Current research in EMG teleoperation includes controlling a wheelchair through a combination of EMG and electroencephalography (EEG) (Han, et al., 2003). In this research, a novel application of EMG has been proposed. In addition to a neural control system for the wheelchair, EMG can be used as a monitoring and alarm system. Other research has used EMG and EEG to control a robot system, with the intent of future use by the handicapped (Ferreira, et al., 2008). In this application, eight subjects were able to control a computer algorithm designed to command devices, with a rightness rate of 95%. Experiments were undertaken to control a robotic arm by EMG signals in the forearm (Flexor Carpi Radialis), control a robotic wheelchair by EMG signals acquired from a neck muscle (elevator scapulae) to allow use by patients with upper and lower limb motor disabilities due to paralysis or amputation (Moon et al, 2003). Yet other research has investigated using EMG to control humanoid robots such as Honda's Asimo (Honda, 2011). Clearly, other possibilities exist, from remotely operating machinery in dangerous locations such as nuclear reactors or deep undersea, to a more intuitive control mechanism for any number of applications. Gesture based control of machinery and computer systems are well within the realm of EMG research, using methods 2 and 3 (Xu, et al., 2009). In these applications, monitoring, warning, and feedback control can be incorporated much more simply and effectively than in previously discussed applications. Each of these remotely operated applications would incorporate a method of feedback. An audio or video warning could be included indicating various states or warnings. An indicator could illuminate to indicate that the device has contacted an object. Complex haptics configurations can be eliminated or greatly reduced in these applications. In order to retain force magnitude "sensing", an array of strain gauges can record forces, and transmit this information to the controller. One is not limited to emulating human capability. Proximity sensors can also be installed to indicate when a remotely-operated device is approaching the desired object. Bar-graph style indicators could be included on a monitor to indicate magnitude based values such as force based control. In any of these applications, just as with worn devices, user comfort must be considered. To this end, a design/evaluate/optimize cycle can be included during the development process, and method four can be used to reduce user fatigue from operation.

9. Emerging applications in modern culture and technology based art

Electromyography is being used to illustrate muscle phenomena in the technology-based-art community. Experimental artists are using EMG to generate a signal from muscles to control audio or video signals, and to actuate electromechanical apparatus in performance settings. As has been the case with previous emerging technologies, artists are using EMG in creative new ways. With the availability of high-speed real-time wireless devices at ever increasingly high bandwidth and low cost, the same technology that allows convenient gathering of walking and running gate-data allows avant-garde dance troupes to collect EMG data during performances to control audio signals or video displays. Artistic applications are

often more fault tolerant than traditional applications (In art, a bad myoelectric signal can hurt an artistic performance. In a prosthetic knee, a bad signal can cause injury or even death). The art community can therefore utilize technologies before the technologies are commercially viable for the mass market.

Australian performance artist Stelarc has been using technology in his art, and using the human body as an art medium since 1976 (Elsenaar & Scha, 2002). His work has explored the boundary between man and machine, using signals from his body to control machinery, and using external machinery to control parts of his body, through mechanical animation, and by electrically stimulating muscles, often using his own body as the art medium. Stelarc has used electromyography in conjunction with numerous other sensor technologies (EEG, ultrasound, electromechanical encoders, goniometers), along with other more broadly used sensors (accelerometers, thermistors, and contact microphones) to control devices in performances around the world. In one work, Stelarc developed a "Third Hand", a robotic appendage, attached to his own arm, but controlled via EMG sensors measuring activation of muscles in his abdomen and thigh. In another piece, Stelarc used a similar suite of sensors to create a variety of sounds, all generated, directly or indirectly, real-time by the human body. In this piece, he contrasted rhythmic sounds (heartbeat, breath) with more "chaotic" sounds such as those found in myoelectric signals (Elsenaar & Scha, 2002). Stelarc uses these techniques and sensors to blur the line between himself, electromechanical devices, and the audience. Many of his performances even blur the line between local and remote self, transmitting the body signals over the internet to control remote devices or manipulate audio-video displays at a performance site far from his physical body in order to question the localized self (Fleming, 2002). In another performance, Stelarc used an electromechanical device to allow audience members to manipulate his body via actuators. EMG was used to detect his muscle actuation, blurring the distinction between his voluntary movements and those caused by the audience. These myoelectric signals were then transmitted to a remote device, where a robotic actuator system was "controlled" by the signals. The audience input was done locally and remotely over the internet. In this piece, Stelarc used himself as a portion of the nonlinear control loop in which the audience indirectly controlled the robotic actuator. Additionally blurring the line between self, machine, and even location (Elsenaar & Scha, 2002).

Electronic/visual artist, Sean Clute often incorporates electronics and technology more traditionally found in other fields in his work. An upcoming piece for his performance group Double Vision (Jennings, 2011) uses EMG extensively. Professor Clute describes the piece as follows:

"Intermedia performance company Double Vision's work entitled Wishing for the Perfect Dorsiflexion depicts a solo performer controlling live-video via a wireless electromyogram interface. Conceptually, the work highlights two symptomatic conditions of Multiple Sclerosis; foot drop (dorsiflexion) and Uhthoff's phenomenon. The performer, who has MS, can be seen walking on stage with increased difficulty over time. Simultaneously, a rear video projection of a recreation trail in Stowe, Vermont can be seen. As the performer shows increased signs of weakened gait the video projection appears to both stumble and become unnaturally high in contrast. Thus, the real-time physical condition of the performer is projected visually for the audience to express the sureality of having a demyelinating disease such as MS.

Double Vision uses a wireless EMG attached to muscles in the anterior portion of the lower legs. The data is sent via the Open Sound Control (OSC) communication protocol developed

at the Center for New Music and Audio Technologies at the University of California at Berkeley. The data is received by a computer using custom software created in the language Max/MSP Jitter. The software takes the incoming data, runs it through a band pass filter, and then maps to the x and y axis of prerecorded video footage. If the EMG activity is below a certain threshold then the video begins to "wiggle." This visually represents the foot drop. Additionally, the same data is used to control the contrast of the video. Artistically, this relationship is to demonstrate the unusual characteristics of Uhthoff's phenomenon including increased optic neuritis and vision abnormalities with nerve weakness.

This work is proof of the growing application of electromyography in the performing arts community. As the cost of producing works using electromechanical encoders decreases with an increase in the shared knowledge base of how to use such technologies, emerging groups such as Double Vision are experimenting with ways to map the human condition artistically" (Clute, 2011).

Such use of EMG in the art world helps expose the technology to ever growing numbers of people from more varied fields. Clute and Stelarc show that as previously arcane technologies become more robust, reliable, and affordable, the arts communities can provide a conduit to expose them to these populations. Figure 12 shows images from the work of Clute's group Double Vision (with co-director Pauline Jennings). Included are a preliminary image for the upcoming performance entitled Wishing for the Perfect Dorsiflexion, and a still image from a previous live performance.

Fig. 12. Double Vision. Left, preliminary image from "Wishing for the Perfect Dorsiflexion". Right, image from a previous performance. (Jennings, 2011a, Jennings, 2011b).

10. Mixed applications - EMG in combination with other technologies

While a powerful tool on its own, some of the greatest benefits of EMG come when combined with other sensing technologies. If well planned, an application can be designed so that the weaknesses in EMG can be supplanted by strengths in other sensors, and the inherent strengths in EMG can be fully leveraged, often overcoming difficulties in other methods. Designers must also keep in mind that myoelectric signals can have a detrimental effect on other signals. Electroencephalography (EEG) practitioners have long found problems with EMG signals contaminating their data. As EEG detects brain signals of even smaller amplitudes (10 to 100 microvolts) noise from the relatively much larger EMG waves signals (10 to 100 milivolts) can completely drown out an EEG signal. As careful as EMG

practitioners must be in minimizing crosstalk when studying EMG signals, EEG practitioners must deal with a much greater relative problem. Fortunately, muscles of the human body are either relatively small (cranio-ocular musculature) or relatively distant from the brain and EEG setup (shoulders, arms, back, legs) (Shackman, et al., 2009). With proper consideration, valuable data can be taken from different technologies simultaneously, valuable information can be learned, and innovative new devices can be developed, all of which would be impossible using only one type of sensor.

10.1 EMG with fMRI

Magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI) allow practitioners to generate detailed internal structures of the human body, often the brain. Of course, such valuable technology comes with features which can be drawbacks or even make the tool unusable in some applications. The devices are very large, not portable, and in the case of MRI, involve a very high dose of electromagnetic radiation. Additionally, the hardware and operation of the devices is very expensive. While tremendously valuable in many applications, these factors make MRI and fMRI prime candidates for mixed use applications, particularly those in which initial procedures can be completed with MRI fMRI, but can later be simplified to eliminate the large expensive machinery. It has been shown (Dai, et al., 2001) that fMRI, EMG, and joint muscle force can be correlated in some cases. Ten volunteer participants were asked to exert a hand grip force as measurements were taken. Brain images were acquired using FMRI, as participants gripped at 20, 35, 50, 65, and 80% of their maximal force. Concurrently, EMG signal data was taken on the activation levels of the flexor and extensor muscles. EMG based signals were directly proportional to brain signal amplitude. Both of these signal intensities also correlated with hand grip force. A novel technique, computed myography (CMG), uses a dense array of individual sEMG electrodes rather than traditional bipolar electrodes to determine muscle activation across several muscle groups. Multiple electrodes were attached to a human forearm to record a broad spectrum of EMG data during flexion/extension (number and locations of sensors were varied based on the experiment performed) Then, using the finite element method (on commercial analysis packages Comsol and Matlab), this array of electrode data is inverted to determine qualitatively and quantitatively the activation levels of the internal muscles. Concurrently, the arm is monitored with fMRI, yielding a well understood map of the desired muscle activation. It is believed that with further correlation, the fMRI can be eschewed completely, and an essentially fMRI level map can be generated using only EMG and this novel CMG method (Vand Den Doel et al., 2008). An EMG based prosthetic arm was used to study the mutual adaptation between the system and the human body. A 13 DOF prosthetic was used, including electrical stimulus for tactile feedback. fMRI data is recorded to clarify the plasticity of portions of the brain due to changes in the device. The experiments show adaptation in the studied areas (from fMRI data) of a phantom limb image to the prosthetic (Kato, et al., 2009).

10.2 EMG with EEG

Recently, great strides have been made in brain-machine interface using EEG. Unfortunately, because EEG signals are several orders of magnitude smaller than EMG, and because interstitial layers, particularly the skull, tends to damp out much of the frequency range of EEG signals, EEG signals are notoriously difficult to record, process, and interpret

accurately (Saneei & Chambers, 2007). Just as advances have been made in interpreting EMG signals, the field of EEG has been rapidly evolving and hardware is becoming available at ever reduced cost to ever larger groups. Concurrently, much research has occurred developing a hybrid approach to human-machine interface utilizing EEG, EMG, fMRI, and recently even motion tracking systems such as the Kinect by Microsoft. EMG has been used in conjunction with EEG in a clinical setting to detect changes in sleep and shift between sleep stages in healthy patients and patients suffering from narcolepsy or other ailments, leading to increased ability to diagnose certain disorders and has lead to a greater understanding of sleep and the many musculo-physical issues associated with it (Ferri, et al., 2008; Rechtschaffen & Kales, 1968). This EMG EEG hybrid approach has also been used to control machinery and virtual conditions. Often, EEG is used as a source of multi-dimensional data, and EMG is used as a more reliable safety/backup system, utilizing the advantages of both systems. Research has been done on wheelchair control, allowing users to control the device with EEG. EMG was used to correlate desired commands with recorded EEG states. While research shows encouraging preliminary results, additional research and possible further hybridization with EMG is required (Blankertz, et al., 2006). This research was particularly encouraging, because it found that very little training was required before subjects could begin controlling the apparatus using only EMG and EEG. Robotic control using EMG and EEG has been proposed and is the subject of several experiments. A technique labeled Biopotential, using EMG and EEG to control machines was studied. Data acquisition rates in EMG and EEG realms are quite high and more work is required to process this magnitude of data real-time (McMillan, 1998). Flight control via EMG and EEG is far from a reality, as any fault could be catastrophic. However, virtual flight control research can readily be performed. EEG was used for control, with EMG as validation and backup signal (Friedman, et al., 2004). Yet another study into flight simulation via human-machine interface actually used both EMG and EEG to control the simulation. In this experiment, subjects showed the ability to control the single DOF simulation with relative accuracy (though some suffered cybersickness from immersion in the simulator). The study presented the questions of users' limits of control, suggesting future experiments including multi-DOF tasks. A program is now underway in the Netherlands to control a lower limb exoskeleton using EEG and EMG signals. Entitled MINDWALKER, the project attempts to develop a device primarily for use among those suffering from spinal cord and other injuries. An ambitious project, the use of both EEG and EEG EMG based controls will be implemented, because it is understood that those with spinal cord injuries may not be able to control such a device using EMG. The addition of EEG with EMG expands the realm of applications, and techniques used for voluntary and semi-voluntary control. Event-related potential (ERP), or the direct brain response to a perception/thought as well as P300, by which the patient can learn to control slow brain waveforms in order to control devices. These techniques along with measures of autonomic system balance (Heart Rate Variability, Skin Conductance) expand the use of EMG into entirely new realms of system control from gaming to dentistry.

11. Future directions

As technologies mature, additional applications become feasible. Just as many applications discussed above were the subject of wild fancy a short time ago, we will continue to see advancements including EMG as the primary driver, or one tool in a suite of technologies

bringing us ever greater opportunities. Energy Harvesting/Scavenging is an ever growing field, in which low power and intermittently powered devices use available energy from the surroundings. Energy sources include heat and vibration, and are absorbed using piesoelectrics and thermopiles (Vullers, et al., 2009), often for applications in difficult to reach areas, where changing a battery or hard-wiring electricity is difficult or costly. In vivo devices are prime examples of such difficult to access applications. One highly plausible method for research is the study of EMG or EKG as a power source for energy harvesting. In such an application, signal clarity, timing, and interpretation are unimportant. Cross talk from other nearby muscles can actually be a benefit. The focus in this application is the magnitude of the signal. It has also been proposed that EMG and EEG can be used as a form of human/robot interaction where a robot/device would sense EMG/EEG signals to learn about nearby humans, not explicitly for control (Bien, et al., 2008). EMG techniques can also be used to monitor users for fatigue, alertness, or other variables in various situations. Work has already begun in user monitoring in wheelchair applications, in which the device will stop if EMG signals fall below a threshold or become abnormal, allowing a failsafe in wheelchair operation (Han, et al., 2003). Research has been conducted on using EMG signals to trigger a hands-free electrolarynx device (Goldstein et al., 2004), in which myoelectric signals are monitored to control initiation and termination of the device. Additional research includes EMG for voice/speech recognition even at the sub-auditory level (Jorgensen et al., 2003)

12. Discussion

The field of Electromyography is developing into new areas. As the necessary technology is developed and the devices become more reliable and less expensive, EMG can be used more reliably and at a reduced cost, making it feasible in an ever increasing range of applications. As the applications of EMG change, we must consider the benefits as well as the potential drawbacks inherent in this proliferation. The applications exploring the possible use of EMG have different priorities, and if used appropriately, many of them may use EMG as a powerful tool. If used improperly, however, erroneous data taken from a myoelectric signal can be useless, if not harmful or even fatal. In traditional applications, crosstalk is a major concern. In energy scavenging, or in spread array techniques such as CMG, crosstalk becomes less of a concern, or even an additional source of electrical energy. Some EMG applications rely on robust signal fidelity, divisible into fine resolution to obtain maximum data. Other applications, such as two state and three state conditions discussed as method three in this chapter, do not require such high signal fidelity. Table 1 below covers major applications of EMG, and addresses the relative importance of major factors for each.

When developing new devices or applications drawing EMG out of the traditional setting, one must consider the challenges, risks, drawbacks, and advantages involved in using EMG. Some challenges are being addressed through modern sensing, signal processing, and computational techniques, but other issues are inherent to the nature of the phenomenon. Advanced hardware now allows us to acquire and filter signals real-time in a ever more portable packages. Computer modeling and other software techniques are now allowing us to learn about myoelectric signal and even predict motions and muscle activity. EMG is being used in various suites of sensors to extract the best components of EMG as well as the other sensors such as fMRI, EEG, and motion tracking. As EMG becomes available to more

Application		Signal Fidelity & Resolution	Realtime	Convenience	Crosstalk & Accuracy	cost
		Consideration				
Worn Devices	Exo (lower extremities)	2	1	3	1	3
	Prosthetic hand, proportional (method 2)	2	1	3	1	3
	Prosthetic hand, gradient (method 3)	3	1	3	3	2
	Lower Limb Prosthetics	1	1	3	1	3
Device control	virtual environment control	2	2	1	3	1
	hybrid, fail-safe, signal check	3	3	3	3	2
Art/dance/culture		3	3	2	3	1
Design validation/ Optimization (methods4, 5)		2	4	2	2	2
Matrix devices/FEA/CMG		2	3	3	4	4
Energy Scavenging		4	4	4	4	3

Table 1. Relative importance, applications vs major areas of concern in EMG. 1. Critical. 2. Important. 3. Somewhat Important. 4. Not Important.

practitioners and applications, it becomes tempting to use the technology as a "black box" (simply extracting data without understanding the details), and not understand the background and limitations. As EMG becomes easier to use, it becomes easier to abuse. Untrained practitioners can draw erroneous conclusions, which can cause harm, injury, or even death. We must be mindful to maintain the integrity of EMG applications, along with the other sensing techniques used, in worn devices, devices to assist the elderly and handicapped, control machinery, and other new and emerging technologies.

## 13. Acknowledgment

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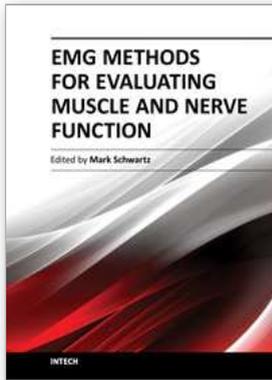
EMG Methods for Evaluating Muscle and Nerve Function

Edited by Mr. Mark Schwartz

This first of two volumes on EMG (Electromyography) covers a wide range of subjects, from Principles and Methods, Signal Processing, Diagnostics, Evoked Potentials, to EMG in combination with other technologies and New Frontiers in Research and Technology. The authors vary in their approach to their subjects, from reviews of the field, to experimental studies with exciting new findings. The authors review the literature related to the use of surface electromyography (SEMG) parameters for measuring muscle function and fatigue to the limitations of different analysis and processing techniques. The final section on new frontiers in research and technology describes new applications where electromyography is employed as a means for humans to control electromechanical systems, water surface electromyography, scanning electromyography, EMG measures in orthodontic appliances, and in the ophthalmological field. These original approaches to the use of EMG measurement provide a bridge to the second volume on clinical applications of EMG.

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