Design and Control of Low- Cost Portable EMG Driven Exoskeleton Device for Human Wrist Rehabilitation

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Abstract- Exercise is an effectual healing process for people who have lost their body functioning of motions due to flimsy muscles. In this paper we propose a method of initiating motion in disabled or physically weak human wrist using his/her diminutive muscular force. The present work introduces a process of sensing Electromyography signals for wrist motion. A low-cost device is presented which involves active bidirectional (hyperextension/flexion) movement of the wrist joint, controlled by specific EMG signals triggered by forearm muscles. The design undertakes all procedures and techniques for extraction of EMG signal, sensatory circuit, signal acquisition, amplification and filtering, ADC, and interfacing of simple model hand controlled by a controller (Arduino) via DC motor for bidirectional wrist movement. The instrument assists its user in moving and strengthening respective muscles. The concept is well-suited for rehabilitation robotics and prosthetic devices for handicap individuals.

Keywords- *EMG, Hyperextension/flexion, Exoskeleton, Microcontroller, Arduino,, Rehabilitation, Robotics*

1. Introduction

Human body is multifaceted biological machinery. The functioning of human body is an intriguing and fascinating activity [1], but one may get deprived of his/her body parts movement due to any misfortune. One of the human limits in performing physical tasks is the muscles' strength [2]. In the society in which the birthrate is decreasing and aging are progressing, it is important that physically weak individuals take care of themselves without the help of others [3]. Loss of wrist operation due to weak muscles can result in loss of functionality of hand. In this perspective, valuable work has been proposed by researchers. We have been developing exoskeleton systems [4]-[7] to assist motion of physically weak persons such as elderly, disabled, and injured persons [8]. It is important for the exoskeleton especially that for medical or welfare uses, to be controlled according to the user's intention [8]. The skin surface Electromyogram (EMG) is one of the most important biological signals in which the human motion intention is directly reflected. Therefore, it is often used as a control command signal for a robot system [8]-[11]. In our research, a control process for exoskeleton system for human wrist (flexion/hyperextension) motion assistance is designed, which is primarily powered by EMG signals of forearm muscles.

Due to the design complexity, most of the systems were mainly for lower limb stroke support [12]. For example Hybrid Assistive Limb (HAL) from Tsukuba University Japan, to help people with hemiplegia [13], BLEEX robotic exoskeleton which was developed by University of California at Berkley for military purposes [14], EXPOS and SUBAR robotic assistive-rehabilitation devices from Sogang University [15],[16],[12]. Some upper limb exoskeleton systems were proposed [12], like 5-DOF wearable MGA exoskeleton from University of Maryland for [17], 5-DOF serial-parallel MAHI exoskeleton for upper limb training rehabilitation which was made in Rice University USA [18], parallel pneumatic actuated exoskeleton from that was proposed by Korea Institute of Science & Technology [19], [12].
Extraction of EMG signals is a hard task. These signals vary significantly even for the same repetitive motion in single person. Furthermore, each muscle activity for a certain motion is highly nonlinear, because the responsibility of each muscle for the motion varies in accordance with joint angles [20], [21], and [8]. Physiological condition of the user also affects the activity level of muscles [22], [8]. The muscle force can either be rapidly changing or relatively constant [23]. Three steps are being undertaken to obtain useful EMG signals: 1) amplification 2) band-pass filtering to eliminate extraneous noises, 3) rectification to generate a nonzero mean signal [23]. This device is being designed to provide

1) assistance
2) intended movement of wrist joint
3) enhanced motion of hand (flexion/hyperextension)
4) EMG control for prosthetic/orthotic device

2. Electromyogram

A person with lost hand movement may generate a minute muscular force by forearm muscles while moving his/her upper-limb. These signals can be utilized as commanding signals for hand assistive device or for prosthetics.
These signals are EMG (Figure 2.1), which when observed using suitable means would give pictorial representation of electrical activity of the contracting muscle [24], [25]

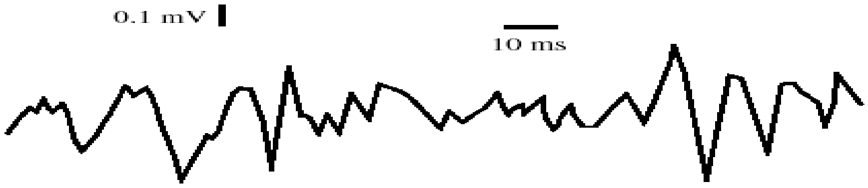
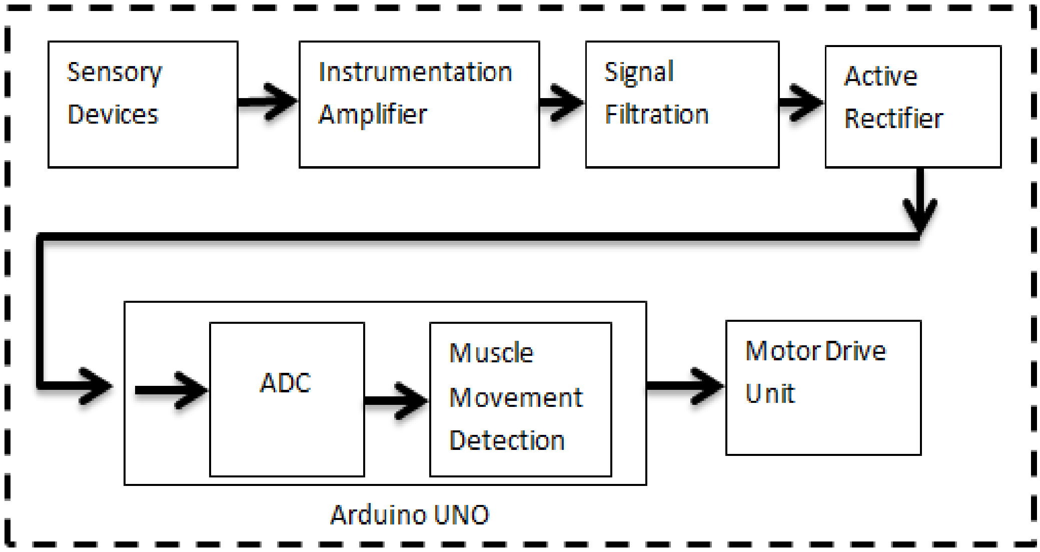


Figure 2.1 Typical EMG signals [25], [26]

Voluntary EMG results from voluntary contraction of muscles, under willful action of the brain [25]. EMG signal, acquired from [25] forearm muscles is sent as an input to a dc servo motor operating the wrist joint, via Arduino. The microcontroller, used to sense the presence of this output, is programmed to decide whether to activate the motor or not, and if yes, in which direction to rotate it [25]. To avoid painful experience by needle electrodes, non-invasive surface electrodes are being used to sense the signal.

3. The Design System

The architecture of the compact devise is illustrated in block diagram below.



Block diagram 3.1

3.1. Sensory Devices

Appropriate electrodes are required to sense bioelectrical movement inside the muscle; Surface electrodes best suited the device requirement. These electrodes are easy to handle; the theory behind these is that they form a chemical equilibrium between the detecting surface and the skin of the body through electrolytic conduction, so that current can flow into the electrode [1]. No medical personnel supervision is required for their use. “Gel-electrodes use an electrolytic gel as a chemical interface between the skin and the metallic part of the electrode. Oxidative and reductive chemical reactions take place in the contact region of the metal surface and the gel. Silver - silver-chloride (Ag- AgCl) is the most common composite for the metallic part of gelled electrodes. The AgCl layer allows current from the muscle to pass more freely across the junction between the electrolyte and the electrode. This introduces less electrical noise into the measurement, as compared with equivalent metallic electrodes (e.g. Ag), due to the fact; Ag-AgCl electrodes are used in over 80% of surface EMG applications” [27].

“Gelled electrodes can either be disposable or reusable. Disposable electrodes are the most common since they are very light. Disposable electrodes come in a wide assortment of shapes and sizes, and the materials comprising the patch and the form of the conductive gel varies between manufacturers.

In addition, electrode placement on the target muscle area known as Motor Unit, The smallest functional unit to describe the neural control of the muscular contraction process [28]. When the motor unit is activated, it produces a ‘Motor Unit Action Potential’ (MUAP) [1], [29]. It is important to distinguish MUAP’s from rest of the muscle so that one can analyze the firing frequency of muscular force. This potential is then fed into the amplifier circuit via electrodes as depicted in figure 3.1.

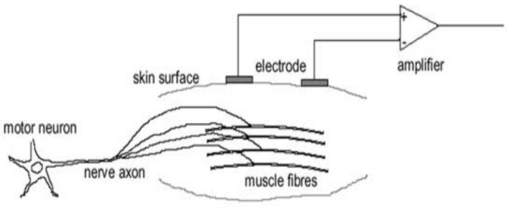


Fig. 3.1

3.2. Instrumentation Amplifier

With differential amplification, it is now possible to measure the full effective bandwidth of the EMG signal. Raw EMG can range between +/- 5000 microvolt's (athletes!) and typically the frequency contents ranges between 6 and 500 Hz, showing most frequency power between ~ 20 and 150 Hz [28]. The EMG signal is gathered with respect to a reference. A reference electrode turns as ground for target signal. After accurately detecting the target muscle site, clearing the skin and placing the EMG electrodes at intended location comes the signal acquisition.

EMG signal is acquired through differential amplification technique. The differential amplifier should have high input impedance and very low output impedance. Ideally, a differential amplifier has infinite input and zero output impedance [30]. For this purpose instrumentation amplifier can be utilized as shown in Fig 3.2.

The differential amplification detects the potential differences between the electrodes and cancels external interferences out. Typically external noise signals reach both electrodes with no phase shift. These "common mode" signals are signals equal in phase and amplitude. The term "common mode gain" refers to the input-output relationship of common mode signals. The "Common Mode Rejection Ratio" (CMRR) represents the relationship between differential and common mode gain and is therefore a criteria for the quality of the chosen amplification technique. The CMRR should be as high as possible because the elimination of interfering signals plays a major role in quality.

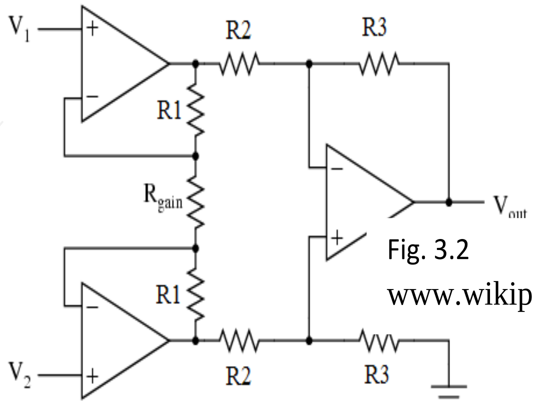


Fig. 3.2
www.wikipedia.com

A value >95dB is regarded as acceptable" [28]. The gain of differential amplifier can be adjusted by easy computation. The equation is given as:

$$Gain = \left\{1 + 2R_1 / R_{gain}\right\} R_3 / R_2$$

$$V_{out} = (V_2 - V_1) * Gain$$

Where R1, R2, R3, and R-ain are resistances, V1 and V2 are the differential inputs of the circuit. In this experiment, we used IC LM741 operational amplifier both for signal buffering and differential amplification due to low cost and efficiency. The gain of the final circuitry was set to 500.

3.3. Signal Filtration

The useable range of EMG signal is from 50-500 Hz. and the dominant information lies in 20-150 Hz. An appropriate band-pass filter (figure 3.3) was designed according to required specifications. Combination of low pass filter and high pass filter eventually forms the band pass filter. The desired cut-off frequencies of respective filters can be calculated through following equation:

$$f = 1/ 2\pi RC$$

Calculated as f1=49.7Hz and f2=483Hz for this study.

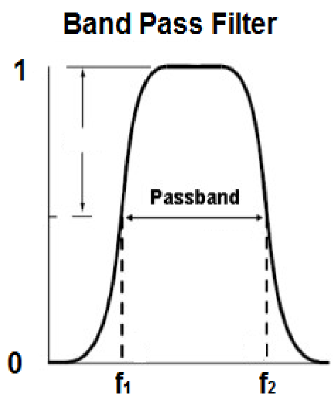


Fig. 3.3

3.4. Active Rectifier

A full wave rectifier with smoothing capacitor was employed for fine DC voltage signal as analog input to Arduino UNO. A simple diode bridge circuit was integrated in series with output of the filter.

3.5. Arduino and movement detection

Arduino Uno is a microcontroller board based on ATmega328. It contain 14 digital input/output pins, 6 analog inputs, a 16 MHz resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. It also encompasses 10-bit ADC which coverts analog signal into digital one which becomes the input to controller.

4. Results

4.1. EMG Signal Amplifier

The individual components of the EMG amplifier were tested separately. All results were extremely close to theoretical values. A sinusoidal input was provided by a function generator and the output was read from an oscilloscope. The differential amplifier results are shown in Table 4.1. The common mode rejection (CMR), or gain, was close to its theoretical value. The common mode gain (CMG) was equally close to its theoretical value of zero.

V1	V2	Vout
Grounded	10mVpp, 20 Hz sin wave	5Vpp, 20 Hz sin wave
10mVpp 20 Hz sin wave	Grounded	5Vpp, 20 Hz sin wave
Grounded	Grounded	0.03 Vpp, 20 Hz sin wave
10mVpp 20 Hz sin wave	10mVpp, 20 Hz sin wave	0.03 Vpp, 20 Hz sin wave

Table 4.1 Differential Amplifier Test Results

A frequency sweep of the band-pass filter was taken, A One volt peak to peak Sin wave was provided at the input. The lower cut-off, mid-band, and upper cut-off frequencies were found to be approximately 49 Hz, 140 Hz, and 480 Hz, respectively. The cut-off frequencies are essentially the same as the theoretical values of 49 Hz and 480 Hz. By multiplying the gain of all components, a total gain of 510 was achieved. This gain is higher than the theoretical total gain of 500 and can be explained by the op amp's deviation from its ideal characteristics. Overall, the EMG amplifier was capable of acquiring muscle potential movement. Figure 4.1 is a picture taken of an oscilloscope displaying the output of the designed circuitry.

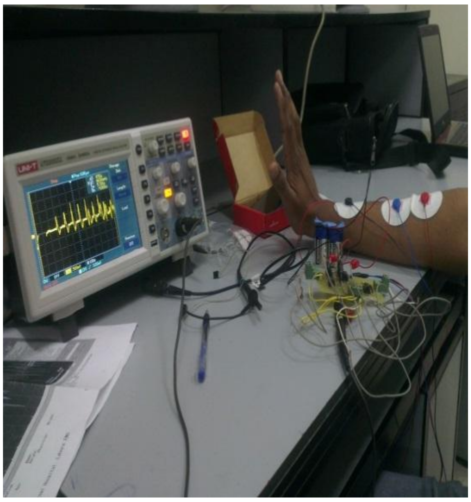


Fig. 4.1

4.2. Movement detection Algorithm

The muscle movement detection algorithm (flexion or hyper extension) is the second most important part after EMG signal acquisition in this study. Arduino software was used for Arduino programming to achieve desired results. The algorithm is presented in figure 4.2 for the detection of the movement. When a signal is detected, the controller check the incoming value with predefined threshold reference voltage value in controller and drive the motor unit in appropriate direction.

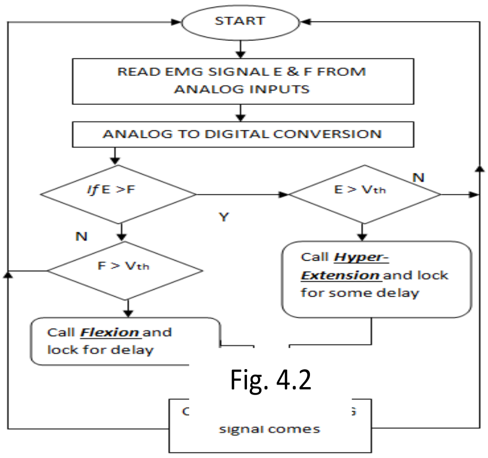


Fig. 4.2

4.3. Motor drive Unit

As per the requirement of this project, a simple servo motor was selected. Servo movements are controlled by the Arduino controller. For driving the mechanical hand-support, a servo motor is elected over a stepper motor servo have greater speed, lesser in weight and it provide smooth rotation at even speed. Moreover, the driving circuits for such motors are cost-effective. A 9 V, 3 W motor, with a rated rpm of 3000, is used in the design. It is programed for 0-180 degree to cover maximum movement of the wrist from flexion to hyper extension. As a test case, a 5v DC signal with a variable resistor in series was given as input given at analog pin of Arduino. A full range of movement from 0-180 degrees was observed against 0-5Volts input, and vice versa.

5. Conclusion

Some developments have already been made in the field of EMG driven exoskeleton devices but no or little concern for Third World countries. The paper discussed a simple, but meaningful design of a portable device for the rehabilitation of wrist and/or prosthesis with a focus on cost-effectiveness. Presently, the primary concern is on perfecting the design: both electrical and mechanical. This paper dealt mainly with the electrical part leaving out the details of the mechanical design. Research is being done on the mechanical design in order to see the face of perfection. The major obstacle that lies ahead is the readiness of apposite material here in our county. The device and the wearable glove (out of the scope of this paper), currently being used, are prepared of steel which makes it heavy and slow in operations. If wearable have been made using a light-weight, but strong material, weight of the complete prosthesis would have pointedly reduced and the performance would have enhanced.

References

[1] Muhammad Zahak Jamal, “Signal Acquisition Using Surface EMG and Circuit Design Considerations for Robotic Prosthesis”, In Computational Intelligence in Electromyography Analysis –A Perspective on Current Applications and Future Challenges,2012, Chapter 18, pp.427- 448

[2] Jacob Rosen, Moshe Brand, Moshe B. Fuchs, and Mircea Arcan, “A Myosignal-Based Powered Exoskeleton System”, IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans, Vol. 31, No. 3, May 2001

[3] R. A. R. C Gopura and K. Kiguchi, “Development of an Exoskeleton Robot for Human Wrist and Forearm Motion Assist”, In Second International Conference on Industrial and Information Systems, ICIIS 2007, 8 – 11 August 2007, Sri Lanka

[4] K. Kiguchi, S. Kariya, K. Watanabe, K. Izumi- and T. Fukuda, "An Exoskeletal Robot for Human Elbow Motion Support - Sensor Fusion, Adaptation, and Control“, IEEE Trans. on System, Man, and Cybernetics, Pan B,vol.3l,no.3, pp.353-361, 2001

[5] K. Kiguchi, K Iwami, M. Yasuda. K. Watanabe, and T. Fukuda, “An Exoskeletal Robot for Human Shoulder Joint Motion Assist”, IEEE/ASME! Trans. On Mechatronics, Vo1.8, No.1, pp.125-135, 2003

[6] K. Kiguchi, T. Tanaka, K. Watanabe, and T. Fukuda, “Exoskeleton for Human Upper-Limb Motion Support”, Proc. of IEEE International Conference on Robotics and Automation (ICRA’03), pp.2206-2211, 2003

[7] K. Kiguchi, R Esaki, T. Tsuruta, K. Watanabe, and T. Fukuda, “An Exoskeleton for Human Elbow and Forearm- Motion Assist”, Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS’OS), pp.3600-3605,2003.

[8] Kazuo Kiguchi, and Toshio Fukuda, “A 3DOF Exoskeleton for Upper-Limb Motion Assist - Consideration of the Effect of Bi-Articular Muscles”, In Proceedings of the 2004 IEEE International Conference on Robotics and Automation New Orleans, LA April 2004

[9] S. Suryanarayanan, “An Intelligent System for Surface EMG-Based Position Tracking of Human Arm Movements for the Control of Manipulators”, PhD. Dissertation, The University of Akron, 1996

[10] O. Fukuda, T. Tsuji, A. Ohtsuka, and M. Kaneko, “EMG-bawd Human- Robot Interface for Rehabilitation Aid”, Proc. of IEEE International Conference on Robotics and Automation, pp.3942-3947, 1998

[11] D. Nishikawa, W. Yu, H. Yokoi, and Y. Kakazu, “EMG Prosthetic Hand Controller using Real-time Learning Method”, Proc. of IEEE International Conference on Systems, Man, and Cybernetics, pp.1-153.1- 158,1999

[12] Galina Ivanova, Sergey Bulavintsev, Jee-Hwan Ryu, and Jury Poduraev, “Development of an Exoskeleton System for Elderly and Disabled People”, In 2011 International Conference on Information Science and Applications (ICISA), Jeju Island, April 26-29, 2011

[13] Hiroaki Kawamoto, Stefan Taal, Hafid Niniss, Tomohiro Hayashi, Kiyotaka Kamibayashi, Kiyoshi Eguchi, and Yoshiyuki Sankai, “Voluntary Motion Support Control of Robot Suit HAL Triggered by Bioelectrical Signal for Hemiplegia” 32nd Annual International Conference of the IEEE EMBS Buenos Aires, Argentina, September 2010, pp.462-466

[14] Justin Ghan and H. Kazerooni “System Identification for the Berkeley Lower Extremity Exoskeleton (BLEEX)” Proceedings of the 2006 IEEE International Conference on Robotics and Automation Orlando, Florida - May 2006, pp. 3477-3484

[15] Kyoungchul Kong and Doyoung Jeon “Design and Control of an Exoskeleton for the Elderly and Patients” IEEE/ASME Transactions on Mechatronics, Vol. 11, No. 4, pp. 428- 432 August 2006

[16] Kyoungchul Kong and Masayoshi Tomizuka, Hyosang Moon, Beomsoo Hwang and Doyoung Jeon, “Mechanical Design and Impedance Compensation of SUBAR (Sogang University’s Biomedical Assist Robot)” Proceedings of the 2008 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Xi'an China, July 2008, pp.377-382

[17] C. Carignan, J. Tang, and S. Roderick "Development of an Exoskeleton Haptic Interface for Virtual Task Training" The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2009 St. Louis, USA, pp. 3697-3702

[18] A. Gupta and M. K. O'Malley and M. Goldfarb, "Design of a Haptic Arm Exoskeleton for Training and Rehabilitation," IEEE/ASME Transactions on Mechatronics vol.11, No 3, pp. 280-289, June 2006

[19] Younkoo Jeong, Yongseon Lee, Kyunghwan Kim, Yeh-Sun Hong and Jong-Oh Park, "A 7 DOF Wearable Robotic Arm Using Pneumatic Actuators", Proceedings of the 32nd ISR(International Symposium on Robotics), pp.388-393, April 2001

[20] W. M. Murray, S. L. Delp, and T. S. Buchanan, "Variation of Muscle Moment Am with Elbow and Forearm Position", Journal of Biomechanics, ~01.28,n oS, pp.513-525, 1995

[21] H. Graichen, K-H. Englmeier, M. Reiser, and F. Eckstein "An In Vivo Technique for Determining 3D Muscular Moment Arms in Different joint Positions and During Muscular Activation - Application to the Supraspinatus", Clinical Biomechanics, Vo1.16, pp.389-394, 2001

[22] E. Park and S. G. Meek, 'Fatigue Compensation of the Electromyographic Signal for Prosthetic Control and Force Estimation", IEEE Trans. on Biomedical Engineering, ~01.40, no.10, pp.1019-1023, 1993

[23] Euljoon Park and Sanford G. Meek, "Adaptive Filtering of the Electromyographic Signal for Prosthetic Control and Force Estimation", In IEEE Transactions on Biomedical Engineering, Vol. 42, No. 10, October 1995

[24] M. B. I. Reaz, M. S. Hussain, F. Mohd-Yasin, "Techniques of EMG signal analysis: detection, processing, classification and applications", Biological Procedures Online 2006; 8(1):11-35

[25] T. Latif, C. M. Ellahi, T. A. Choudhury, and K. S. Rabbani, "Design of a Cost-effective EMG Driven Bionic Leg", In 5th International Conference on Electrical and Computer Engineering ICECE 2008, 20-22 December 2008, Dhaka, Bangladesh

[26] B. H. Brown, R. H. Smallwood, D. C. Barber, P. V. Lawford and D. R. Hose, "Medical Physics and Biomedical Engineering", Medical Science Series, IOP Publishing, Figure 16.24 An EMG recorded from surface electrodes

[27] Dr. Scott Day "Important Factors in Surface EMG Measurement", Bortec Biomedical Incorporated

[28] Peter Konrad, "The ABC of EMG", a Practical Introduction to Kinesiological Electromyography, Version 1.0 April 2005

[29] Carlo J. De Luca, "Use of Surface Electromyography in Biomechanics", Journal of Applied Biomechanics, Vol.3, 1997

[30] "Instrumentation Amplifier Application Note", Intersil Incorporated, 2009