Miniature Active Concentric Ring Sensor For
Localized Body Surface EMG Measurement

Chih-Cheng Lu
Division of Medical Engineering Research, National Health Research Institute, Taipei, Taiwan
clu@nhri.org.tw, Tel:011-886-2653-4401-7164

*Abstrac*t-

EMG detection is critical in gait analysis. Localized EMG detection usually calls for invasive method using needle electrode [1]. Body surface EMG provides global information about the muscle activity of a general area. This global information is not as useful compared with the localized EMG signal. Concentric ring electrode with build-in amplifier provides superior localized EMG signal from body surface. A light weight (2 gm) miniature (15mm in diameter 3.5 mm in thickness) active concentric ring sensor (Harbinger Technology HT-EMG, Chung-Ho City, Taipei County, Taiwan) with high input impedance (10GΩ) is used to obtain localized EMG activity form body surface without skin preparation. The amplifier is mounted directly above the concentric ring electrode with low system noise (0.7mV rms at gain of 1000) with a high pass filter of 15 Hz and a low pass filter at 10KHz. The reference connection is at the back, on top of the active sensor. The high common mode rejection ratio (118dB typical) with high input impedance and lightweight makes concentric ring EMG active sensor user-friendly and easily adaptable to most EMG acquisition system.

***Keywords* - EMG, Active Sensor, Concentric Ring Electrode.**

I. INTRODUCTION

The use of a concentric ring sensor for recording bioelectric activity was pioneered by Fattorusso, in 1949 [2] [3]. It consisted of a ring conductor and a central dot designed to record the spatial derivative of an electrical signal directly under the concentric electrode. It was used to study myocardial infarcts from the abnormal heart muscle activity. However, the lack of sensitive electronic instrumentation caused the work to stop and be forgotten for several decades.

The essential tool in this study is the active sensor with a set of concentric ring electrodes combined with a signal-conditioning amplifier in a self-contained, compact module. In comparison with a passive sensor, an active one achieves a higher signal to noise ratio (SNR) thanks to its high input impedance and low output impedance. A comparison of unipolar (UP: E1-Ref), bipolar (BP: E1-E2) and bipolar concentric ring and small dot type (BC: E1-E2+E3) contact electrodes show that their selectivities progressively increase toward nearby events as their numbers increase and the distance between them decreases. In electrophysiology, the local field is the result of dipoles representing depolarization wave fronts traveling through the muscle and creating a field within the torso, a volume conductor. While the UP dot's sensitivity is spherically symmetrical, when two or more dots are used to form BP or TP sensors, they act as vectorial

sensors and are maximally sensitive to fields directed in parallel to the sensors' axis and sense nothing from orthogonally oriented fields. In contrast, concentric bipolar sensors are omni-directional in a plane, the smaller the rings, the more localized the sensing and detection of EMG. However, as the sensors become small, they become less sensitive to "far-field" events. Kaufer, in 1990, analyzed the behavior of such sensors and optimized their dimensions in terms of the expected distance from the active sources [4].

Rasquinha's work stemmed from the earlier work of Tarjan et al. [5] who first proposed concentric, planar, tripolar epicardial ring sensors for arrhythmia detection for use in implantable devices. Those sensors were intuitively designed with approximately 5 mm outer diameter, and chronically tested in dogs to obtain specific, localized information for the detection of arrhythmias.

Oosterom analyzed the characteristics of similar "axially symmetric" sensors with a dot within a ring using a numerical model, and suggested various applications for the ring sensor [6]. Effort was aimed to detect local activation by detecting spatial partial derivatives of the surface potential at the sensor, regardless of the direction of activation, as if one were to detect the moment an object passes a certain beam by looking at its point source through a straw.

II. INSTRUMENTATION

The EMG acquisition system consists of a notebook personal computer and an active concentric ring sensor.

The active sensor itself consists of two components: a set of concentric ring electrodes on a non-conductive substrate and a signal-conditioning amplifier mounted directly on the back of the substrate.

Concentric ring electrode

A concentric ring electrode was designed and constructed for the purpose of acquiring information from the surface of the body without using a conductive gel or paste. The dot was etched on a printed circuit board with gold plated surface. A 15 mm outer diameter and 0.5 mm in thickness

housing of the active sensor serves the function of the outer ring electrode. The contact area between the outer ring and the body surface is thus 22 mm^2. The ring/dot in the center is 5.4 mm in diameter with 22 mm^2 contact area.

The contact surface area of the

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle	Contract Number
Miniature Active Concentric Ring Sensor for Localized Body Surface EMG Measurement	Grant Number
	Program Element Number

Author(s)	Project Number
	Task Number
	Work Unit Number

Performing Organization Name(s) and Address(es)	Performing Organization Report Number
National Health Research Institute Division of Medical Engineering Research Taipei, Taiwan	

Sponsoring/Monitoring Agency Name(s) and Address(es)	Sponsor/Monitor's Acronym(s)
US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification	Classification of this page
unclassified	unclassified

Classification of Abstract	Limitation of Abstract
unclassified	UU

Number of Pages
3

conductive ring is equal to the dot electrode. This renders the source impedances of the two input leads for the amplifier equal, decreasing their mismatch and improves the CMRR of the amplifier.

When the concentric ring sensor is in the magnetic field of a strong power line, it induces a 60 Hz sinusoidal signal that interferes with the signal of interest. Adding a large ground plane on the multiplayer PCB substrate can eliminate this differential 60 Hz inductively coupled interference. By grounding this plane, the sensor can be shielded and the interference minimized.

Signal conditioning amplifier

The amplifier mounted on the back of the substrate of the TCB sensor has two major functions: first, to amplify the very small signal detected from the ring sensor and second, to reject interference. Specifications for a typical active sensor's amplifier are presented in the following table.

Specifications for the signal-conditioning amplifier.

Order	1st order	2nd order	2nd order
Type	Quasi HP	high-pass	low-pass
Gain	Av =100	Av = 10	Av = 10
Corner F.	F = 15 Hz	F = 15Hz	F=10KHz
Damping		$\zeta = 0.5$	$\zeta = 0.707$

A differential input, quasi high-pass differential amplifier, with a unique method for direct coupling to the source was developed as the first stage of the preamplifier. It provides unity gain for the DC component generated from the half cell potentials between the skin and the conductor of the electrode, while amplifying the signal detected from the TCB electrode. The differential amplifier is operated at a low power with a low offset voltage and a low input bias current. This differential amplifier is configured as a high gain amplifier for the very low level differential signals (300 μV or less), with a high CMRR of 118dB and a gain of 100. The very high input impedance (10G Ω) of the amplifier renders it insensitive to fluctuations of the skin-electrode impedance. Therefore, skin preparation for bioelectric measurements is not necessary.

A second-order active high-pass filter having a gain of 10 with a damping factor of 0.5 is implemented with half of a low-power dual operational amplifier. It rejects the remaining DC offset from the quasi-AC coupled differential amplifier. Combining the first order quasi-high-pass filter of the differential amplifier and this second order high-pass filter results in a third-order Butterworth high-pass filter with a corner frequency of 15 Hz. High frequency interference is reduced by a second-order Butterworth low-pass active filter with a gain of 10. The amplifier was designed to have a total gain of 10K with a pass band from 15 Hz to 10K Hz for surface localized EMG recordings.

Stereo mini phone jack was used to connect the active sensor and the microphone input of the computer. A 3V Lithium battery or 2 of 1.5V alkaline battery was used to power the active sensor. Care must be taken not to saturate the MIC input of the computer by lowering the overall gain of the active sensor.

LabVIEW was used to program the personal computer. Localized EMG signal was first high pass filtered to remove the DC component from either sensor offset or windowing effect. Fast Fourier transform were used to convert the time domain information to frequency domain information. Peak power and peak frequency was depicted on the monitor for estimation of muscle power.

IV. RESULTS

The front panel of the LabVIEW program provides detail information in time and frequency domain as well as the short time Fourier transform figure for detail trend analysis.
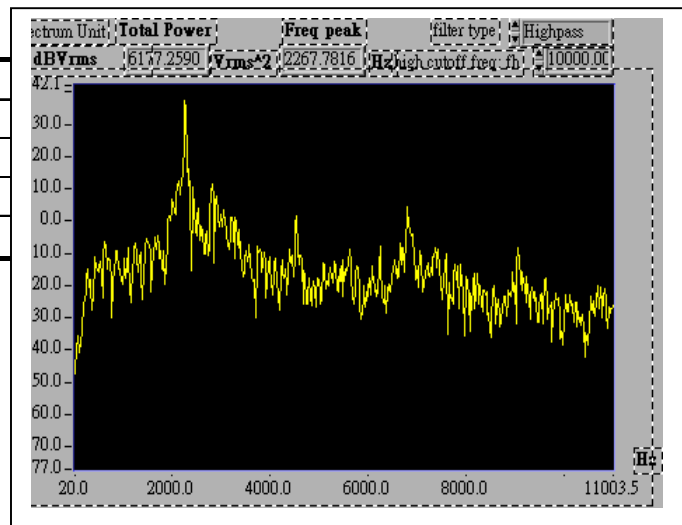
The subject does not need skin preparation for the acquisition of the localized EMG signal using active concentric ring sensor. The lightweight of the sensor reduces the motion artifact. It also improve the signal quality by EMG under test not the EMG from carrying additional weight from the sensor and the measurement system.

V. DISCUSSION

The concentric ring active EMG sensor demonstrates that local activation can indeed be detected and present results from patients with various pathologies. Based on our work to date, these active EMG sensors clearly point to numerous medical applications. The data can be displayed with a portable notebook computer or even a palm size PDA. The sensors can detect both spontaneous and voluntary muscle activities. The latter have applications in medical diagnosis, guidance of minimally invasive procedures, rehabilitation, and in industry, whenever a person needs another hand by using 2 or 3 sensors on the forehead to classify volitional facial movements for activation of a tool

or certain function. The active sensor can also detect atrial flutter or even atrial fibrillation. In conjunction with a Holter monitor, the monitoring of all four chambers of the heart may be achieved non-invasively. The sensors are also advantageous for Brain Stem Auditory Evoked Potentials, EEGs, EMGs, assistive devices and respiration monitoring. Non-invasive guidance of minimally invasive therapeutic procedures would offer economic benefits and safety.

VI. CONCLUSION

A lightweight active concentric ring sensor was developed for pasteless localized EMG measurement. The sensor directly connects to the PC's microphone port for direct digital signal processing without any other hardware. This user friendly portable EMG acquisition system can promote home health care application.

REFERENCES

[1] Henneberg, K.-A. and R. Plonsey, *Boundary element analysis of the directional sensitivity of the concentric EMG electrode.* IEEE Transactions on Biomedical Engineering, 1993. 40(7): p. 621-631.

[2] Fattorusso, V., M. Thaon, and J. Tilmant, *Contribution a L'etude de L'electrocardiogramme precordial.* Acta Cardiol, 1949. 4: p. 464-487.

[3] Fattorusso, V. and J. Tilmant, *Exploration du champ electrique precordial a L'aide de deux electrodes circulaires, concentriques et rapprochees.* Arch. Mal de Coeur, 1949. 42: p. 452-455.

[4] Kaufer, M., L. Rasquinha, and P.P. Tarjan. *Optimization of multi-ring electrode set.* in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society.* 1990.

[5] Rasquinha, L., M. Kaufer, and P.P. Tarjan. *Arrhythmia detection with spatially differentiating epicardial sensors: signal processing.* in *Proceeding of the 7th Purdue conference on Cardiac Defibrillation.* 1992

[6] Oosterom, A.v. and J. Strackee, *Computing the lead field of electrodes with axial symmetry.* Medical & Biological Engineering & Computing, 1983. 21(July): p. 473-481.