Coupled microphone-accelerometer sensor pair for dynamic noise reduction in MMG signal recording

J. Silva and T. Chau

External noise sources such as movement artefact may interfere with mechanomyography (MMG) signal recording, compromising signal detection for electrically-powered prosthesis control. A novel coupled microphone-accelerometer sensor pair, intended to facilitate noise reduction, was designed and tested on a below-elbow amputee. Sample recordings demonstrate clear distinction between motion artefact and useful MMG signals.

Introduction: Mechanomyography (MMG) is the superficial measurement of the axial vibrations elicited by contracting muscles [1]. Orizio *et al.* reported a linear relationship between the root-mean-square (RMS) values of MMG signals recorded from the biceps brachii and the force of the contraction between 20% to 80% of maximum voluntary contraction (MVC) [2]. Therefore, MMG may substitute current electromyography (EMG) measurements in electrically powered prosthesis control.

Barry *et al.* have already used MMG signals acquired from the wrist flexors and extensors of below-elbow amputees to control a free-standing prosthetic hand in a controlled laboratory setting [3]. However, external mechanical noise sources such as movement artefact are known to cause considerable interference, compromising signal detection and classification. Therefore, a reliable and robust MMG sensor is a prerequisite to the practical use of MMG-driven electrically powered prostheses. MMG signals have been measured with accelerometers [4, 5] and microphones [5–7]. Considerably lower signal-to-noise ratios (SNR) have been reported for accelerometers [4, 6]. This difference in noise sensitivity between microphones and accelerometers can be exploited in a coupled instrumentation setup to extricate information-bearing signal from noise.

Sensor design: Fig. 1 shows a schematic diagram of the sensor design. It consisted of two micro-machined, coupled vibration transducers (microphone–accelerometer pair (see notes 1 and 2)) surface mounted on a printed circuit board (PCB) and enclosed in a silicon case. Both sensors were aligned to the direction of muscle vibration. Skin vibrations originating from contracting muscles caused a proportional displacement of the silicon contact membrane. These vibrations then modulated the acoustic pressure measured by the microphone inside the air chamber [7]. The silicon acted as a passive lowpass filter that helped to increase the SNR of the measurement [4]. The approximate surface area of the device was 1.9 × 1.9 cm and 1 cm in height. Based on previous studies, a cylindrical air chamber (1.3 and 0.2 cm in diameter and height, respectively) and silicon shores 20 and 35A for the silicon case and membrane, respectively, were chosen for the design [6]. Note that the accelerometer was placed behind the microphone. This caused a further decrease in the SNR of the accelerometer since the silicon membrane and air chamber dampened any mechanical vibration arriving from the microphone side. At the same time, the accelerometer was capable of recording the direct effects of forces acting on the forearm as a whole (e.g. inertia caused by limb movement), i.e. there was a desirable mechanical impedance mismatch between both transducers for signals arriving from the microphone side, while both transducers were sensitive to signals originating from external forces. Therefore, the accelerometer can be seen as a dynamic reference sensor particularly sensitive to noise.

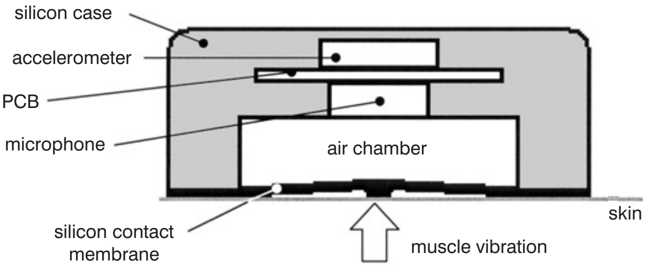

Fig. 1 *Schematic diagram of MMG sensor pair, placed against skin*

Data acquisition: Recordings were taken from a client with a traumatic below-elbow amputation. Three sensor pairs (Fig. 1) were placed around the distal end of the residual limb, separated by equidistant angles (120°) at approximately 1.5 cm from the distal end of the stump. An elastic fabric bracelet was used to hold the sensors in place. The client was asked to perform one of three different activities namely: (i) extension; (ii) flexion; or (iii) random limb movement during a two-second period defined as the activity period. The extension and flexion activities corresponded to the typical contractions usually performed by the client to open and close, respectively, her current EMG-based prosthetic hand. Signals from the accelerometers were amplified (gain = 240) using general-purpose operational amplifiers. Audible alarms indicated the start and end times of the activity period. Five recordings for each activity and sensor pair were acquired using the MATLAB environment, and stored for further comparison.

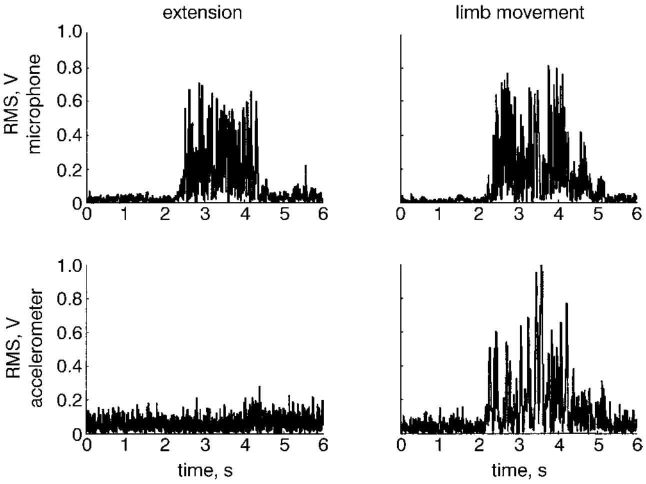

Fig. 2 *Sample measurements of extension (left) and random limb movement (right)*

Note considerable differences in accelerometer signal (bottom pair of graphs)

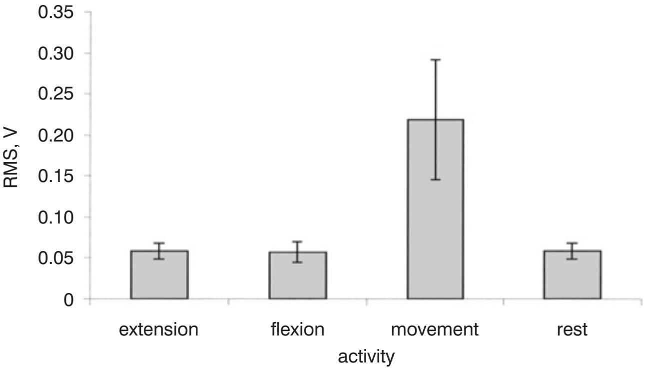

Fig. 3 *Comparison of mean RMS values and standard deviations among different activities for each transducer*

Note increased RMS value in accelerometer during random limb movement

Results: Fig. 2 shows sample recordings of rectified extension and random limb movement signals for each transducer in a single sensor pair. During extension, the amplitude of the microphone signal is directly proportional to the strength of the contraction. However, it can be readily observed that, without the additional information provided by the accelerometer (bottom pair of graphs), the correct determination of the nature of the signal, in this example, extension against limb movement, would not be possible, i.e. with the microphone alone, we would not be able to discriminate between limb movement and useful MMG signals. Fig. 3 further emphasises the importance of the accelerometer with a graph of mean RMS values of the accelerometer signals over all sensors for each activity. In contrast to the microphone, the accelerometer's mean RMS values during flexion (0.0567 ± 0.0123 V), extension (0.0584 ± 0.0101 V) and rest (0.0568 ± 0.0107 V), were not significantly different as determined by the Kruskal-Wallis test ($p = 0.59$). This verified the assumption that the accelerometer would have diminished sensitivity to signals arriving from the microphone side (i.e. muscle contraction). Note however, the statistically significant increase ($p = 3 \times 10^{-6}$) in the mean RMS value of the accelerometer signal (0.2184 ± 0.0720 V) during random limb movement.

Putting together the above results, a straightforward detection technique could simply use the RMS value of the accelerometer signal as a dynamic threshold for the microphone signal. Specifically, when the RMS value of the accelerometer signal is low, the microphone signal is admissible for prosthesis control. Conversely, a high RMS value in the accelerometer signal indicates the presence of motion artefact and the microphone signal should not be used directly for prosthesis control. We remark, however, that the relationship between the microphone and accelerometer signals is not trivial. Further studies are needed to determine the exact mathematical relationship between the transducers.

Conclusions: The compact size of and complementary information provided by the coupled-transducers may facilitate the practical use of MMG signals in prosthesis control. The sensor pair may also be valuable in other electronics applications where the contamination of an acoustic signal by ambient vibration confounds detection but cannot be easily removed (e.g. similar power density spectrum and random phases for both signal and noise). The straightforward detection technique suggested in this Letter exemplifies the powerful potential of simple, hardware-based sensor fusion.

Notes: 1. Omnidirectional electret condenser microphone model MD6022ASC-0 from Emkay Innovative Products.

2. Single axis accelerometer model BU7135 from Emkay Innovative Products.

18 August 2003

Electronics Letters Online No: 20031003
DOI: 10.1049/el:20031003

J. Silva and T. Chau (*Mechanical & Industrial Engineering Department, Institute of Biomaterials and Biomedical Engineering, M5S 3G9, University of Toronto, Toronto, ON, Canada*)

T. Chau: Also with Rehabilitation Engineering Department, Bloorview MacMillan Children's Centre, M4G 1R8, Toronto, ON, Canada

References

1 ORIZIO, C.: 'Muscle sound: bases for the introduction of a mechanomyographic signal in muscle studies', *Crit. Rev. Biomed. Eng.*, 1993, **21**, (3), pp. 201–243

2 ORIZIO, G., *et al.*: 'Spectral analysis of muscular sound during isometric contraction of biceps brachii', *J. Appl. Physiol.*, 1990, **68**, (2), pp. 508–512

3 BARRY, D.T., *et al.*: 'Acoustic myography as a control signal for an externally powered prosthesis', *Arch. Phys. Med. Rehab.*, 1986, **67**, (4), pp. 267–269

4 SILVA, J., *et al.*: 'Systematic characterisation of silicon-embedded accelerometers for mechanomyography', *Med. Biol. Eng. Comput.*, 2003, **41**, (3), pp. 290–295

5 WATAKABE, M., *et al.*: 'Mechanical behaviour of condenser microphone in mechanomyography', *Med. Biol. Eng. Comput.*, 2001, **39**, (2), pp. 195–201

6 SILVA, J., *et al.*: 'Optimization of the signal-to-noise ratio of silicon-embedded microphones for mechanomyography'. Proc. IEEE Canadian Conf. on Electronics and Computer Engineering, Montreal, Canada, May 2003

7 COURTEVILLE, A., GHARBI, T., and CORNU, Y.J.: 'Mmg measurement: a high sensitivity microphone-based sensor for clinical use', *IEEE Trans. Biomed. Eng.*, 1998, **45**, (2), pp. 145–150