Intarsia-Sensorized Band and Textrodes for Real-Time Myoelectric Pattern Recognition

Shannon Brown , Max Ortiz-Catalan *Member, IEEE*, Joel Petersson, Kristian Rödby
and Fernando Seoane *Senior Member, IEEE*

***Abstract*— Surface Electromyography (sEMG) has applications in prosthetics, diagnostics and neuromuscular rehabilitation. Self-adhesive Ag/AgCl are the electrodes preferentially used to capture sEMG in short-term studies, however their long-term application is limited. In this study we designed and evaluated a fully integrated smart textile band with electrical connecting tracks knitted with intarsia techniques and knitted textile electrodes. Real-time myoelectric pattern recognition for motor volition and signal-to-noise ratio (SNR) were used to compare its sensing performance versus the conventional Ag-AgCl electrodes. After a comprehending measurement and performance comparison of the sEMG recordings, no significant differences were found between the textile and the Ag-AgCl electrodes in SNR and prediction accuracy obtained from pattern recognition classifiers.**

I. INTRODUCTION

Surface Electromyography (sEMG) has applications in prosthetics, clinical diagnostics, and neuromuscular rehabilitation devices, such as rehabilitation robotics, treatment after stroke and spinal cord injury [1, 2], phantom limb pain treatment [3], and as a tool for non-invasive EMG monitoring [4].

Traditionally Ag-AgCl electrodes are used to acquire sEMG signals because the conductive adhesive in the electrodes limit motion artifacts and its gel conductive layer ensures a good skin-electrode interface for voltage sensing, most often, guaranteeing high quality signal acquisition. However, these electrodes when used for extended periods of time cause skin irritation [5]. Additionally, when used in upper limb applications for prosthetics, and therapies for amputees, they are difficult to apply and remove particularly when only one limb is available.

The use of smart textile technology to address these problems in sEMG signal acquisition has been an increasing area of study, as well as the study of textile applications in biosignal monitoring such as Electrocardiography (ECG) and Electroencephalogram (EEG) [6, 7]. Textile electrodes, also known as textrodes, have been studied extensively in multiple forms including screen printed, knitted, woven and embroidered sensors [6, 8, 9]. More specifically, in the case of the study by Zhang *et al.*, screen printed electrodes for sEMG monitoring showed promise in movement identification for transradial amputees using both offline classification techniques as well as real-time recordings [9].

This study proposes a fully integrated textile solution for sEMG monitoring in the form of an armband fabricated using intarsia knitting, for electrical connection of the recording device with the textrodes. The textrodes were done with the knitted silver fabric used in [10].

Intarsia is a well known and spread knitting technique in textile manufacturing that enables textile electronic integration at the level of fabric production by using conductive yarns which form knitted courses through the fabric. This technique has been previously introduced for e-textiles for ECG recordings [11], electro-stimulation [12] and even for thoracic bioimpedance recordings [8].

Using this sensorized armband and textrodes, this study aimed to assess:

1st. The performance of the textile electrode for sEMG recording on the upper limb in a real-time environment

2nd. The feasibility of using a fully textile sensorized arm-strap for the real-time classification of hand-movements based on sEMG.

The functionality of both textrodes and Ag-AgCl electrodes was previously studied using the intarsia-sensorized band by examining offline pattern recognition accuracy of hand postures [13]. The textrodes here are further evaluated against the Ag-AgCl in real-time and the SNR was then used to compare the signal quality and floor noise for the two electrodes.

II. METHODS

A. Textile Fabrication

The textile band was used as an interface with the same EMG amplifier developed for [3] and the electrodes. The band was fabricated using an intarsia flat knitting machine SHIMA SEIKI SRY 12 gauge with multiple feeders of cotton and silver yarn 110 f 34 dtex HC+B. The electrical pathways were knitted together with cotton and sewn to an elastic fabric made with elastan. Snap buttons were used for interconnecting the textile conductive pads and the electrodes through the fabrics. A zipper was added at each end of the strap as the closing mechanism.

S. Brown is with the School of Caring Science, Work Life and Social Welfare, University of Borås, SE-50190 Borås, Sweden (e-mail: shannon.brown@hb.se)

F. Seoane is with the Faculty of Caring Science, Work Life and Social Welfare, University of Borås, SE-50190 Borås, Sweden and School of Technology and Health, KTH-Royal Institute of Technology, Huddinge, SE-14152 Sweden (email: *fernando.seoane@hb.se*).

M. Ortiz-Catalan is with the Dept. of Signals and Systems, Chalmers University of Technology, SE-41296 Gothenburg, Sweden, the Centre for Advance Reconstruction of Extremities at Sahlgrenska University Hospital, SE-413 45, Gothenburg, Sweden, and Integrum AB, 431 37 Mölndal, Sweden. (email: *maxo@chalmers.se*)

J. Petersson and K. Rödby are with The Swedish School of Textiles, University of Borås, SE-50190 Borås, Sweden

978-1-4577-0220-4/16/$31.00 ©2016 IEEE

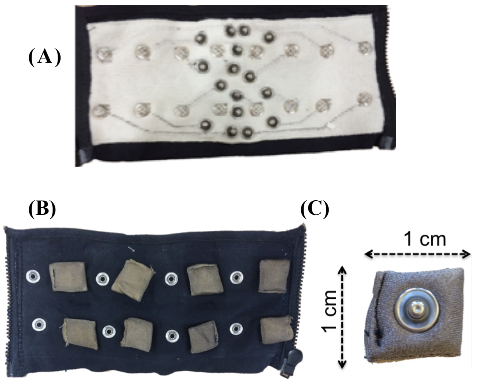

Figure 1. A. External side of the intarsia knitted cotton piece with snap connectors for wire connections to amplifier. B Internal side of the textile band with textrodes attached. C. Foam padded textrode

The design of the band allows for a total of eight sEMG channels to be simultaneously recorded. However for the purpose of this comparative study, only four channels were used. For both Ag-AgCl and textile electrodes a differential input was formed with 3 cm between each channel of the band. The band with textile electrodes is shown in Figure 1.

The textrode was fabricated with a conductive knitted Shieldex Technik-tex fabric sewn around a foam pad. A snap connector was attached to connect to the textrode to the band. The dimensions are 1 x 1 cm as shown in Figure 1 C.

B. Protocol for Ag-AgCl and Textrode Comparison

The upper arm movements of five healthy volunteers between 23-30 years old were recorded (2 males and 3 females). The band was placed on the dominant arm with the channels assigned as seen in the Figure 2 with channel 2 placed on the Extensor carpi ulnaris muscle. An Ag/AgCl electrode was used for reference in all measurements. The experiments were approved by the Västra Götalandsregionen ethical committee.

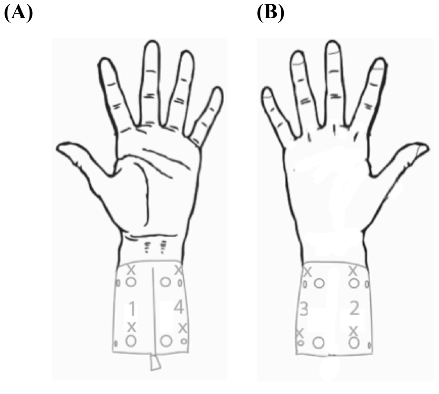

Figure 2**.** Arm strap with electrode placement and channel numbers. The x spot indicates the location of Ag/AgCl

Simultaneous recordings were used for the test with both Ag/AgCl electrodes connected using traditional twisted wires and textrodes connected to the band. The EMG activity was recorded for six-movements. The executed movements were performed in the following in order: open, close, flex, extend, pronate, and supinate. Three repetitions of each movement were performed and the EMG superficial biopotential was acquired with a sampling frequency of 2000 Hz for a measurement time of 10 seconds and a duty cycle of 50%. *i.e. 5 second movement time with a 5 second rest between movements*. The textrodes were wet with 2 ml of undistilled water to improve skin electrode interface [6].

The real-time performance was evaluated using the "motion test" as implemented in the open source software BioPatRec [14]. Each of the five subjects performed two trials repeating each movement two times in each trial for a total of four repetitions. The order of the type of electrode tested, Ag/AgCl or textrode, was randomized to account for fatigue and learning. Movements were requested in a randomized order. The subject was allowed a five-minute rest between motion tests to further decrease the effect of fatigue. Each volunteer had used the system at least once before the trials as a familiarization phase.

B. Signal Analysis:

Signals were acquired and analyzed for real-time accuracy in Pattern Recognition using BioPatRec software [14]. Four signal features were extracted and selected for the pattern recognition process: mean absolute value, wave length, zero crossing and slope change with a linear discriminant pattern recognition algorithm in a one-vs-one topology [15, 16]. These features have been shown to be successful in previous real-time studies [14, 15]. The percent accuracy showing the ratio of correct predictions over the total amount of predictions was calculated. Completion rate shows the rate of successfully predicted movements. A movement is considered as successfully predicted if it is correct 20 times within 5 seconds [14].

The SNR for the movements was then calculated using Equation 1 where S-rms represents the RMS of the signal amplitude during movement and N-rms represents the RMS of the floor noise during rest.

$$SNR_{db} = 10 * log_{10}\frac{S_{RMS}^2}{N_{RMS}^2} = 20 * log_{10}\frac{\sqrt{\frac{1}{n}\Sigma_1^n S_i^2}}{\sqrt{\frac{1}{n}\Sigma_1^n N_i^2}} \quad (1)$$

Finally a TOST was performed to calculate the percent equivalence of the two signals [17, 18]. The t value was calculated using the following equation:

$$t = (\bar{x}_{text} - \bar{x}_{agcl} - \delta)/\sqrt{\frac{s_{Ag/AgCl}^2}{n} + \frac{s_{textile}^2}{n}} \quad (2)$$

Where $\bar{x}$ is the sample population mean, δ is the accepted error, s is the sample standard deviation and n is the sample size.

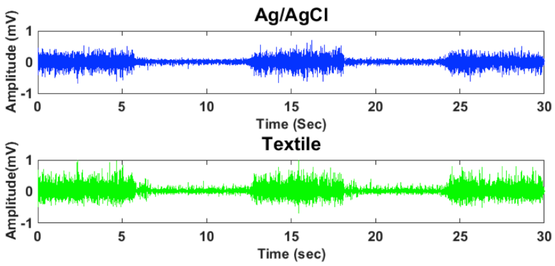

Figure 3. Example of Ramp Recording obtained from Ch. 2 Extension in Extensor Capri Ulnaris

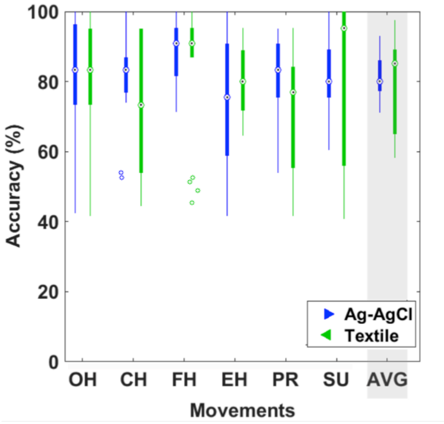

Figure 4. Real-time pattern recognition accuracy of completed movements across 5 subjects (Open Hand, Close Hand, Flex Hand, Extend Hand, Pronate, Supinate and Average). Targets represent median while the circles represent outliers in the data set

III. RESULTS

A. sEMG Recorded

A typical recording obtained with the sensorized strap is shown in Figure 3. The two signals exhibit similarities in both signal amplitude during contraction and floor noise during rest.

B. Pattern Recognition Accuracy

In Figure 4, the accuracy obtained with both type of electrodes for each of the six movements shows a wide range of accuracy in both electrode types. The median across movements is 81.42% and 78.48% for the Ag-AgCl and the textrodes, respectively.

C. Completion Rate

As shown in Figure 5, the difference between the mean completion rates for the average completion rate obtained with the two types of electrodes is 0.016. With the largest difference of 0.65 for EH and the smallest zero difference for OH and PR. Similarly, the median completion rate difference for the two electrode types is 0.125 with the largest difference again for EH while OH, FH and PR show the smallest zero difference.

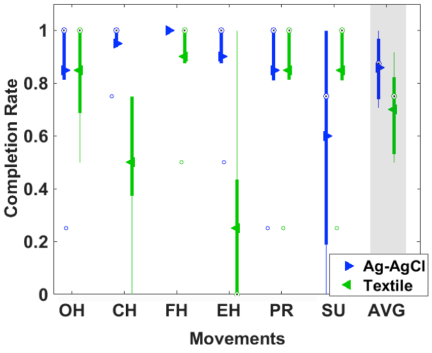

Figure 5. Completion Rates for six movements across five subjects

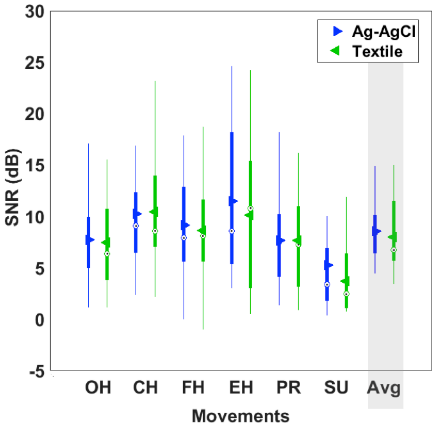

Figure 6. SNR for six movements across five subjects

D. Signal to Noise Ratio

Figure 6 shows the SNR obtained during all the recorded movements. The average difference in SNR across all the movements and subjects is 0.60%. The maximum difference in SNR between means across all six movements is 1.53%.

Figure 7 shows, for increasing levels of significance the evolution of the average percent equivalence. The SNR equivalence of the recorded sEMG signals ranges from 76.69% to 90.0% reported for significance levels ranging from 99% to 90%, respectively.

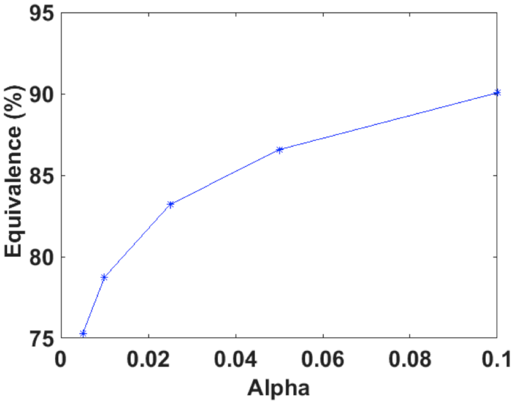

Figure 7. SNR equivalence for different confidence levels

IV. DISCUSSION

In the time domain, sEMG recording with both Ag/AgCl and textrodes are very similar, both in the amount of floor noise and in the signal intensity during the movements. Additionally, the pattern recognition algorithm applied for classifying the hand movements produced accuracy values in the same range for both electrode types, with the median and the mean accuracy across all movements being equivalent. Moreover despite the smaller number of electrodes used in this study, the combined reported real-time accuracy using the textrodes, 83 ± 7% is within the reported accuracy for optimal electrode placement reported in [19].

Analysis of the accuracy for all movements, the difference between mean and median is negligible which suggest that both kind of electrodes exhibit the same robustness to measurement artefacts.

Regarding the completion rate, textrodes recordings an equivalent or better rate form full movement completion in 4 out of 6 movements. For CH and EH, the completion rate obtained with the textrodes is remarkably lower than for Ag/AgCl electrodes, the contrary than for SU. Such difference in completion rate cannot be actually predicted from the values obtained for movement classification accuracy. This issue must be investigated further including the potential influence on the placement of electrodes on the performance of the interpretation engine.

From the signal quality perspective, the statistical analysis of equivalence indicates equivalence levels up to 90.0% at the 90% significance level.

The combination of the textile electrodes and the band can reduce the application time and skin irritation due to the long-term use of conventional gel Ag-AgCl electrodes. The lack of chemical agents from the adhesive and hydrogel layer and avoidance of irritation of the skin upon removal of the electrode are a certain advantages of the textrode [5]. The textrodes would be useful for muscular therapies for amputees such as treatment for phantom limb pain and strengthening of the residual muscle as well as myoelectric prosthetics, which require wearing electrodes for extended periods of time.

V. CONCLUSION

The preliminary results from this study suggest that the intarsia technique for knitting in electrical pathways and the knitted textile electrodes could provide a quality interface for sEMG monitoring of upper arm movements in a controlled real-time environment. These results agreed with the results recently reported in [13] confirming the feasibility of using the textrodes and knitted arm strap for pattern recognition of myoelectric signals.

Further research is required regarding movement classification of transradial amputees and the influence of washing and wearing the electrodes on performance. However, if the results continue to support this fully textile sensorized garment as suitable sensing interface for acquisition of sEMG, this might be the cornerstone enabling the use of conductive smart textiles for novel applications in muscular therapies for amputees such as treatment for phantom limb pain, strengthening of the residual muscle, as well as myoelectric prosthetic control.

ACKNOWLEDGMENT

The authors would like to express their gratitude to SHIMA SEIKI EUROPE LTD, Syverket AB and the Whitaker International Foundation for their support in this project.

REFERENCES

[1] D. S. Andreasen, S. K. Alien, and D. A. Backus, "Exoskeleton with EMG based active assistance for rehabilitation," in *Rehabilitation Robotics, 2005. ICORR 2005. 9th International Conference on*, 2005, pp. 333-336.

[2] L. Dipietro, M. Ferraro, J. J. Palazzolo, H. I. Krebs, B. T. Volpe, and N. Hogan, "Customized interactive robotic treatment for stroke: EMG-triggered therapy," *IEEE Trans Neural Syst Rehabil Eng,* vol. 13, pp. 325-34, Sep 2005.

[3] M. Ortiz-Catalan, N. Sander, M. Kristoffersen, B. Håkansson, and R. Brånemark, "Treatment of phantom limb pain (PLP) based on augmented reality and gaming controlled by myoelectric pattern recognition: a case study of a chronic PLP patient " *Frontiers in Neuroscience,* vol. 8, 2014.

[4] M. Cifrek, V. Medved, S. Tonković, and S. Ostojić, "Surface EMG based muscle fatigue evaluation in biomechanics," *Clinical Biomechanics,* vol. 24, pp. 327-340, 5// 2009.

[5] N. Meziane, J. G. Webster, M. Attari, and A. J. Nimunkar, "Dry electrodes for electrocardiography," *Physiological Measurement,* vol. 34, p. R47, 2013.

[6] J. Löfhede, F. Seoane, and M. Thordstein, "Textile Electrodes for EEG Recording — A Pilot Study," *Sensors,* vol. 12, 2012.

[7] V. Marozas, A. Petrenas, S. Daukantas, and A. Lukosevicius, "A comparison of conductive textile-based and silver/silver chloride gel electrodes in exercise electrocardiogram recordings," *Journal of Electrocardiology,* vol. 44, pp. 189-194, 3// 2011.

[8] F. Abtahi, G. Ji, K. Lu, K. Rodby, and F. Seoane, "A knitted garment using intarsia technique for Heart Rate Variability biofeedback: Evaluation of initial prototype," in *Engineering in Medicine and Biology Society (EMBC), 2015 37th Annual International Conference of the IEEE*, 2015, pp. 3121-3124.

[9] H. Zhang, L. Tian, L. Zhang, and G. Li, "Using textile electrode EMG for prosthetic movement identification in transradial amputees," in *Body Sensor Networks (BSN), 2013 IEEE International Conference on*, 2013, pp. 1-5.

[10] F. Seoane, J. Ferreira, L. Alvarez, R. Buendia, D. Ayllon, C. Llerena, *et al.*, "Sensorized garments and textrode-enabled measurement instrumentation for ambulatory assessment of the autonomic nervous system response in the ATREC project," *Sensors (Basel),* vol. 13, pp. 8997-9015, 2013.

[11] R. Paradiso, Loriga, G., Taccini, N., Gemignani, A., & Ghelarducci, B. , " WEALTHY-a wearable healthcare system: new frontier on e-textile.," *Journal of Telecommunications and Information Technology,,* pp. 105-113., 2005.

[12] L. Li, W. M. Au, Y. Li, K. M. Wan, S. H. Wan, and K. S. Wong, "Design of Intelligent Garment with Transcutaneous Electrical Nerve Stimulation Function Based on the Intarsia Knitting Technique," *Textile Research Journal,* vol. 80, pp. 279-286, 2010.

[13] S. Brown, M. Ortiz-Catalan, J. Petersson, K. Rodby, and F. Seoane, "Intarsia-Sensorized Band and Textrodes for the Real-Time Acquisition of Myoelectric Signals " presented at the The Second International Conference on Smart Portable, Wearable, Implantable and Disability-oriented Devices and Systems, Valencia, Spain, 2016.

[14] M. Ortiz-Catalan, R. Brånemark, and B. Håkansson, "BioPatRec: A modular research platform for the control of artificial limbs based on pattern recognition algorithms," *Source Code for Biology and Medicine,* vol. 8, pp. 11-11, 2013.

[15] M. Ortiz-Catalan, B. Håkansson, and R. Brånemark, "Real-Time and Simultaneous Control of Artificial Limbs Based on Pattern Recognition Algorithms," *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 22, pp. 756-764, 2014.

[16] L. J. Hargrove, E. J. Scheme, K. B. Englehart, and B. S. Hudgins, "Multiple Binary Classifications via Linear Discriminant Analysis for Improved Controllability of a Powered Prosthesis," *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 18, pp. 49-57, 2010.

[17] S. J. Richter and C. Richter, "A Method for Determining Equivalence in Industrial Applications," *Quality Engineering,* vol. 14, pp. 375-380, 2002/03/25 2002.

[18] G. B. Limentani, M. C. Ringo, F. Ye, M. L. Bergquist, and E. O. McSorley, "Beyond the t-Test: Statistical Equivalence Testing," *Analytical Chemistry,* vol. 77, pp. 221 A-226 A, 2005/06/01 2005.

[19] G. Li, A. E. Schultz, and T. A. Kuiken, "Quantifying Pattern Recognition—Based Myoelectric Control of Multifunctional Transradial Prostheses," *IEEE transactions on neural systems and rehabilitation engineering : a publication of the IEEE Engineering in Medicine and Biology Society,* vol. 18, pp. 185-192, 01/12 2010.