Intarsia-Sensorized Band and Textrodes for the Acquisition of Myoelectric Signals

Shannon Brown
University of Borås
Shannon.brown@hb.se

Max Ortiz-Catalan
Chalmers University of Technology
Maxo@chalmers.se

Joel Petersson
University of Borås
Joel.peterson@hb.se

Kristian Rödby
University of Borås
Kritian.Rodby@hb.se

Fernando Seoane
University of Borås
Fernando.seoane@hb.se

***Abstract*— Surface Electromyography (sEMG) has applications in prosthetics, diagnostics and neuromuscular rehabilitation, and has been an increasing area of study. This study attempts to use a fully integrated smart textile band with electrical connecting tracks knitted with intarsia techniques to evaluate the quality of sEMG acquired by knitted textile electrodes. 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. Overall no significant differences were found between the textile and the Ag-AgCl electrodes in SNR and prediction accuracy obtained from pattern recognition classifiers. On average the textile electrodes produced a high prediction accuracy, >97% across all movements, which is equivalent to the accuracy obtained with conventional gel electrodes (Ag-AgCl). Furthermore the SNR for the Maximum Voluntary Contraction did not differ considerably between the textile and the Ag-AgCl electrodes.**

Keywords—Textrodes; Smart Textiles, Pattern Recognition; Intarsia.

I. INTRODUCTION

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

Traditionally Ag-AgCl electrodes are used to acquire sEMG signals because the electrodes limit motion artifacts due to its conductive layer and, most often, ensure high quality signal acquisition. However, these electrodes when used for extended periods of time cause skin irritation [4]. Additionally when used in upper limb applications for prosthetics, and therapies for amputees, they are difficult to apply and remove with limited dexterity.

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) [5][6]. Textile electrodes, also known as textrodes, have been studied extensively in multiple forms including screen printed, knitted, woven and embroidered sensors [6-8]. In the case of the study by Zhang screen printed electrodes for sEMG monitoring showed promise in movement identification for transradial amputees using both offline classification techniques as well as live recordings [7].

This study proposes a fully integrated textile solution for sEMG monitoring in the form of an arm-band fabricated using intarsia knitting, for electrical connection of the recording device with the textrodes. The textrodes were done with a knitted silver fabrics similarly to those used in [9].

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 [10], electro-stimulation [11] and even for thoracic bioimpedance recordings [8][9].

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

1st The performance of the textile electrode for sEMG recording on the upper limb

2nd The feasibility of using a fully textile sensorized arm-strap for the application of classification of hand-movements from sEMG recordings

For that, the functionality of both textrodes and Ag-AgCl electrodes was studied using the intarsia-sensorized band, performing a study based on their offline pattern recognition accuracy, i.e. the performance of classifiers using signals for the two types of electrodes was analyzed. The SNR was then used to compare the signal quality and floor noise for the two electrodes during Maximum Voluntary Contraction (MVC).

Section II describes the methods for textile fabrication of both the band and the textrodes as well as the protocol for the electrode signal comparisons and analysis. Section III describes the results of the signal comparison in the raw signal, percent accuracy and signal to noise ratio (SNR), Section IV discusses the significance of the singal equivalencies and Section V describes the future work to be done.

II. METHODS

A. *Textile Fabrication*

The textile band was used as an interface with the EMG amplifier 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.

The design of the band allows for a total of eight sEMG channels to be simultaneously recorded, however for the purpose of this study only four channels were used. For both gel and textile electrodes, 1 cm of space was allotted between the electrode pair used to form a differential input and 3 cm between each channel of the band. The band with textile electrodes is shown in Figure 1:

(A)

(B)

Figure 1. A. Textile Band (internal) with Textrodes attached. B. External Intarsia knitted cotton piece with snap connectors for wire connections to amplifier

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 1x3 cm as shown in Figure 2.

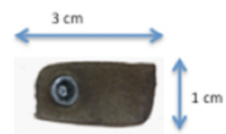

Figure 2.Foam padded textrode

B. *Protocol for Ag-AgCl and Textrode Comparison*

The upper arm movements of six healthy volunteers between 23-30 years old were recorded (3_male and 3 females). The band was placed on the dominant arm with the channels assigned as seen in the Figure 3 with channel 2 placed on the Extensor carpi ulnaris muscle. An AgCl electrode was used for reference in all measurments.

Two experimental measurement setups were used for the test, one with only AgCl Electrodes in the band then and another with only textrodes. The EMG activity was recorded with the subjects

(A) (B)

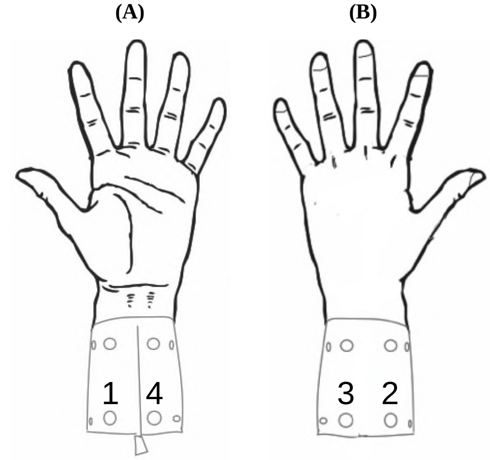

Figure 3. Band Placement with Channel Numbers. Channel 2 on Extensor Carpi Ulnaris

performing a ramp exercise for each type of contraction. The ramp exercise involves one MVC and then increasing contractions up to MVC guided by a computer program, namely BioPatRec [12]. The executed contractions included the following in order; open, close, flex, extend, pronate, and supinate. Three repetitions of each contraction 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 contraction time with a 5 second rest between contractions.*

The textrodes were wet with 2 ml of undistilled water to improve skin electrode interface [6]. Between tests the subject had a bandage placed on top of the band ensure the placement of the electrodes remain consistent while the AgCl electrodes were replaced with the textrodes.

C. *Signal Analysis:*

Signals were acquired and analyzed for offline accuracy in Pattern Recognition using BioPatRec software [12]. Four signal features for the pattern recognition were used including mean absolute value, wave length, zero crossing and slope change with a linear discriminant pattern recognition algorithm in a one-vs-one topology [12][13]. The sEMG recordings from the six hand movements were then processed. In order to calculate the percent classification accuracy a total of 206 time windows of 0.2 seconds were extracted per subject: 84 for training, 41 for validation and 83 for testing.

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

The SNR for the movements was then calculated using Equation 1 above where SRMS represents the RMS of the signal amplitude during movement and NRMS represents the RMS of the floor noise during rest.The strongest SNR signal of each of the four channels was used for each movement. Therefore to perform the SNR calculation equal levels of ground noise was found to be similar for all channels within the same test. The distribution and mean of the SNR for MVC was then found across all subjects.

Signal comparison was done from the sEMG recording obtained from the extension of the extensor carpi ulnaris on channel 2 for wrist extension of each subject, the strongest contraction signal, for both recordings performed with Ag-AgCl electrodes and textrode. For visual comparison the difference in SNR, the RMS and the power frequency spectrum were calculated and evaluated. Finally a Two One Sided T-test (TOST) [14][15], was performed to show that both electrodes had equivalent performance in accurately identifying the signal features for pattern recognition. The TOST was used to show that the mean difference between the two groups is less than the accepted error of 4.1%, which is the variation observed in classification accuracy with long term use of sEMG [16]. For $H_{01} = \mu_{text} - \mu_{AgCl} \geq 4.1$ and $H_{02} = \mu_{text} - \mu_{AgCl} \leq -4.1$.

The t value was calculated using Equation 2.

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

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 The H01 is rejected if -t ≤ -Critical T value, and H02 is rejected if t ≥ Critical T Value. The following section shows the results of the signal comparison.

III. RESULTS

A. *sEMG Recorded*

A typical recording obtained with the sensorized

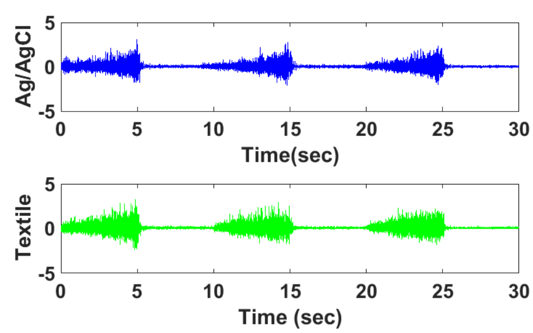

Figure 4 .Example of Ramp Recording obtained from Ch. 2 Extension in Extensor Capri Ulnaris

strap is shown in Figures 4 and its power spectrum in Figure 5 filtered with a 50hz Notch filter.

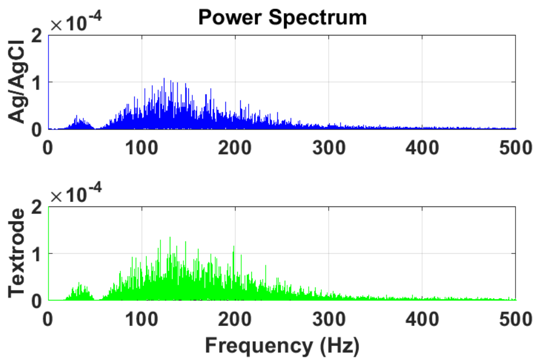

Figure 5. Power Density Spectrum Ag-AgCl and Textrodes.

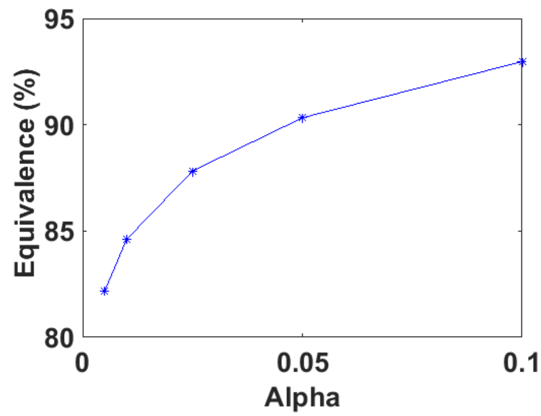

Figure 8.Percent Equivalence for each Confidence level

B. *Pattern Recognition Accuracy*

In Figure 6, the accuracy obtained with both type of electrodes for each of the six movements shows, in either case, values superior to 95%. The average across movements is 98.89% and 98.96% for the Ag-AgCl and the Textrodes respectively.

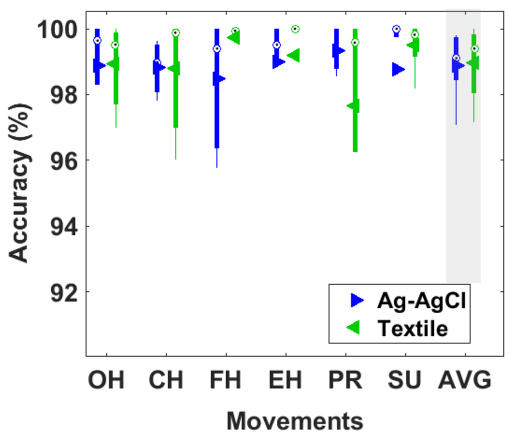

Figure 6. Movement Specific Pattern Recognition Accuracy for Six Core Movements across 6 subjects (Open Hand, Close Hand, Flex Hand, Extend Hand, Pronate, Supinate and Average).

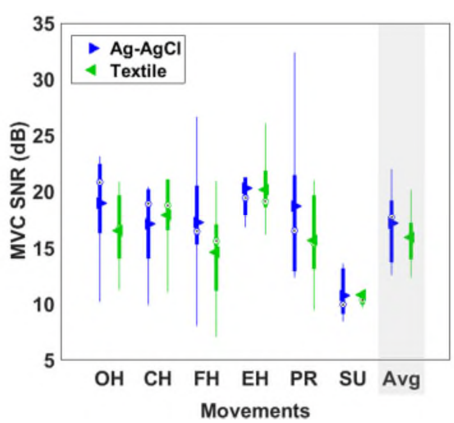

Figure 7. SNR during MVC for core six movements.

Table I indicates the values obtained for the t-statistic tests performed in the TOST procedure, indicating statistical equivalence.

TABLE I. T-VALUES FOR TOST

Margin Error	Movements					
	OH	**CH**	**FH**	**EH**	**SU**	**PR**
$\delta = 4.1$	-4.667	-5.201	-3.517	-3.907	-15.27	-2.783
$\delta = -4.1$	4.806	5.100	6.514	4.309	12.232	3.974

Note 1: $\alpha = 0.05$, δ =[-4.1,4.1], T-critical=1.8125 for n=6
Note 2: after outlier removal for SU, T-critical =1.833 and n=5

C. *Maximum Voluntary Contraction Signal to Noise Ratio*

Figure 7 shows the SNR obtained during the Maximum Voluntary contraction. The average difference in SNR across all the movements and all the subjects is 0.084%. The maximum difference in SNR between means across all six movements is 1.67%.

Figure 8 shows the average percent equivalence across six movements for which, the SNR obtained can be considered equivalent for increasing confidence levels. The percent equivalence ranges from 82.0% to 93.0% can be found for confidence levels ranging from 99.5% to 90% respectively. In the following section the significance of these equivalencies is discussed.

IV. Discussion

As seen in Figure 4, the two signals are visually similar in both in the amount of floor noise and the signal intensity during the contractions. This similarity is further supported by the power spectral density plots showing that the two electrode readings have similar frequency content. Additionally, the pattern recognition accuracy obtained with the classifiers in the offline simulation testing is above 95 in all cases as shown in Figure 6. Moreover, the average accuracy across all movements is very high and almost identical 98.89% and 98.96% for the textrodes and Ag-AgCl electrodes respectively. Regarding the observed accuracy, it can be seen that the recordings produce an statistical significant equivalent classification performance below 4.1% error, which is the average drop expected during the day in this kind of upper limb prosthesis [16]. Although it can be observed in Figure 7 that the movements show a range of performance in which the electrodes performance differs over two percent in accuracy such as in FH and SU the overall performance on average remains in the same range.

From the signal quality perspective, it is observed that the recordings produce a high equivalence at high confidence level with 93.0% equivalence at 90% confidence level.

The observed good performance and similarity between the signals of both the Ag-AgCl electrodes and the textrodes on the sensorized armband fabricated using intarsia-knitting techniques suggest that the use of intarsia as a method of forming electrical connections is valid. There is no evidence of cross talk between the signals on the band or noise added by the knitted pathways. The intarsia electrical pathways therefore seem to provide a reliable interface for sEMG recordings.

Due to the high level of accuracy of the textile electrode found in the offline pattern recognition system, their use in this sensing application would be able to provide a fully integrated textile solution to 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 advantage to increase patient comfort by avoiding skin irritation [3].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. Conclusions

The preliminary results from this study suggest both 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.

Further research must be done in finding the effect of washing and wearing of the textrodes and the sensorized intarsia knitted band on the classification performance and signal quality of the recordings. Furthermore live recordings of transradial amputees for movement prediction must be performed in the next steps.

The viability of using textile electrodes and the intarsia knitted electrical pathways on healthy subjects with offline pattern recognition using a fully integrated intarsia-based textile system has been successfully evaluated. Given the current penetration of intarsia knitting in the textile industry, we might have found the way towards true volume manufacturing of seamless integrated textile-electronic sensorized garments.

Acknowledgements

The authors would like to express their gratitude to SHIMA SEIKI EUROPE LTD and Syverket AB for their support to this project.

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