# Textile Integrated Contactless EMG Sensing for Stress Analysis

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# Textile Integrated Contactless EMG Sensing for Stress Analysis

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***Abstract*— Stress has become an important issue in today's society. Forty to fifty percent of the work related illnesses are directly or indirectly related to stress. In the ConText project, a biofeedback shirt for daily use is being developed to register muscle activity. The user receives feedback about muscle fatigue and/or the level of stress in order to lower the risk on musculoskeletal disorders. Comfort is an important factor to lower the acceptance threshold to wear the shirt. To achieve optimal comfort, the project aims for unobtrusive measurements with contactless sensors which are textile integrated. Working with contactless sensors induces new challenges for instance the displacement of the sensor in the shirt relative to the anatomical position of the muscles. This could affect the recorded signal and lead to errors in the signal. In this paper, we present the results of the quantification of this misalignment. Secondly, we present the first tests with the embroidered sensor.**

## I. Introduction

WORK RELATED musculoskeletal disorders (MSD) [1] of the neck and the shoulders are a growing problem in society. MSD are caused by a combination of factors such as bad posture, repetitive movements and force exertion. But also psychological stress is related to MSD. MSD have personal consequences, such as discomfort, pain, malfunctioning and disability, as well as socio-economical consequences such as reduced productivity, reduced performance and increased absenteeism [2]. Forty to fifty percent of all work-related absences are affected by MSD. This problem leads to losses of 0.5 to 2% of GNP per year. The problem is noticed by the European Commission and reported in two memo's [3] [4]. The EU Advisory Committee on Safety, Hygiene and Health at work emphasizes that a number of measures should be taken to enable successful prevention of MSD.

A tool to measure stress could be very useful. Clothes are omnipresent in our daily life. Bringing the measurement equipment and electronics in our environment could be beneficial, so the acceptance threshold for continuous monitoring can be lowered. The European project Context [5], [6] develops a wearable tool for continuous monitoring of muscle activity with contactless sensors [7] incorporated in textiles. A high degree of textile integration of the electronics and contactless sensors enables unobtrusive monitoring which augments the comfort of wearing the shirt. The use of contactless sensors however implies constraints on the design of the shirt. To reduce misalignment artifacts, such as a variable sensor-muscle distance or variable inter sensor distance, a tight fitting shirt is needed to create a more fixed position of the sensors relative to the muscle. Also the muscle-sensor misalignment, i.e. the shift of the sensor from the optimal sensor position according to SENIAM [10] during body movements must be taken into account in the design. These constraints for the design are tested and discussed in chapter III of this paper. To integrate contactless sensors in textile, the following techniques, laminating, printing, embroidering and weaving, are investigated. In this paper, the results and the first measurements with the embroidered sensor are presented.

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## II. Stress

Stress is defined as a mismatch between perceived demands and perceived capacities to meet those demands. Stress induces a number of physiological reactions, known as the fight or flight reaction. This reaction is hormonal, neurological, cardiovascular, metabolic and muscular. The influence of mental stress on various physiological functions is well documented [8]. Frequently used biomarkers of stress are blood pressure, heart rate, heart rate variability and catecholamine and cortisol secretion. The influence of mental load on muscle activity of the trapezius muscle has been investigated in some recent studies and a significant increase in trapezius muscle activity had been found during mental stress [9]. Chronic stress can lead to an overload or exhaustion of physiological systems.

The ConText project aims at continuous and unobtrusive monitoring of physiological parameters of the body. Contactless measurements of muscle activity and heart rate in combination with advanced signal processing can provide adequate information on stress and/or muscle fatigue.

In order to develop muscle activity and stress algorithms for biofeedback, we developed a 'stress and muscle fatigue test' protocol where subjects were placed in four different

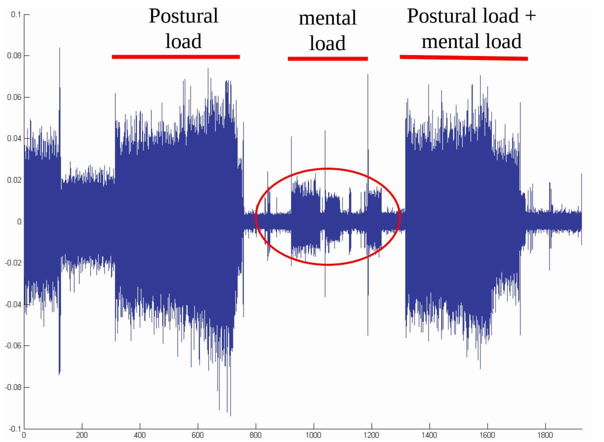



Fig. 1. Muscle activity of the M. Trapezius pars descendens of the right shoulder during the test. Y-axis shows the EMG-activity (in V), the X-axis shows the time. The four states can be distinguished in the figure: postural load, rest, mental load and mental load, combined with postural load.

conditions: rest, postural load, mental load and postural load in combination with mental load. Muscle activity of the M. Trapezius pars descendens, M. Infraspinatus and the M. Deltoideus medius from the left and the right shoulder are measured, together with the heart rate (ECG). Figure 1 shows the muscle activity of the M. Trapezius pars descendens of the right shoulder. As expected, high muscle activity is seen during postural load and postural load in combination with mental load. We also see muscle activity during mental load although there is no movement or postural load at that moment. Analogue results can be found in the research of Lundberg [9], described earlier in this chapter.

Further research is needed to determine whether EMG-signals can be used to develop stress-algorithms. Design of the shirt

### A. *Design*

The application of the vest determines the design of it. As we are working with contactless sensors, the shirt has to fit well around the muscles of interest. Figure 2 shows the design of the first feasibility prototype. The shape of the garment fits the body perfectly. An important constraint is the displacement of the shirt due to movements of the body. Quantification of possible displacement and the effect on the EMG signal is described in II.B.

In ConText, we aim at a high degree of integration of sensors in textile. The positions of the contactless sensors are located on the muscles according to the SENIAM reference position [10].

Also the wires are textile integrated. The wiring has been guided as such to avoid stress on the wires and limitations to body movement. The wires are located on the front of the shirt, where the fabric does not need to provide much elasticity.

The technologies which are investigated in ConText for integrated electrodes and wiring are printing, weaving, embroidering and laminating.

Material tests are performed to investigate the required textile mechanical properties. An important mechanical property of the textile is the elasticity. Different materials were tested: a bi-stretch fabric with a low elasticity and a high flexibility, a supple stretch fabric with a high elasticity and a more rigid stretch fabric. The sensitivity to electric charging of several fabrics was also tested.

Fig. 2. The feasible prototype of the shirt.

A type of Lycra, Coolmax, which is often used for sports clothing, proved to be the best material for this application. It is not very sensitive to electric charging, has good stretch properties in two directions and has favorable moisture and heat regulating properties.

### B. *Muscle-shirt alignment*

It is important that the sensor position during movements of the user stays aligned with the desired muscle. The displacement of the shirt relative to the skin is quantified. Reference markers are placed on the skin on three anatomical places: acromion left and right and the vertebra C7. The middle between the acromion and C7 is indicated as the ideal place for the EMG-sensor for the trapezius muscle [10]. On the shirt, the markers are placed at the same positions. During anteflexion, abduction, retroflexion and elevation of the shoulder, the positions of the skin and shirt markers are recorded in function of time.

Figure 3 shows the displacement of the shirt relative to the anatomical reference of the right shoulder on the skin during the described movements. We see displacements up to 1 cm towards the acromion and 1 cm up to vertebra C7 along the x-axis. In the y-axis, we see a shift from -2.5 cm to 1 cm compared with the reference. The results for the left shoulder are analogue.

How this amount of displacement influences the EMG signal, is tested with the following procedure. We measured the muscle activity of the trapezius muscle at 5 positions: the reference position (SENIAM) and at 2,5cm and 5cm towards

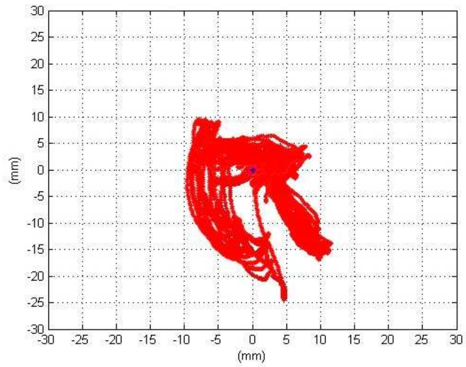



Fig. 3. Displacement of the sensor markers on the right shoulder, relative to the anatomic reference point during movement during anteflextion arm, abduction arm and elevation shoulder.

the spine and towards the acromion. The amplitude and frequency content for the left and right trapezius muscle are compared. The frequency response for every measurement is similar compared with the SENIAM reference. Figure 4 shows the average RMS-value of the amplitude of the muscle activity during movement. Towards the spine, the variability of the amplitude is rather low, whether towards the acromion, there is a high variability. If the displacement is within 2,5cm, the signals are acceptable.

From figure 3, it can be concluded that the displacement of the shirt relative to the muscle is within the marked edges of 2,5cm. The displacement perpendicular to the axis (acromion – C7) is acceptable as the electrodes stay on the muscle. Displacements of sensors on the bone are not acceptable.

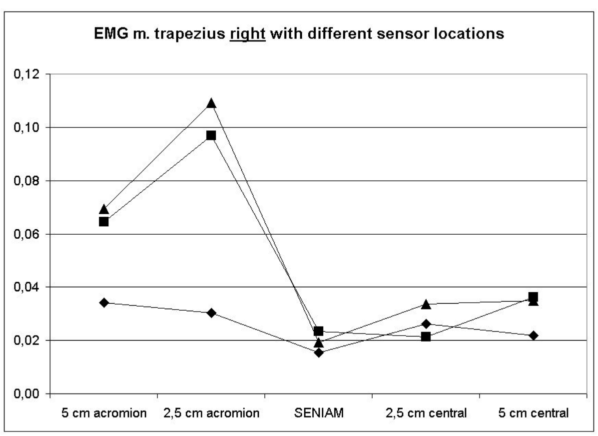



Fig. 4. Amplitude of muscle activity of the m. Trapezius right measured at 5 different positions during movement: anteflexion of the arm (●), abduction of the arm (■) and elevation of the shoulder (▲).

## III. Embroidered Sensor

There are a number of different approaches to integrate sensors into textile and to connect them with electronics. Embroidery is one of the textile technologies investigated for integration. In [11] it was demonstrated how an electronic module can be connected with conductive yarn by embroidering through the module. The image below shows how a conductive thread lies on a conductive pad on the flexible substrate and makes an electrical and a mechanical connection.

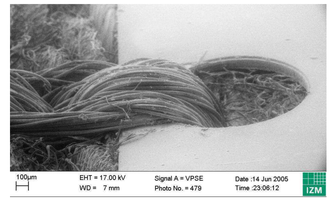
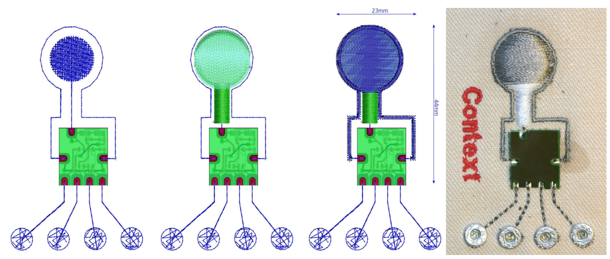


Fig. 5. Conductive Yarn embroidered through a flexible substrate.

In ConText this interconnection technology is currently being improved concerning its reliability. Furthermore it has been enhanced by a multi-layer embroidery process to build a contactless EMG sensor with the same thread that is used for the interconnection with the electronics. [12]




(a) (b) (c) (d)

Fig. 6. Manufacturing the embroidered contactless EMG Sensor.
(a) embroidering of the sensing disk with conductive material
(b) embroidering of the isolation layer with non-conductive material
(c) embroidering of the shielding layer with conductive material
(d) picture of the embroidered sensor

Based on the results described above (in chapter III) a shirt was developed with two sensors on the shoulder to measure the trapezius muscle in a differential manner. Not only the sensors and their connection have been embroidered but also part of the wiring to the electronics. As a long "wire" to the computer a woven ribbon with six conductors was used to retain the textile character of the demonstrator. Later this wire may be replaced by a wireless connection.

To reduce the noise a galvanic contact between the body and the circuit ground was used. For this purpose a conductive ribbon was placed in the neck area of the shirt where the label sits. This ribbon is the only body contact required. The sensors themselves can measure the signal through another layer of clothing like a T-shirt.

Fig. 7. Two contactless embroidered sensors integrated into a vest. Wiring with embroidery and woven conductive yarn (white ribbon).

An example of a time domain signal produced by such an embroidered pair of sensors placed on the biceps is shown in the figure below. The test person was asked to take two postures and to alternate them: relax the arm and then lift a weight of 2.5kg and hold the forearm at a right angle to the upper arm. The measurement reveals a rather good signal to noise ratio. I.e. the contractions can be clearly differentiated from the relaxations. At one point the amplifier is clipping. This is a result of movement of the sensor with respect to the body. It takes quite some seconds for the system to recover from motion artifacts and to function properly again. Currently we are investigating how to reduce these movement artifacts.

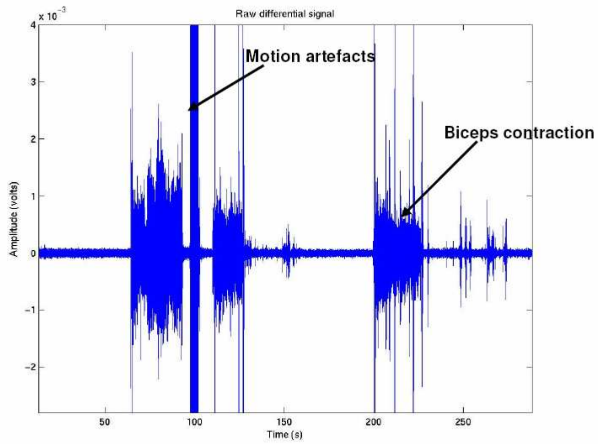



Fig. 8. Differential signal from two contactless embroidered EMG sensor on the body. Y-axis shows the EMG-activity (in V), the X-axis shows the time.

## IV. Discussion

In this project, we aim to develop a bio-feedback system which gives the user information about the state of muscle activity and/or stress. To make it acceptable to use, optimal comfort is required. We work with contactless sensors and wiring, incorporated in textile to obtain an unobtrusive monitoring system. The use of contactless sensors has a big advantage on the comfort and application possibilities, but sets new requirements to the technology. In this paper, we described how we cope with the muscle-sensor misalignment. Also artifacts caused by variation of the distance between the body and the sensors need further research.

The integration in textile of electronics requires more severe specifications from the developed and investigated techniques. Next to the technology and the reproducibility of the technology, other typical textile properties like washability, wearability, durability, softness… are issues in the selection of the technology and the design of the vest. The textile integration technology is at the moment at an acceptable level, i.e. embroidery which is presented in this paper. A new step in the development of the technology comprises the investigation and validation of the textile properties of each technology. These findings will affect for sure the decision on the technology.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