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***ABSTRACT*:** Wearable electronics are technological devices that are incorporated into garments with embedded systems and provide constant interaction with the user performing a specific task. This technology often focuses on devices to monitor physiological variables and seeks the most convenient and portable form for continuous monitoring. Although sEMG has emerged as a tool used in laboratory research for many years, with the development of technology in the fields of electricity, electronics, computers, and biomedicine, it has been used for different purposes in kinesiology (the branch of science dealing with human movements), rehabilitation, sports medicine, sports sciences, and many sports branches. In this study, textile based sEMG electrodes were produced by using knitting technology with silver plated polyamide conductive yarn with different densities. Then resistivity and sEMG signals of the produced samples and conventional disposable electrode were compared.

Key Words: Smart textile, textile-based electrode, medical textiles, sEMG signal, physiological monitoring

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***ÖZ*:** Giyilebilir elektronikler, gömülü sistemlerle giysilere dahil edilen ve belirli bir görevi yerine getiren kullanıcı ile sürekli etkileşim sağlayan teknolojik cihazlardır. Bu teknoloji genellikle fizyolojik değişkenleri izlemek için cihazlara odaklanır ve sürekli izleme için en uygun ve taşınabilir biçimi arar. sEMG uzun yıllardır laboratuvar araştırmalarında kullanılan bir araç olarak ortaya çıkmış olsa da elektrik, elektronik, bilgisayar ve biyotıp alanlarında teknolojinin gelişmesiyle birlikte kinesiyoloji (insan hareketlerini inceleyen bilim dalı), rehabilitasyon, spor hekimliği, spor bilimleri ve birçok spor branşında farklı amaçlarla kullanılmaktadır. Bu çalışmada, farklı yoğunluklarda gümüş kaplı poliamid iletken iplik ile örme teknolojisi kullanılarak tekstil bazlı sEMG elektrotları üretilmiştir. Daha sonra üretilen numuneler ile konvansiyonel tek kullanımlık elektrotların özdirenç ve sEMG sinyalleri karşılaştırılmıştır.

Anahtar kelimeler: Akıllı tekstil, tekstil tabanlı elektrot, medikal tekstil, sEMG sinyali, fizyolojik izleme

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1. INTRODUCTION

The role of technology in healthcare is gaining importance day by day. The research and development studies on smart garments for monitoring physiological condition is growing very rapidly in scientific and technological areas. Such smart garments, popularly also known as electronic textiles, find applications in varied fields like civilian, medical, military etc.

Surface Electromyography (sEMG) is an assessment tool that is frequently used in many areas of medical science today and is used to analyze muscle function. With the help of this measurement technique, which contains important information about the contraction of our body muscles, it is determined which muscles are activated in which movement. sEMG provides information on which stage the muscles are active, especially in activities that contain important data such as walking movement. In addition, it allows evaluating muscle fatigue and making muscle strength estimates. Surface electromyography (sEMG) is one of the most common methods used to measure muscle activity in athletes and patients. Textile-based electrodes cover a larger area to acquire the sEMG signal, thus achieving muscle stimulation from all muscle groups. Real-time measurement of textile-embedded EMG electrodes has been shown to significantly improve clinical outcomes after rehabilitation. Scientific studies show that sEMG muscle signals can be obtained from muscle groups in the human body with conventional electrodes (Giggins et al.,2013; Pehlivan, 2006) or textile-based electrodes (Catarino et al., 2012; Pani et al., 2019; Colyer et al., 2018) integrated on a garment. When the studies in this field are examined, it is seen that textile-based electrodes can be created by various methods.

Biopotential monitoring has been greatly facilitated by advances in wearable technologies and textile electronics has become an important technology. The human body itself is a critical signal “source” in wearable applications. The material type and production technology have important effects on the performance and functionality of the textile-based electrodes. Textile-based electrode production is fundamentally based on the integration of conductive materials in the form of fabric. Commonly used conductive materials include metals and conductive polymers. With these materials, electrode fabric form is applied using knitting, weaving, embroidery techniques or using various other methods such as printing, electroplating, physical vapor deposition (PVD), chemical coating and chemical polymerization (Stoppa et al., 2014; Takamatsu et al., 2015).

Knitting, weaving, and embroidery technology are the most known and widely used techniques in wearable technology. Using various conductive fibers and yarns, electrode surfaces can be created by knitting, weaving and embroidery techniques directly. Woven textiles are produced by interlacing two perpendicular yarn groups. In contrast, the knitting technique uses a needle that constantly connects a series of thread chains. The embroidery method is a kind of decoration method for creating a pattern by including different sewing forms on a fabric surface. Among these methods, knitted fabrics, provide consumers skin comfort, low weight, and great flexibility, and the knitting process is a well-established approach that allows a whole garment to be made on a single machine (An et al., 2018; Xu et al., 2008). Electroless plating is a technique that involves spontaneous reactions in an aqueous solution without requiring the application of an external electric field, unlike galvanic plating, which uses an electrode current to reduce metal cations for plating (Mallory et al., 1990). Electrodeposition techniques and physical vapor deposition (PVD) are the most prominent techniques for metal coating on non-conductive yarns and textiles. PVD techniques such as thermal/e-beam evaporation and sputtering depend on the formation of conductive layer on the textile material, similar to electrodeposition in the microelectronic process industry. Metals are evaporated and deposited to form a thin film layer on various textile products (Mattox et al., 2010; Silva et al., 2012). Dip coating is one of the simplest methods of coating yarns or fabrics and is still used in the textile industry. Upon application of a conductive solution to textiles, excess material is removed, and a drying step known as curing is performed to evaporate the solvent and fix the conductive particles on the fiber surfaces (Shang et al., 2013; Garcia-Breijo et al., 2015). Printing techniques such as inkjet and screen printing are widely used to create conductive patterns on textile substrates and are already being used on a large scale to print stickers/images on textiles (Ujiie, 2006).

In the scope of this study, knitted fabric samples with different loop densities were produced using conductive yarn in order to obtain textile based sEMG electrodes. The effect of loop densities and so fabric tightness on resistivity and signal reception capability were investigated. Then, resistivity and signal reception capability of textile-based electrodes were inspected in comparison to conventional electrodes.

2. MATERIALS AND METHODS

A prototype vision inspection system is developed to acquire image frame of the yarn bobbin and fabric. In this study, it is aimed to produce a textile-based electrode samples for measuring sEMG signals. For this purpose, it is planned to produce electrode surface by using silver-coated polyamide yarns (Statex/Shildex Group, 117/17 dtex) via circular knitting technology. Since the conductivity and measurement accuracy of the produced textile-based electrodes is affected by the structural parameters, it is aimed to evaluate the textile-based electrode samples with different loop densities. The produced textile-based electrodes have a voluminous structure and form a surface area in contact with the body, conductivity levels were determined by resistivity measurements. The resistivity measurements were done by using a digital multimeter device. Three knitted fabric samples were produced with different levels of fabric density as loose, medium and tight, as single jersey structure. For this aim, a sample circular knitting machine with 3.5” gauge, 22 fein was used at 20±2 rev/min production speed. All fabric samples were conditioned according to TS EN ISO 139 before the tests and the tests were performed in the standard atmosphere of 20±2ºC and 65±4% relative humidity. Fabric mass, thickness, loop density and loop length properties of samples were determined according to TS EN 12127:1999, TS 7128 EN ISO 5048:1998, TS EN 14971:2006 and TS EN 14970:2006 respectively. All measurement results were given in Table 1. The produced fabric samples images were illustrated in Figure 1.

After the knitted fabric samples were produced and the necessary measurements were completed, the fabric samples were sewn on the torniquet in order to get the muscle signal. The knitted fabric samples with 1x1 cm size were prepared and sewn on the torniquet using conductive yarn. Arm muscle signals were obtained with the prepared torniquet as in Figure 2. Muscle signals captured using the Arduino sEMG sensor were displayed on the computer screen. Grove - EMG Detector was purchased for this investigation. Muscle and nerve EMG signals can be captured using sensors in the EMG measurement kit. Microcontrollers such as Arduino or other embedded systems might be used to implement the measurement kit. An Arduino-based EMG sensor serves as an interface between the electrical components and the physical body in this investigation. The sensor picks up twice-amplified and filtered electrical impulses from small muscles. The sensor output is detectable by Arduino. In standby mode, the sensor outputs 1.5V. Muscle contraction causes the output signal to increase to 3.3V.

Table 1. Structural properties fabric samples

Samples	Resistance, ohm/10 cm	Thickness, mm	Course density, course/cm	Wale density, wale/cm	Loop length, mm
Dense	1.4	0.34	11	16	2.9
Medium	1.4	0.35	10	14	2.7
Loose	1.5	0.36	9	12	2.5

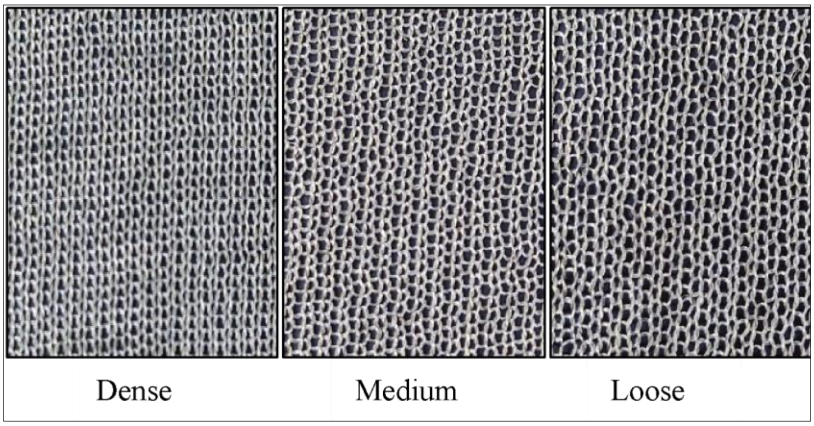

Figure 1. Knitted fabric images

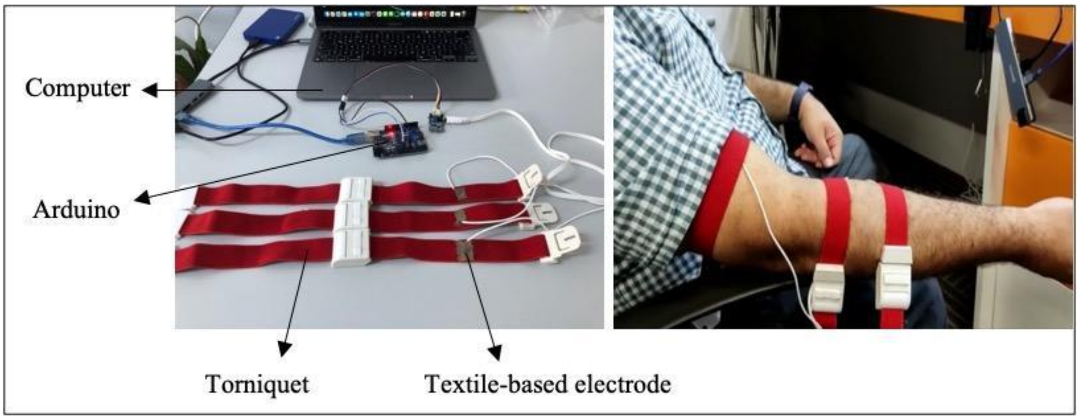

Figure 2. Conductive fabric placed on the torniquet

3. RESULT AND DISCUSSION

Surface resistivity measurements of the knitted fabric samples were carried out as shown in Figure 3. The fabric sample is placed in a hoop to keep the fabric tension constant and regular. The resistivity value of the fabric was measured at a certain distance by placing the probes of the digital multimeter device on the fabric surface. After that a square signal was created using Arduino and the characteristic of the signal transmitted through the fabric sample was analyzed via oscilloscope device. The signals acquired from each sample was compared. It was observed from the oscilloscope device that there was no loss in the generated square signal (Figure 4).

Muscle signals were acquired from three textile-based electrode samples and conventional disposable electrodes. In order to compare the signals, they were captured from the same person and same muscle group. The person made the same arm movement during the signal acquisition. When the muscle signals were analyzed, it was seen that all three fabric samples have similar results with disposable electrodes. It is clearly seen in Figure 5 that the signals received from the arm muscle have a similar characteristic. This result can be attributed to the close resistance values of the fabric samples. The disposable electrodes and all textile-based electrodes used in the experimental setup captured signals in the range of 200 to 800 millivolts. The obtained findings as a result of this study are also similar to the literature. It has also been stated in previous studies that textile-based electrodes and disposable electrodes perform similar measurements (Lee et al., 2018; Babusiak et al., 2018).

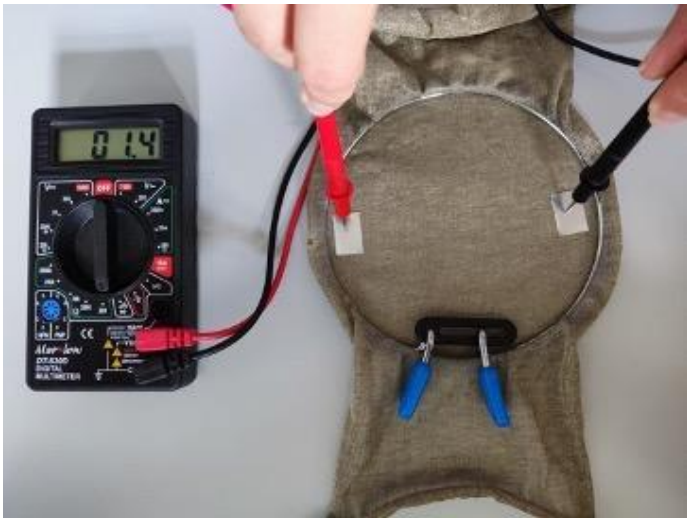

Figure 3. Surface resistivity measurement of knitted fabric sample

Figure 4. Signal measurement of knitted fabric sample

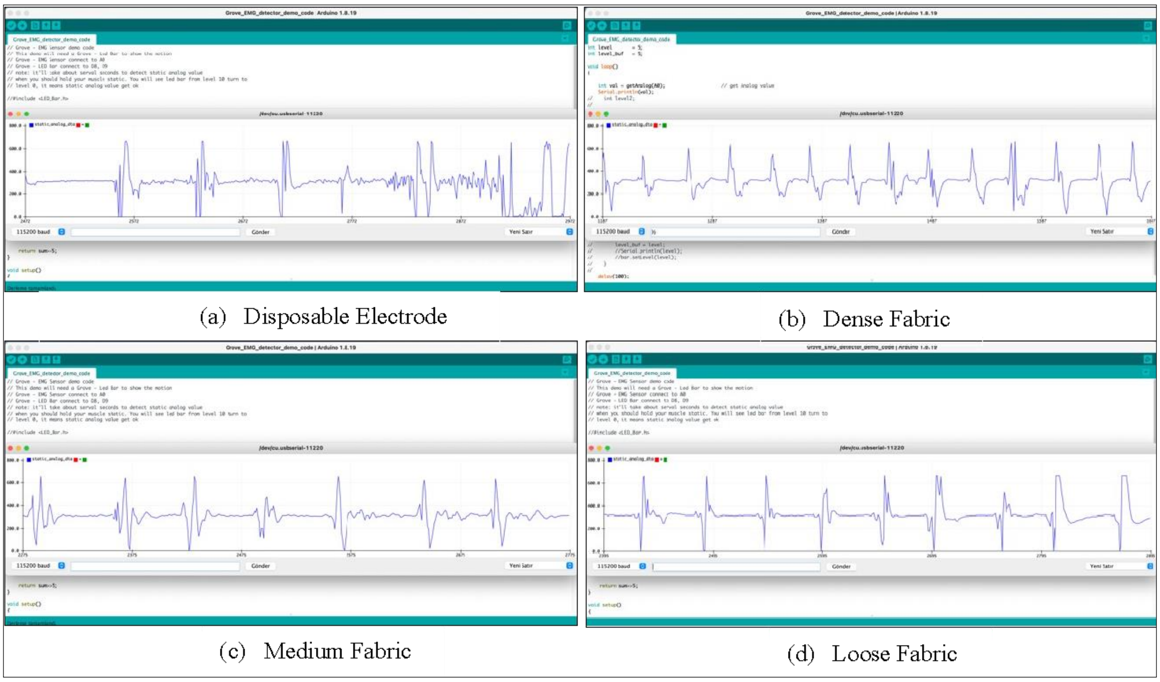

Figure 5. Comparison of sEMG signals captured from (a), (b), (c), (d) samples

4. CONCLUSION

In this work, it is aimed to submit information about textile-based electrode properties and to create textile-based electrode structures containing silver-plated polyamide conductive yarn. By producing knitted fabrics with three different densities with conductive yarn, textile based sEMG electrodes were produced. Then, surface resistivity and signal transmission levels of textile based and conventional sEMG electrodes were observed. It was seen that sEMG signals acquired from textile-based electrodes and conventional electrodes are very close to each other. It shows that the electrode structures produced by using conductive yarns, can be used in sEMG measurements. As a result, it is seen that textile-based electrodes can be used as an alternative to disposable electrodes. Thus, it can be concluded that the reliability of smart textiles to be used in the medical field is very high.

It is possible to collect clinical and behavioral data using wearable technology, which may be categorized under broad categories such real-time monitoring of health status in the medical area, diagnosis, and therapy. Numerous application examples highlight this benefit of wearable technology. As a result of this study, it can be demonstrated that smart clothing made with textile-based sEMG electrodes is adequately accurate for real time health monitoring. The smart clothes allow it to analyze muscle signals during active exercise, which is superior to measurements in medical environment. Smart clothes produced with textile electrodes provide comfort to the user in terms of both ease of measurement and comfort. As technology advances, consumers' perceptions of computers are changing from desktop computers to smart phones, tablets, and eventually wearable devices. According to market studies, this technology is becoming more and more prevalent in our daily lives. It has established itself as a significant player in the market with a wide range of products as a result of users' growing awareness of its benefits.

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