SPWID 2021

The Seventh International Conference on Smart Portable, Wearable, Implantable and Disability-oriented Devices and Systems

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SPWID 2021 Editors

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SPWID 2021

Foreword

The Seventh International Conference on Smart Portable, Wearable, Implantable and Disability-oriented Devices and Systems (SPWID 2021), held between May 30 – June 3rd, 2021, is an inaugural event bridging the concepts and the communities dealing with specialized implantable, wearable, near-body or mobile devices, including artificial organs, body-driven technologies, and assistive services

Mobile communications played by the proliferation of smartphones and practical aspects of designing such systems and developing specific applications raise particular challenges for a successful acceptance and deployment.

We take here the opportunity to warmly thank all the members of the SPWID 2021 Technical Program Committee, as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to SPWID 2021. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the SPWID 2021 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that SPWID 2021 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the areas of smart portable devices and systems.

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GuideMe: A System for Indoor Orientation and Guidance

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***Abstract*— The demand for indoor navigational systems is increasing daily. The use of navigational systems is ranging from smart cities and robots to visually impaired people support to navigate safely. The GuideMe Project aims to provide guidance and security for people suffering from blindness, and in the time being, it is in the final development stage. This paper presents GuideMe Project goals GuideMe Project architecture and GuideMe final prototype. GuideMe Project architecture consists of the wearable device curried the user has, the anchors with which the wearable device works to determine the position of the user, the smartphone that is informed by the system for the route the user must follow and converts the message into audio information through the user's headset. The headset in order to guide the user in indoor places and the local server who controls the protocols and the information, are the last parts of the architecture. It is clear that the system is quite complex, it consists of several entities and requires them to work together harmoniously to provide the prescribed functionality, in real-time. All the technologies developed to this final system, each of which has multiple sub-entities as mentioned, handle the required functionality that is the provision orientation of users who are located and moving indoors.**

Keywords-GuideMe; indoor navigation; indoor guidance; people with special needs.

I. INTRODUCTION

The GuideMe project involves the design and development of an indoor tracking and navigation system for people suffering from blindness. The core of the system is a device which will provide the ability to navigate through voice instructions. These instructions will be based on the positioning and orientation capabilities of the device.

For outdoor navigation and pathfinding, the Global Positioning System (GPS), is the most commonly used technologies, among others. GPS though is only applicable for outdoor localization because issues arise when is about indoor localization. Of course, indoor navigation is very important to humans and has many applications for robots too. The most common issue regarding the use of GPS in an indoor environment is that there is no line of sight between the GPS receiver and the satellites because the building walls and the indoor obstacles can lead to signal reflection and absorption. GPS technology use is not possible inside buildings which makes indoor navigation more complicated, and the reasons are thoroughly explained in 0.

Following the previous research in the context of GuideMe project, this paper presents the architecture and the modules of the GuideMe system that were used and developed for indoor navigation. Detailed presentation of the positioning and navigation modules of GuideMe system has been presented in [2]. Audio guidance refers to the ability of the GuideMe system to guide the user with voice navigation commands. The corresponding module has been presented in [3]. The GuideMe system consists of the following modules: (a) Indoor positioning and navigation algorithms: For indoor positioning, the trilateration method was selected because of the UWB technology. UWB technology provides very good position estimation, thus trilateration provides sufficiently precise localization. For navigation, the A* algorithm was implemented. It is a heuristic algorithm, finding the shortest distance. It searches for the minimum optimal path, among all possible paths to the final node (destination). (b) Text-to-Speech module: For the acoustic guidance, voice composition via Google's text-to-speech (TTS) was selected. Using the Google platform and the corresponding API, the application creates an audio mp3 file from the text that will be the input to the specific text-to-speech functionality of the platform. (c) Wearable and anchor module: Wearable is a device that the user carries and works with other system entities to determine the location. Anchors are devices in specific locations inside the buildings which are used for the wearable device to locate itself. The device transmits and receives fixed point messages via UWB protocol. In addition to communicating via UWB with the wearable device, the anchors communicate with the local server via Wi-Fi. The wearable device is not connected anywhere. It's an entity that just exchanges messages with the anchors when asked. (d) Mobile application: The smartphone that the user carries is informed by the system about the route that must be followed by the user and converts this information into audio messages in the user's

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headphones. In addition to headset communication (BLE or wired), the smartphone also communicates with the local server via Wi-Fi. (e) Servers: Local server has multiple roles; it communicates with the host server via MQTT protocol messages. It also communicates with fixed devices via Wi-Fi for the relative distance of each mobile device. Through communication with the main server, it is informed about the user's destination and calculates routes to the destination. The main server collects and manages all the information for the users. The configurations required are integrated into the system, the top views, the applications that are used, and presents all the data that has been collected. The buldings floorplans are uploaded-stored to the server and computer vision (to detect walls, obstacles, etc.) and routing technologies are used to extract the best route.

The rest of this paper is organized as follows. Section II describes the motivation behind our work. Section III provides a literature review of other current works on this subject. Section IV addresses the system’s architecture whereas Section V goes into finer details regarding the system modules for positioning and navigating in indoor spaces. Finally, Section VI summarizes our main findings and conclusions and suggests probable future work.

II. MOTIVATION

Visual impairment or as it is known “Blindness” is a decreased ability to see and can cause difficulties in daily activities. Blind people face problems not fixable by usual means and they always depend on others. The main problem and the motivation of this project are that blind people may face problems to move through places without help.

According to the World Health Organization, the following are the key facts regarding blindness and vision impairment [4]: (a) At least 2.2 billion people have a vision impairment or blindness globally, of whom 1 billion could have prevented or has not been addressed yet. (b) That 1 billion include those that have a moderate or severe distance vision impairment or blindness due to unaddressed refractive error. (c) The main causes of vision impairment are uncorrected refractive errors and cataracts. (d) The majority of people with vision impairment are over the age of 50 years. The motivation of the GuideMe project [5] is to provide guidance and security for outdoor travel. The main component of the system is a portable device that provides the ability to route and navigate the user by voice commands. The device guides the user based on its location and orientation capabilities.

The motivation of the paper and the main goal is to improve the convenience and security of the social life of blind people and people with special needs too. Using the above-mentioned system, the users will feel more secure and comfortable in visiting public places, especially buildings, such as stations, airports, shopping malls, etc. as they will be guided by the GuideMe system in order to arrive at their destination. It is also important to mention, that the user will be informed in case of an emergency such as fire, earthquake, accidents, etc.) and the user will be guided to the nearest exit. The target is to increase up to 20% the presence of the population with mobility or other problems in buildings.

III. RELATED WORK

In this section, related research works will be mentioned that concern the navigation and routing indoors. The studies concerning indoor positioning techniques and systems are strongly increasing as the location-based services growing. Previous works focus on the need to study the general way of positioning and then they propose algorithms and methods for indoor positioning while others propose a different way of system architecture to achieve efficient indoor navigation.

Significant work regarding indoor navigation for people with special needs is available. A comprehensive solution was provided by Kishore et al. [6] for indoor public transport for people with disabilities. Beacons (small low-power devices) were placed indoors and transmitted signals to the cell phone sensors via Bluetooth Low Energy (BLE) technology. Another study using BLE is presented by Cheraghi et al. [7]. GuideBeacon is beacons-based for indoor navigation that simulation showed that GuideBeacon application reduces the time that disabled person needs to cross an unknown indoor area at the percentage of 30%-50%. It also reduced the distance the disabled person has to walk by at least 50%. FootPath (Link et al. [8]) is a system that consists of a geographic map from OpenStreetMap. When the geographic map is downloaded, the system uses the accelerometer and compass on the user's phone to calculate and detect the user's steps. The results showed that the FootPath system is very accurate and can assist users with disabilities. Megalingam et al. [9], suggested an algorithm called Location-Aware and Remembering Navigation (LARN), which depends on Dijkstra’s algorithm to find the optimal path. Daramouskas et al. [10] present Multilateration, Trilateration, and Particle Swarm Optimization (PSO) algorithm in a study using methods for location estimation on Low Power Wide Area Networks (LPWAN). Zhu et al. [11] propose an indoor-outdoor positioning for pedestrians and vehicles by connecting an integrated IMU system and a GNSS receiver. Using a horizontal positioning indicator PACCH detects the indoor-outdoor transition and decides whether to merge with GNSS positions. Next, Krishnaveni et al. [12] did an overview based on UWB technology for indoor positioning.

In the existing literature about positioning, machine learning algorithms are widely used to calculate the position of the user. In [13], Peltola et al. present an architecture design using GNSS and UWB technologies simulated in MATLAB using multiple users, methods, and sensors. A survey of the latest indoor positioning technologies is provided by Alarifi et al. [15], who analyse UWB technologies with an analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT). On the other hand, Al-Ammar et al. [16] present new taxonomies and review some major recent advances on indoor positioning techniques. In a different study, [17], Mahida et al. are dealing with algorithms and various positioning enabled wireless technologies used in realistic scenarios in order to provide indoor navigation.

The algorithm proposed in [18] named FPP, combined its internal path and interior information. The study introduced a new method for dynamically changing the navigation path indoors. The FPP algorithm was compared with Dijkstra and Elastic and the comparison results showed that FPP can provide the shortest route for indoor navigation faster than the other two algorithms can. Using A* algorithm, a study in order to reduce the time that is required by a user to get to its destination is conducted by Goel, et al. [19]. In the first section of the paper A* algorithm is detailed presented, while in the second one, the authors demonstrated successfully why the A* algorithm is better than the Dijkstra algorithm for indoor navigation with barriers. Comparing A* and Dijkstra algorithm, A* achieves better results for indoor navigation through heuristic searches and delivers better results faster. Based on these rich and various studies mentioned above, in this section, we will present similar projects to GuideMe. San Francisco International Airport and Indoo.rs put their work together and created an app for visually impaired passengers [20]. Edwin M. Lee collaboration with the White House and other partners of San Francisco developed the Entrepreneurship-in-Residence (EIR) project. At the beginning of 2014, they chose to help the San Francisco Airport (SFO) create a tool to assist blind and visually impaired travelers [20]. Recommendation ITU-T F.921 [21] determines how audio-based network navigation systems can be designed to make sure that they are responsive and dedicated to the needs of people with visual impairments. The goal is to provide network visual system designers with the audio data they need in the early stages of development. They do that contemplate and vanquish any constraints or obstacles that prevent vision-impaired users from making full use of the built environment. A module-based application developed in [22] whose purpose was the blind user being able to use public transport secure and successfully navigate in complex public transport terminals. Through an appropriate user interface, the system combines real-time communication to and from public transport vehicles with precise positioning and guidance. It also provides additional navigation assistance.

INK 2016: Indoor Navigation and Communication in ÖPNV for blind and visually impaired people [23] combines real-time communication to and from public transport vehicles. Giving accurate positioning and guidance and having additional video call navigation assistance where the user can communicate with a professional operator. Arikovani UK’s WeWalk, Imperial College London, Astra Terra, and the Royal National Institute of Blind People (RNIB) will join forces to moderate indoor challenges by developing an indoor navigation system that is reliable and fully accessible too for visually impaired people and anyone that may struggle to navigate the built environment [24].

A new personalized indoor navigation system that aims on increasing public transport accessibility for all passengers but especially for the visually impaired is presented in [25]. Project Ways4all helps the visually impaired, enabling them to access public transport and the necessary up-to-date traffic information in a very simplified way. Concluding, Project “Using An Integrated Techniques for Developing Indoor Navigation Systems to Allow the Blind and Visually Impaired People to Reach Precise Objects” [26] uses various technologies such as WIFI, Bluetooth, and RFID in order to help the user reach a microelement in the navigated environment. It composes an intelligent interface for accurate indoor navigation for blind and visually impaired people only using a smartphone.

IV. SYSTEM ARCHITECTURE

This section discusses the general architecture of the GuideMe project. The architecture consists of the following parts (see Figure 1): the wearable device that the user is wearing, the anchors that are devices located inside a building that helps in the positioning process, the mobile application (installed in the end-user mobile phone), the wireless headset that provides the user with the audio commands for the navigation inside the building, a local server, and a remote server.

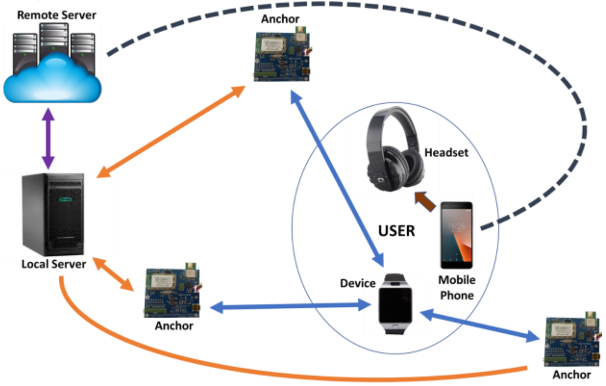


Figure 1. Overview of the proposed architecture

In this project, the main component is a small wearable device that helps in the user’s positioning through UWB technology. This technology provides perfectly accurate positioning, with an error of up to 10 cm. This device, apart from the ability to locate the user, can also determine the orientation of the user, receive voice commands, and transmit voice instructions to guide the visually impaired people. Specifically, as it is shown in Figure 1, in GuideMe system, our smart device can communicate to anchors via UWB technology, in order to locate the user. This device has the ability to provide route and navigation information to the user via voice commands. The anchors are calculating and measuring the distance between the user and the anchor. The distance data (between the user and the anchors), is transferred to a local server to measure the exact position and run positioning algorithms, which in our case will be based on the trilateration approach. The communication between the anchors and the local server is done using Wi-Fi technology and as far as the communication protocol is concerned the Message Queuing Telemetry Transport (MQTT) [27] is used.

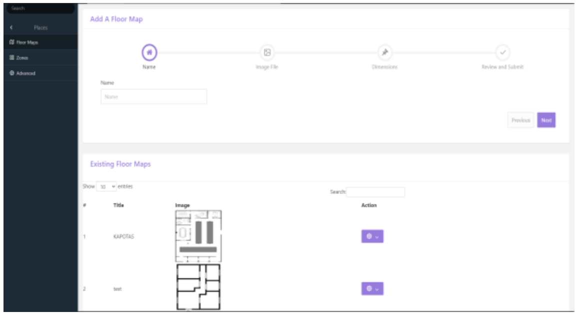
Furthermore, there is a remote server that has a floorplan of the building. This remote server, having the details of the building, the position of the user, and the destination of the user, can guide the user by giving directions. Also, the communication of the local servers with the remote server is done over REST API that ensures seamless communication, speed, and scalability. The navigation directions are given by the smartphone to the user through wireless headphones, using voice commands. Specifically, the communication between the wireless headset and the smartphone is based on Bluetooth technology. The mobile application is responsible to provide the navigation commands. The audio commands are extracted in the remote server and transmitted through the Wi-Fi network to the mobile application.

V. SYSTEM MODULES

In this section, the parts of the aforementioned architecture are thoroughly presented. Firstly, the indoor positioning and navigation algorithms used in this project are presented. After that, the Text-to-Speech part and the anchor technology are presented. Finally, the server, web, and mobile applications are described.

A. *Indoor positioning and navigation algorithms*

As the main goal of the GuideMe project is to provide indoor localization and navigation to blind people, thorough research has been conducted in order to choose the best solution. As far as the indoor positioning is concerned, the trilateration method was selected. The main reason for this choice is that UWB technology provides very good estimation, thus trilateration provides sufficiently precise localization. The algorithm was implemented following these steps: a) for each UWB anchor with which the user connects, a circle is created, with the centre the position of the user, and with a radius the distance between the user and the anchor. To locate the user, the user must be connected with at least three anchors.



#	Title	Image	Action
1	KAPOTAS		
2	test		

Figure 2. The UI of the dashboard when adding a floorplan.

Regarding the navigation algorithms, the A* algorithm [31] was implemented. A* algorithm is a heuristic algorithm for pathfinding, that can “discover” the optimal path, under some circumstances. This algorithm depends on the structural graphs. An initial node is defined as the start point on the graph and tries to find the endpoint with a minimum cost. The cost function is defined as the travel cost is used on par with an estimate of the cost required to extend to reach the final node. In (1) the cost equation is defined.

$$f(n)=g(n)+h(n) \qquad (1)$$

the g(n) signifies the travel cost from the initial node to the n-th node. The h(n) is the estimated cost from the nth node to the final node.

As far as the development is concerned, the pathfinding procedure was implemented based on the [28]. Firstly, the library provides a floorplan with a grid. In each cell of the grid, we can set with 0 or 1 if the cell can be accessible (if there is not an obstacle in this cell). After defining the cells that have obstacles, then the initial point coordinates and the final point coordinates are defined.

Figure 2 shows the dashboard with which the user adds a floorplan in the GuideMe project.

B. *Text-to-Speech*

The navigation commands to the end-user are provided through the Android application, using the Google Cloud TTS platform. The commands extracted from the TTS procedure are provided to the user via the SSML [32] language. SSML language is a part of a greater set of markup specifications for voice commands. The flow of the TTS conversion is the following: TTS operates by converting SSML input into audio data. Audio data is in human speech. The process of translating the text into human speech is called synthetic speech.

C. *Wearable device and Anchors*

As far as the wearable device is concerned, the processor that is chosen is the EC32L13 module developed by Econais [20]. The EC32L13 is a 32-bit processor of the product family STM32 processors. The processors in this family of processors are energy efficient, in order to expand the battery life. A WiFi module is also integrated into the wearable device. For the connectivity through UWB, we have chosen the module DWM1000 of Decawave [33].

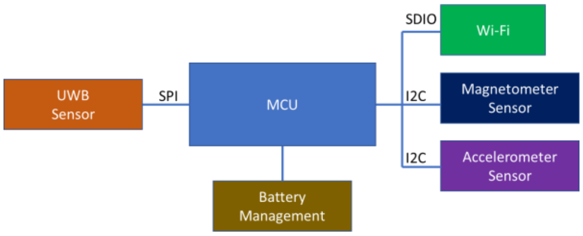


Figure 3. Overview of the device's architecture.

In Figure 3, we present the general architecture of the wearable device. The device consists of a number of sensors including, the magnetometer and accelerometer sensors, the UWB module, the WiFi module, the Main Computing Unit, which in our case is the EC32L13, and the module for the battery management in order to expand the battery life as long as possible. In Figure 4 the user’s wearable device prototype is presented.

The EC32L13 module is incorporated in both wearable devices and anchor. In contrast to the anchor, the wearable device has many sensors that help to understand the orientation of the user. Specifically, the gyroscope FXAS21002FS, and the magnetometer/accelerometer KMX62 were used. The FXAS21002FS is a small, low-power gyroscope with a 16-bit resolution (ADC). Its full range is adjustable and can reach from ± 250 ° / s to ± 2000 ° / s. Microprocessor interface capabilities include I2C and SPI protocols. The KMX62 is a 6-degree sensor system that provides 16-bit precision digital outputs that can be accessed via the I2C interface. The KMX62 sensor consists of a three-axis magnetometer and an additional three-axis accelerometer. Its size is 3 x 3 x 0.9mm (LGA) - 0.18um CMOS technology. Includes a programmable accelerometer ± 2g / ± 4g / ± 8g / ± 16g and +/- 1200 uT range for the magnetometer.

Figure 4. Wearable device prototype of the GuideMe project.

The next section describes the mobile application.

D. Mobile App

As far as the mobile application is concerned, we focused on creating an Android-based application. The application is responsible for several functions: (a) Connection to the local server via a Wi-Fi network and receive on-site navigation commands. The application receives the commands in a format defined by the communication protocol between the server and the defined application, converts them into voice commands, and transmits them to the headset. (b) Interface through which the user enters his passwords and is verified that he has the right to use the service. The authentication process is based on the Cognito platform of Amazon Web Services. (c) Interface for the wearable-application pairing. The wearable device was programmed to transmit to Bluetooth Low Energy (BLE) beacons, and particularly iBeacons [34]. iBeacons is the technology standard that enables mobile apps to listen to signals from Bluetooth devices. The logic we follow in the GuideMe application is this: The device periodically emits an iBeacon. In case we want to connect the application to the device, the user presses the corresponding button and places the phone very close to the device. At the touch of a button, the phone starts 'listening' to BLE devices in the area for 5 seconds. If it “listens” to a device that it is near it (based on the RSSI value), at the end of five seconds it notifies the user that this GuideMe device (beacon) has been detected and asks the user if it wants to pair. (d) Provides tracking service assistance, using the built-in sensors (magnetic field detection sensor, accelerometer, etc.) on the Android mobile phone running the application. (e) Connection to wireless (Bluetooth) or wired headphones carried by the user and guidance with voice commands.

E. Local and Remote Server

Finally, project GuideMe consists of two types of servers, the local servers, and the remote server. The server offers device management functionality. There are different types of devices and each type is managed differently. Specifically, the devices that the local server manages are: (a) Mobile UWB devices that users carry (tags) and are responsible for locating them indoors. (b) UWB devices that located in specific areas and communicate with both mobile stations and the local server. (c) The local server is located on the building premises.

As far as the remote server is concerned, the main responsibilities of the remote server are the following: (a) Offer user management functionality. Different levels of users are provided, each with different capabilities and rights. Users log in to the platform using a username/password. Modern user authentication methods incorporate additional mechanisms in parallel with the password-based methods, to verify the identity of users. In the GuideMe project, the Amazon Web Services' Cognito platform [35] was used. We generalize authentication into two common steps, which are implemented through two APIs provided by the platform: InitiateAuth and RespondToAuthChallenge. (b) Manage the information of buildings, such as maps (floorplans). (c) Gather the information sent by the devices, provide previous information, e.g., the previous locations of the user. (d) Provide information concerning the use and cost of the use of the system (accounting/billing). (e) Capture the position of the devices in the space on the floorplans.

VI. CONCLUSION AND FUTURE WORK

This work refers to the project of GuideMe. The state of the art of existing approaches and the system modules that were implemented to complete the above-mentioned project in terms of navigation and indoor routing were presented. The system provides a wearable device, and the project’s purpose is the contribution to indoor navigation and positioning assistance for people with difficulties. The user is guided from the wearable device for the indoor orientation through voice commands and help him to avoid obstacles. This work is the final phase of the project that relates to transmitting the correct instructions to the user using the information and modules of the aforementioned through voice commands. Future work will include the participant-based evaluation of the GuideMe system and study the impact of such a system in museums. Also, future work may include an extension of this current work by also covering outdoor areas through the application.

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A Surface Electromyography-Based Platform for the Evaluation of Sarcopenia

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Abstract— **Sarcopenia is a disorder characterized by a loss of muscle mass and muscle strength. It is associated with the natural ageing process, as well as geriatric medical conditions and bed rest. Consequently, it is very beneficial from a medical point of view to periodically monitor patients at risk of developing sarcopenia to early detect its onset or progression through objective and specific indicators. In the last years, surface electromyography (sEMG) increasingly plays an important role for prevention, diagnosis, and rehabilitation in this research area. Moreover, the recent progresses in EMG technologies have allowed for the development of low invasive and reliable smart EMG-based wearable device. The paper presents the design and implementation of an integrated platform that includes a sEMG based wearable device and interfacing with a processing software for clinical monitoring and management of the pathology. The system has been designed to both preventive (early diagnosis) and monitoring purposes of the patient's condition over time. Here, we present a preliminary study on the feasibility of the developed platform for management of sarcopenia. Specifically, this work deals with the identification of the best trade-off between sampling frequency of the EMG signals and variance of the highly discriminative features extracted within the EMG signals for the automatic measurement of sarcopenia.**

Keywords- wearable device; EMG; Sarcopenia; Ambient Assisted Living; Ageing Adults.

I. INTRODUCTION AND RELATED WORKS

A serious change associated with aging is the progressive decline in muscle mass, a downward spiral that can lead to reduced strength and function. In 1989, Rosenberg proposed the term 'sarcopenia' to describe this age-related reduction in muscle mass [1]. Although sarcopenia is primarily a disease of the ageing adults, its development may be associated with conditions that are not exclusively seen in older persons, but it can also be seen in younger patients, such as those with inflammatory diseases [2]. In sarcopenia, the loss of muscle mass and the consequent loss of strength are also accompanied by a decreased function of the muscles. In general, sarcopenia produces a deterioration in physical functions and means postural instability, alterations of thermoregulation (increased mortality in summer or in extreme winter), worse bone trophism (lack of stimulation of contraction), modification of glucose homeostasis (lack of storage and consumption) and reduction of basal energy production. With the passing of the years of life of a standard subject, the loss of muscle mass progresses in step with the loss of muscle strength, which can be of the same proportions or even greater. By age 50, many people have already lost around 10% of their muscle mass and by age 70 they will have lost around 70%.

Generally, sarcopenia is very difficult to treat because it is not easy to evaluate the temporal trend of its three fundamental components, which are: 1) muscle strength, 2) muscle mass, 3) physical performance such as walking speed. In the current state of the art, the three components mentioned above are evaluated with different non-invasive gold standard techniques, such as Computed Tomography (CT), Dual energy X-ray Absorptiometry (DXA) or Magnetic resonance Imaging (MRI) [3][4]. But all the aforementioned exams are rarely used in practice due to lack of portability and high equipment costs. Moreover, their use requires highly trained medical personnel.

In the last years, smart technologies such as wearable devices, mobile apps and embedded systems are frequently discussed in the healthcare field and without doubt the use of enabling hardware and software technologies will play a crucial role in the creation of innovative and unobtrusive Ambient Assisted Living (AAL) systems that can support for early diagnosis and monitoring of patients affected by sarcopenia. Surface EMG (sEMG) is an important non-invasive measurement for monitoring muscle fatigue among the physiological measurement systems. EMG signals are the electrical activity produced by the muscle's motor units during their contractions. The sEMG measurement method is safer and less invasive than the intramuscular technique and it presents good performance in the muscle action potentials monitoring. It uses noninvasive, skin surface electrodes, realized with pre-gelled, textile or hydrogel materials, located near the muscles of interest [5]. Several works in literature have focused the attention on the use of the EMG signals in medical context [6]. For example, in [7][8] different applications of EMG-driven muscle models for determining muscle forces in the ankle, knee, back, and upper limb, for normal and pathological conditions were described. In [9] the authors developed an EMG patch, which could be worn on the lower leg, the gastrocnemius muscle, to detect real-time muscle fatigue while exercising. Kuthe et al. [10] quantified muscle strength based on force generated by the muscle during isometric contraction and the muscle fatigue using sEMG. Yu et al. [11] developed a wireless medical sensor measurement system, inclusive of EMG, motion detection, and muscle strength, to detect fatigue in multiple sclerosis patients.

As highlighted by the brief state of the art introduced, sEMG is widely used for the analysis of specific pathologies but very few works in literature have focused their attention on the use of sEMG for monitoring/evaluating sarcopenia.

Consequently, the aim of the proposed work is to develop a novel platform that integrates smart sEMG technology and a software to provide a decision support tool to healthcare personnel. The platform has been included in a first validation in a research laboratory aimed to demonstrate the sensors performance and the system effectiveness.

The paper is structured as follows. Section II describes materials and methods that have been used in this study, providing an overview of the system architecture, and detailing the algorithmic steps of the proposed pipeline. Section III presents some experiments carried out to evaluate the best trade-off between sampling frequency of the acquired signals and variance of the obtained feature values. Finally, section IV draws some conclusions and final remarks.

II. MATERIAL AND METHODS

The overall system is compound of two main components, a hardware device capable of detecting all sarcopenia-related parameters and a software component capable of processing the data coming from the hardware component (sEMG), storing them, and making them available to the end user.

To acquire data, the sEMG sensors were located on the Gastrocnemius Lateralis and Tibilias Anterior muscles. They were placed along the approximated direction of muscle fibers, with the inter electrode distance of about 20mm to obtain the maximal surface EMG amplitude. The electrodes for Tibialis muscles were applied at about 1/3 of the distance between the tip of the fibula and the tip of the medial malleolus. As for Gastrocnemius, the electrodes were placed at about 1/3 of the line head of fibula on the most prominent bulge of the muscle. To increase the stability of the probes and to reduce the movement artifacts, each sensor was held in place by an elastic band. A representation of the proposed EMG-based platform for the measurement and management of Sarcopenia is shown in Figure 1.

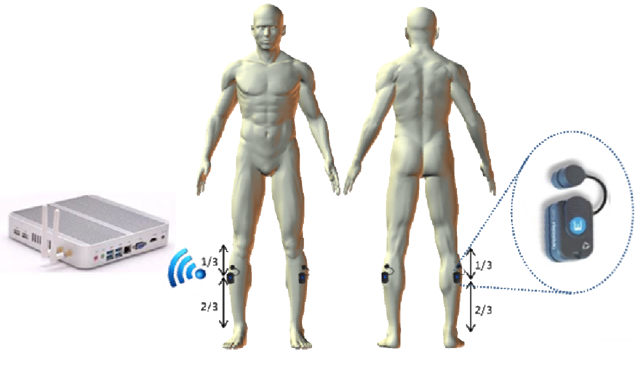


Figure 1. Overview of the proposed EMG-based platform for the measurement and management of sarcopenia.

The hardware setup has been developed by using the wearable sEMG system FREEEMG1000, produced by the BTS Bioengineering [12].

The system is made up of a USB receiver and up to 10 wireless EMG probes. The considered sensors are minimally invasive: no wire is used, dimensions are 41.5 × 24.8 × 14 mm, and the weight is about 10 gr. They are attached to the common pre-gelled electrodes by using clips, allowing a fast, simple, and robust mounting for the user's movements at the highest level of usability.

The probes integrate the active electrodes, which reduce the noise and an on-board solid-state buffer memory system, which guarantees the data safety in case of signal loss during the acquisition. The range of the wireless data transmission is about 20 meters in free space, according to the IEEE802.15.4 protocol. It is possible to acquire the data for more than 8 hours in streaming mode, through the rechargeable lithium-ion integrated batteries. The sampling rate of up to 1000 Hz and the 16-bit resolution permits a high degree of accuracy.

The real-time application has been realized using Microsoft C# language (Figure 2). In the design of the interface, it was considered that it can be used by medical operators and consequently it is as user friendly as possible. The main functions offered are: 1) display of the connection status of the probes (and relative battery life), 2) entry of the end-user fiscal code in order to associate the acquisition session with the user, 3) setting, pairing of the probes, 4) graphic display of the trend of the raw signals 5) start and stop of acquisition for any sub-sessions, 6) buttons for feature processing and possible sending of data (structured via REST/JSON messages) to external processes.

Port: COM3

☑ Disable Calibration

Figure 2. Interface of the software developed for the acquisition of raw EMG signals, data elaboration and sending to external processes.

The algorithmic framework for the acquisition and elaboration of the EMG signals is on an embedded PC, which receives the data through the compact (dimensions 82 × 44 × 22.5 mm, weight 80gr), wireless and USB interfaced receiver. The evaluation of muscle strength from a raw EMG signal generally follows three basic procedures: (1) continuous sample acquisition; (2) signal pre-processing, (e.g., filtering and/or normalization); (3) feature extraction, i.e., selection of relevant parameters for the specific application context. Some details of the implemented algorithmic pipeline (Figure 3) are reported in the next subsections.

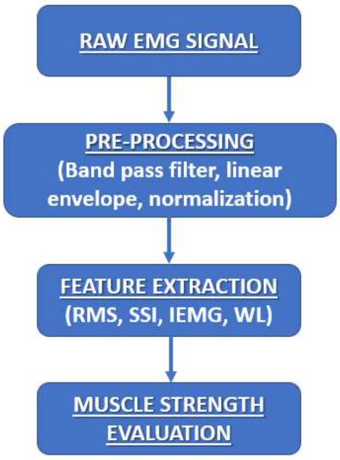
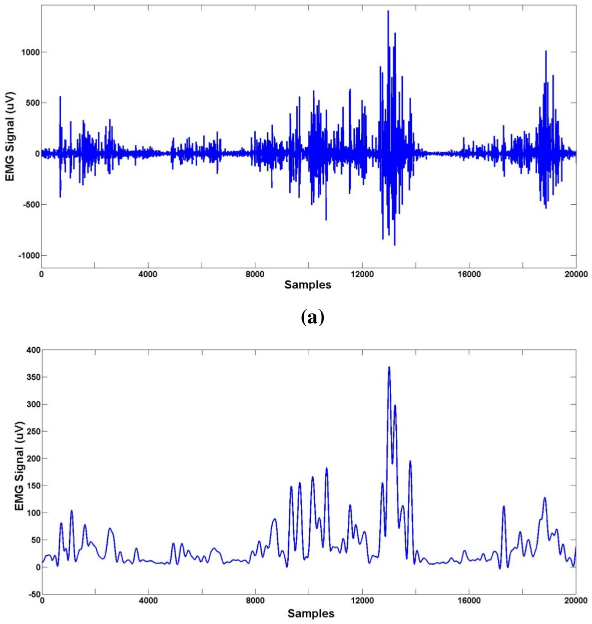


Figure 3. Representation with a logical block of the implemented pipeline for measurement and management of sarcopenia.

A. *Pre-processing*

The raw EMG signal acquired from each probe is subject to a pre-processing algorithmic stage to reduce the disturbances caused by movement artifacts and environment noise. In the present work this is achieved through the application of a bandpass filter within a frequency range of 20–450 Hz. Moreover, for EMG-tension comparison, the signals are processed by generating their full wave rectification and their linear envelope [13]. This was carried out with the use of 10th order low-pass Butterworth filter, with a cut-off frequency of 10 Hz. An example of sEMG signal emitted from a single probe (a) before and (b) after the pre-processing step is depicted in Figure 4.



(a)

(b)

Figure 4. (a) An example of raw EMG signal. (b) EMG signal after pre-processing step.

Before the evaluation of muscle strength, to increase the objectivity of data due to differences in individual muscle strength of the study subjects, a normalization stage is necessary with the purpose to evaluate the baseline of the signals. The normalization is performed in 3 phases. First, the subject is required to remain in an idle condition for a period of 5 seconds and during this temporal window the baseline of the sEMG signals for each probe is measured using the mean of the data acquired. Next, the subject executes the ankle plantar flexion against a fixed resistance and holds it constant for 5 seconds to obtain the highest possible sEMG signal resulting from Gastrocnemius Lateralis muscles contraction. The values of Maximum Voluntary isometric Contraction (MVC) [14] are calculated taking the mean amplitude of the highest signal portion of the data acquired. Finally, the subject executes the ankle dorsi flexion against a fixed resistance and holds it constant for 5 seconds to obtain the highest possible sEMG signal resulting from Tibialis Anterior muscles contraction. Even in this case the values of MVC are calculated employing the mean.

B. *Feature extracion*

To evaluate muscle strength, attention was focused on several low computational cost features, commonly used in the analysis of the lower-limb muscle activity. Usually, the analysis of EMG signals can be investigated in two ways based on the time domain and frequency domain characteristics [15].

In the present work, the following low-cost time-domain features were computed and tested for each probe: Root Mean Square (RMS), Simple Squared Integral (SSI), Integrated EMG (IEMG), and Waveform Length (WL). The features were evaluated through the following mathematical equations:

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} EMG_i^2}{N}} \tag{1}$$

$$SSI = \sum_{i=1}^{N} |EMG_i|^2 \tag{2}$$

$$IEMG = \sum_{i=1}^{N} |EMG_i| \tag{3}$$

$$WL = \sum_{i=1}^{N-1} |EMG_{i+1} - EMG_i| \tag{4}$$

The RMS value has been used to quantify the electric signal because it reflects the physiological activity in the motor unit during contraction. SSI expresses the energy of the EMG signal. IEMG is generally used as a pre-activation index for muscle activity. It is the area under the curve of the rectified EMG signal. Finally, WL is the cumulative length of the waveform over the segment. The resultant values of the WL calculation indicate a measure of the waveform amplitude, frequency, and duration [15].

III. RESULTS

The hw/sw platform described in Section II has been implemented within the SIMMS project (Sarcopenia Integrated Measurement and Management System), whose purpose is to develop an integrated technological system, consisting of measuring devices, including mobile and wearable devices, which interface with a software system for data collection and processing, clinical monitoring, and management of sarcopenia. Due to COVID-19, the trial was started with considerable delay, consequently at the time of writing this document the results obtained on samples of patients monitored directly in hospitals are not yet available.

However, to validate the platform primarily in controlled contexts, experiments were carried out within the laboratory used as a "smart home", located inside the Institute for Microelectronics and Microsystems (IMM) in Lecce. A total of fifteen participants, six young (mean age of 34.8 years), five middle-aged (mean age of 53.1 years) and four older (mean age of 68.7 years) women and men participated in this study after providing voluntary consent. Table 1 presents the total number of participants in the preliminary experimentation, broken down by age group and gender:

TABLE I. TOTAL NUMBER OF SUBJECTS INVOLVED IN THE EXPERIMENTATION BROKEN DOWN BY AGE GROUP AND GENDER

Gender	Age (years)			
	(29-47)	(48-64)	(> 65)	Total (29-73)
Male	4	3	2	9
Female	2	2	2	6
Total	6	5	4	15

The study involved data analysis during the execution of two different tests: 1) the walking test and the 2) sit-to-stand test. The walking test consisted of the subject being monitored in the execution of a 5-meter journey, whereas sit-to-stand (Figure 5) is commonly used in clinical context for evaluating lower limb muscle function [16].

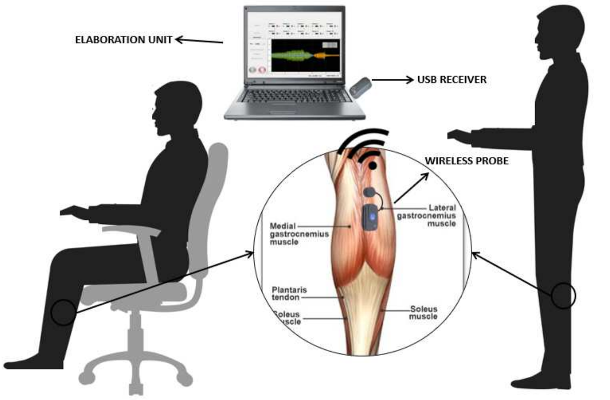


Figure 5. Sit-to-stand test setup.

The objective of the first experiment was to evaluate the mean and variance of the features introduced in the previous section by acquiring the EMG signal with different sample rates. Tables 2 and 3 report the mean and variance of the feature values for each test required by the experimental protocol, and considering 250Hz, 500Hz and 1000Hz as sampling rate of the raw EMG signal.

TABLE II. MEAN AND VARIANCE OF THE FEATURE AT VARYING OF SAMPLE RATE DURING THE EXECUTION OF WALKING TEST

Sampling	Feature			
Rate	RMS	SSI	IEMG	WL
250Hz	0.36 (0.07)	13.01 (3.88)	36.05 (5.23)	.12 (0.06)
500Hz	0.56 (0.04)	31.57 (2.90)	56.18 (2.52)	.26 (0.03)
1000Hz	0.58 (0.03)	35.33 (2.78)	59.43 (2.38)	.28 (0.02)

TABLE III. MEAN AND VARIANCE OF THE FEATURE AT VARYING OF SAMPLE RATE DURING THE EXECUTION OF SIT-TO-STAND TEST

Sampling	Feature			
Rate	RMS	SSI	IEMG	WL
250Hz	0.87 (0.11)	22.09 (5.78)	52.18 (6.55)	.86 (0.10)
500Hz	1.16 (0.07)	43.12 (4.19)	71.34 (4.11)	.33 (0.08)
1000Hz	1.19 (0.05)	49.19 (3.53)	76.21 (3.78)	.47 (0.05)

The two previous tables show how the absolute values of the features have a limited variation when the sample rate is halved from 1000Hz to 500Hz while there is a fairly evident variation when the raw EMG signal is sampled at 250Hz, and this is true for each considered feature and for each of the two tests performed by the subjects involved in the experimentation.

The second experiment aimed to evaluate the time interval required to extract the features with different sample rate and as the duration of the exercise changes. Tab. 4 reports the average processing time of the features extracted during the walking test by varying the duration of this test in the time interval 30 seconds - 2 minutes. This assessment was not necessary for the sit-to-stand test due to its limited time duration.

TABLE IV. PROCESSING TIME (EXPRESSED IN SECONDS) FOR THE FEATURE EXTRACTION AT VARYING OF WALKING TEST DURATION

Sampling	Walking test duration			
Rate	30 sec	60 sec	90 sec	20 sec
250Hz	0.848 s	1.345 s	1.786 s	.124 s
500Hz	1.112 s	1.732 s	2.203 s	.568 s
1000Hz	1.121 s	1.918 s	2.413 s	.834 s

From the analysis of the data reported in the previous table, the variations in computational times are negligible. Consequently, to obtain the best trade-off between accuracy in the evaluation of the features and computational cost, the sample rate was set to 500Hz for the subsequent validation in the clinical context.

A. Clinical protocol for validation

Due to the COVID-19 emergency, the initial 6-month test phase was reduced to approximately 2 months and will be performed at Casa Sollievo della Sofferenza Hospital in San Giovanni Rotondo (Lecce, Italy) on a randomized cohort of 100 patients aged ≥ 65 years and at risk or suffering from sarcopenia (i.e., ADL ≥ 4 and SARC-F ≥ 4), either admitted to the Geriatrics Operational Unit or evaluated at the Geriatrics clinic. The study will focus on the assessment of sarcopenia and will be carried out according to the EWGSOP2 guidelines [17] in which muscle strength, muscle mass and functional status will be determined. For the evaluation of muscle strength, the EMG platform described in this paper will be used. Moreover, the total body Skeletal Muscle Mass (SMM) and the Appendicular Skeletal muscle Mass (ASM) will be determined during the clinical trial and their values will then be corrected for BMI. All data will be recorded and subsequently entered in a digital platform through a mobile app carried out within the same project by a private partner.

IV. CONCLUSION

The sEMG platform described in this work was developed within a larger research project (SIMMS project) that is referred to the development of an integrated technological system, consisting of measuring devices, including mobile and wearable devices, interfacing with a data collection and processing software system, that can be used for early diagnosis and monitoring of sarcopenic patients.

All the devices included in the technological system can evaluate sarcopenia-related parameters through the use of wearable devices. Specifically, the implemented sEMG platform was designed and developed to provide doctors or caregivers with a decision support tool to evaluate in an innovative way the temporal evolution of sarcopenia. Another added value of the platform is that all collected information can be sent to a software platform through an app developed on smartphones for patients, caregivers or doctors and can be consulted by medical personnel through a web application for diagnosis and interventions.

As future work, regarding the EMG data, correlation will be extrapolated and statistical analyzes will be carried out on time series of the extracted features with the aim to implement an intelligent and automatic tool for early diagnosis of the considered pathology.

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E-textiles the Need to Breath: A Novel Manufacturing Process and Textile for Lightweight Transparent Sustainable E-textiles and Wearables

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Abstract—**The adoption and growth of e-textiles and wearables is largely reliant on how discreetly electrical devices can be applied without limiting functionality and compromising textile qualities. Electrical components are an important parameter for a variety of applications where devices are required to be in close proximity to the skin. One example is within the health and leisure industry, where sensors are used for monitoring and tracking bodily functions. Historically, electronics were aesthetically intrusive when applied to textiles, although, by becoming smaller and flexible this is less of an issue. A method to compliment those advancements further would be to incorporate small electrical components into a complimentary, open structured, lightweight, transparent textile. This would provide increased breathability and reduce fabric weight, resulting in more comfort for the user. This paper introduces a novel manufacturing process that accommodates these features. A process whereby fabrication is achieved through entangling the fibres on the surface of yarn. Observation is used to assess the level of fabric openness in relation to air permeable capacity, transparency and end weight. Quantitative methods were used via tensile testing to establish if textiles manufactured by the novel process met industry strength requirements. Eight samples were tested in total, each showed slight variations in results. For example, two samples tested in the weft direction showed a difference of 40% strain capacity. It was assumed the irregularity was the result of differing quantities of fibre on the yarn surface used for entanglement. However, all eight samples that underwent tensile tests were confirmed to meet the British Test Standard ISO 2062.**

Keywords-Wearables; Transparent e-textiles; breathability; Sustainable e-textiles; Novel textile manufacturing process; Lightweight e-textiles; electronic textiles; textile innovation

I. INTRODUCTION

Textiles are one of mankind's most used products. The earliest references to textiles come 27000 years ago in the form of impressions on pottery of yarn [5]. The earliest woven material was found in southern Turkey in Cayonu and is dated at 7000 BCE [2]. The earliest known examples of knitting have been found in Egypt and dates between the 11th and 14th century CE [6]. The knitting process involves the interlooping of a single yarn and the weave process involves the interlacing of at least two yarns [4]. Nonwoven fabrics are created from fibre webs that have not been spun into yarn [9]. Continuous agitation and pressing results in the hooking together of the fibre creating a uniform piece of nonwoven fabric [2]. Despite the multidisciplinary nature of electronic textiles and the market predicted to 'approach $5 bn by 2027' [3], the process for manufacturing e-textiles and wearables is limited to the three ancient practices. Wearable technology is a growing field. This can be credited to the decrease in size of electrical components and changes in people's attitudes toward personal electronics [8]. This further supports the need for additional textile manufacturing technology with the capacity to support the trend of electronics miniaturization.

The structure of this paper consists of the following: Section 2 provides the objectives of the research. Commencing by giving clarity to how the new process differs from known textile manufacturing. Methods is then presented in section 3, and this section identifies the methodology, machinery and materials used in this investigation. In section 4, the procedure, testbed, challengers and failures are discussed. Focus is given to revealing how the new process lends itself to particular aspects of current manufacturing practices, also, production challengers are addressed. Section 5 presents the results from the quantitative data collected. This information was derived from tensile tests obtained from eight samples manufactured by the new process. In section 6, there is discussion on fabrics created by the novel process. Particular attention is set around the capabilities and benefits that the new structure offers. This discussion is followed by the conclusion, section 7. Presented, is a summary of the functions, potential of the novel process and products created. Lastly, this section concludes by identifying industry sectors who would find value from the new method and materials.

Figure 1. Microscopic image of the novel textile.

II. OBJECTIVES

This paper presents a novel manufacturing process and textile that is created by yarn that requires neither interlinking or interlooping as in the woven and knitting structure. Therefore, providing a textile surface more suitable for the inclusion of electronics. The differing properties of electronics and textiles such as durability (bend, stretch, twist and shear) is a concern for e-textile development [1]. The new manufacturing process removes the necessity to bend the e-yarn or filament, totally removing interloping and interlacing, which have proven problematic during the production of E-textiles and wearables. In contrast, the new textile manufactures a fabric with a linear structure allowing individual yarn strands to be fully visible, as in Figure 1. Thus, allowing a straight surface for electrical components to easily and discreetly be attached or embedded, as in Figure 4.

FOYSE® is the name given to the novel manufacturing process. The word FOYSE is derived from the acronym: Fibre On Yarn Surface Entanglement. Two fabric structures have been manufactured using the FOYSE process to demonstrate design capability named Zephlinear® and Hover-Tex™. The name Zephlinear is derived from two words Zephyr and Linear and applied when the FOYSE process is used to manufacture a textile with one layer of yarn as in Figure 1 and 2.

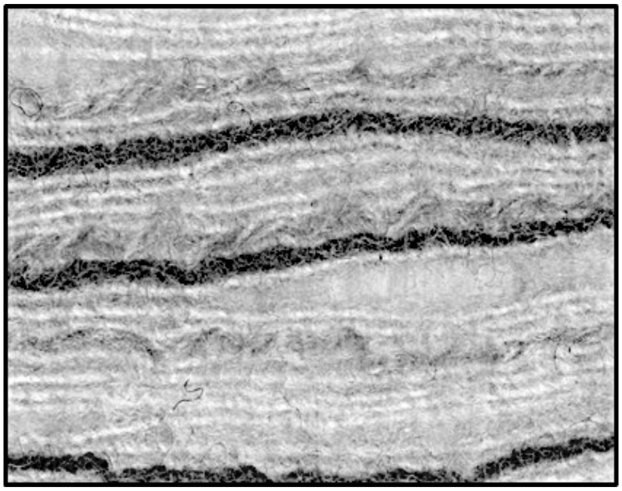

Figure 2. S. M. Reynolds, *Zephlinear Single Layer Stripes Multi Yarn Count (ZL047)*, Pennsylvania: University of Pennsylvania Fisher Fine Arts Library Material Collection.

Hover-Tex is applied when the FOYSE process is used to create a minimum of two-layers of yarn, giving the appearance of the second layer of yarn to hover over the first. The layering method provides space for the embedding of additional elements such as yarns or filaments as in Figure 3 and Figure 4. Hover-Tex is constructed by laying out one layer of parallel array of yarn and then a second layer placed at a 90-degree angle to the first. It is important to note that the process is not limited to create fabrics with a linear appearance, but yarn colour and positioning can be used to create a preferred end appearance or function. The fabric surface Hover-Tex is the material that will undergo mechanical testing and be discussed in this paper.

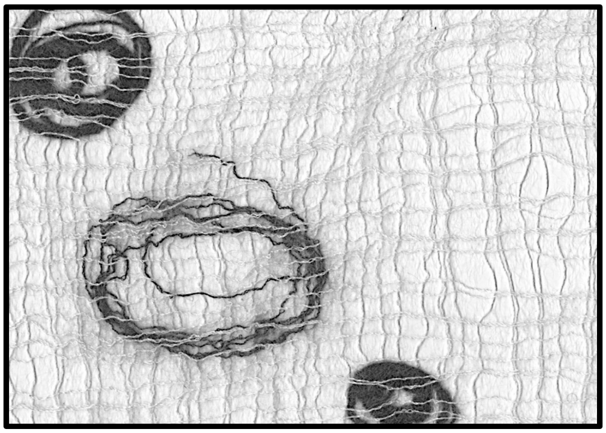

Figure 3. S. M. Reynolds, *Zephlinear Swirls Within Open Net (ZL044)*, Pennsylvania: University of Pennsylvania Fisher Fine Arts Library Material Collection.

III. METHODS

Quantitative data was collected via tensile tests on eight Hover-Tex fabric samples. This data collection method is an established process to measure the breaking point of a textile material. By doing this, fabric strength is also determined. In addition, results provide numeric data that can be interpreted into several forms. Tensile tests were utilized as they are a proven method for evaluating the development of new materials while providing valuable information about a fabric and its associated properties. The sample in Figure 4 and 5 are manufactured using three layers of yarn. A first and third layer of yarn, 70% mohair and 30% silk, and the second layer of yarn, 100% merino wool twisted with fine copper wire containing a programable LED. The Hover-Tex fabric was divided into eight equal parts for tensile testing. Four samples in the warp direction and four in the weft direction to obtain breaking points and elongation measurement, which are illustrated in Figure 6 and 7. Visual observation was conducted with the LED switched on and off to demonstrate level of transparency and discreet embedding.

IV. PROCEEDURE, CHALLENGES AND FAILURES

FOYSE manufacture is a semi-automated process that utilizes a hybrid approach, composed of adopting elements of the three current textile production methods. Laying out of a parallel array of yarn as in the woven process. The use of a single feed, or multiples thereof, to carry yarn similar to the knitting process. The entanglement of fibres via a wetting and drying of fibre as in the nonwoven process, albeit unlike nonwoven, this takes place after fibre has been spun into yarn. Yarn with high surface hairiness proved suitable for surface fibre entanglement. Yarns with minimal surface hairiness underwent an uncurling process via a brushing system to increase the capacity of surface fibre for entanglement. An Olympus Digital Microscope was used as a testbed to observe samples created by FOYSE. A Z2.5 Zwick/Roell tensile testing machine was used as a testbed for mechanical testing of FOYSE manufactured fabrics resistance against force. Optical microscopy, image analysis and tensile tests were conducted to investigate an assumed correlation between yarn surface entangled fibre, open areas and material strength. The research produced multiple challenges and failures, namely, methods to ensure fibre entanglement was limited to the fibre on the yarn surface. Identifying a method to regulate yarn position during entanglement is a present challenge as some yarns shift during the wetting and drying process. This results in yarns curving slightly which create fabrics with a wavy appearance.

V. RESULTS

Eight samples in total underwent tensile testing, four in the warp and four in the weft direction. The results from the first cycle of four Hover-Tex samples to be tested are presented in Figure 6 and 7. The warp of the Hover-Tex sample was constructed from mohair and silk mix yarn. The result stress-strain curve deviates from proportionality abruptly. This occurred as the yarn snapped due to pressure applied by the tensile testing machine. This resulted in changes at a peak point producing a zig zag visual appearance on the stress curve shown in Figure 6. The large open space per Hover-Tex sample also contributed to the sharp changes. In addition, the tight spinning of the mohair and silk yarn would contribute to the harsh change in the curves. The abrupt snapping of the yarn occurs at breaking point when the samples cannot withstand the stress applied, such as the nature of the tensile testing. The curves W2 and W4 exhibit breaking points 50% earlier than W1 and W3. This can be attributed to the samples having fewer yarns in the weft which can occur during the current manufacturing process. The results from the second cycle of four Hover-Tex samples to be tested are presented in Figure 7. The weft of the Hover-Tex samples is constructed from merino wool yarn. The stress curves on the graph presents a steady decline of each of the four curves in contrast to the snapping action portrayed in the samples in the warp direction. This illustrates that, although the merino yarn had less stress resistance, it provided almost 50% extra elongation capacity. Weft samples W2 and W4 showed a difference of 40% strain capacity. This is contributed to the slight variation in the length of fibre used to manufacture the yarn during the spinning process, in addition, the irregularity in which the fibre on the surface of the yarn entangles. Results confirmed that all samples have resistance strength suitable for textile material according to British Test Standard ISO 2062.

VI. DISCUSSION

Hover-Tex fabrics provide a structure with a unique linear appearance. In addition, they provide channels that offer an uncomplicated method for seamless insertion of electronic devices. The FOYSE process of manufacturing textiles, including adding yarn layer upon layer, provides benefits unachievable by woven and knitting technology. The removal of interlacing and interloping provides space between the layers of yarn to embed large or irregular shaped non-textile components. Incorporating different types of yarn elements and embellishments can dramatically alter the fabrics' unique appearance and character. Assembling the fabric with thick and thin yarns, or coloured yarn can create artistic designs that enhance visual appeal. The new textile can potentially weigh 70% less than traditional fabrics due to large open areas and air circulating the raised fibres on the yarn surface. This provides superior breathability, which in turn, enhances skin comfort as textiles are often used to regulate temperature, moisture levels and airflow.

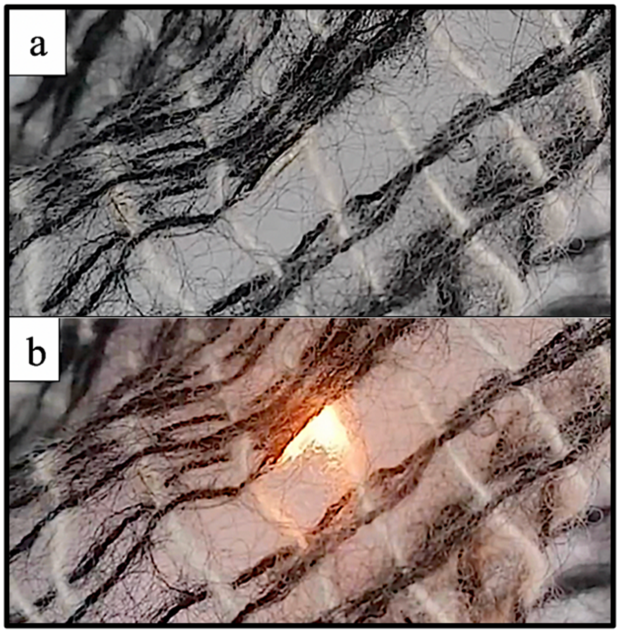

Figure 4. A 3mm light-emitting semiconductor device (a) switched off (b) switched on, embedded with Hover-Tex.

Control of airflow in woven and knit structures have been obtained by tightening or loosening the tension in the warp and weft to open up a gap in the fabric. However, this creates a fabric prone to movement, as within the woven and knitting process, the tightness of the interlacing or interloping contributes to the rigidness of the fabric. FOYSE fabrics provide options for increasing or decreasing insulation to regulate heat or cool, without loosening the fabric structure. This is due to the entangled fibre on yarn surface that sets the yarns in place. The level of fibre entanglement on the surface of yarn is only visible via observation through a microscope.

In Figure 5, the black fine yarn appears to rest or hover above the white yarn. Therefore, fabric manufactured by the FOYSE process can appear fragile and unrealistic for textile use. However, tensile test results shown in Figure 6 and 7 contradict the fragile visual appearance. The size of the open sections can be large yet have no bearing on moveability of the yarns once the fabrics manufactured by the FOYSE process have been finished. This is due to the fabric strength lays within the actual yarn or entangled fibres on the yarn.

Figure 5. Hover-Tex 2sq m sample with a 3mm programmable light-emitting semiconductor device switched on. Coin battery holder and circuit to power and control embedded device.

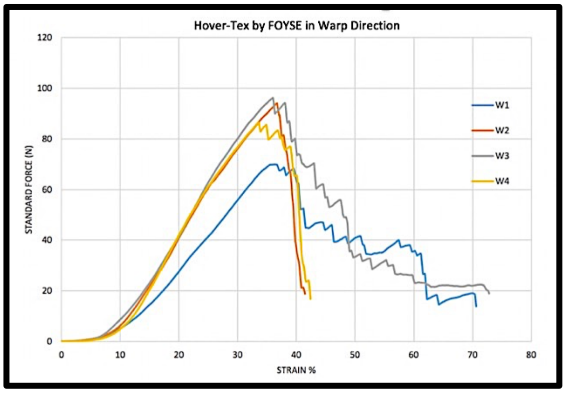

Figure 6. Results from the four Hover-Tex samples in the warp direction.

It is important to note, the yarns used to manufacture the Hover-Tex samples discussed in this paper are commercially available. Therefore, it is recognised that strength tests are conducted to confirm the yarn adequacy for constructing a textile. The FOYSE manufacturing process did not degrade the yarn structure based on the microscopic observation and tensile test results which are presented in Figure 6 and 7.

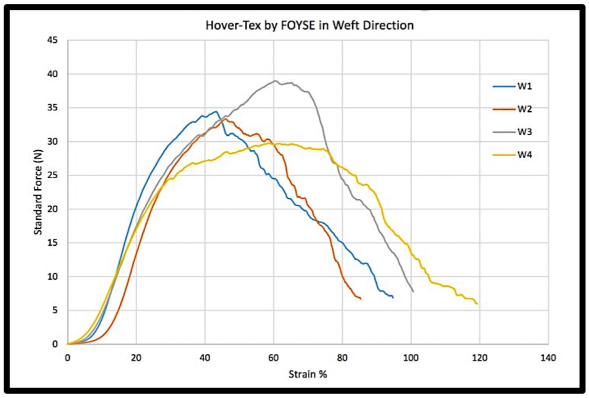

Figure 7. Results from the four Hover-Tex samples in the weft direction.

VII. CONCLUSION

The FOYSE manufacturing process allows textile structures to be produced with large open areas for increased breathability, transparency and lightweight fabric surfaces. In addition, the process provides multiple opportunities for seamless and uncomplicated integration of a variety of elements used to create e-textiles. This can be achieved by using the FOYSE process to create fabrics that embed electronics within the yarn, yarn twisted with conductive filaments or embedding components within the actual layers of entangled fibres. Moreover, the FOYSE process has successfully created and characterized fabrics using 100% natural fibres, supporting the demand for sustainable textiles. Furthermore, data from mechanical testing confirms fabrics created by FOYSE have strength sufficient for industry standards. Therefore, the FOYSE manufacturing process and textiles created by FOYSE will be of interest to the textile innovation sector and to the e-textile and wearables industry.

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