MIPHAS:
Military Performances and Health Analysis System

Gennaro Laudato[1], Giovanni Rosa[1], Simone Scalabrino[1,2], Jonathan Simeone[2], Francesco Picariello[3], Ioan Tudosa[3], Luca De Vito[3], Franco Boldi[4], Paolo Torchitti[4], Riccardo Ceccarelli[5], Fabrizio Picariello[6], Luca Torricelli[6], Aldo Lazich[7], Rocco Oliveto[1,2]

[1]*STAKE Lab – University of Molise, Pesche (IS), Italy*

[2]*datasound srl, Pesche (IS), Italy*

[3]*LESIM lab, University of Sannio, Italy*

[4]*XEOS., Roncadelle (BS), Italy*

[5]*Formula Medicine, Viareggio (LU), Italy*

[6]*TexTech Technologies, Reggio Emilia (RE), Italy*

[7]*Ministero della Difesa, Roma (RM), Italy*

{gennaro.laudato, simone.scalabrino, rocco.oliveto}@unimol.it, g.rosa1@studenti.unimol.it, jonathan@datasound.it {fpicariello, ioan.tudosa, devito}@unisannio.it, {f.picariello, l.torricelli}@textechtechnologies.com, {franco.boldi, paolo.torchtti}@xeos.it, riccardo.ceccarelli@formulamedicine.com, aldo.lazich@marina.difesa.it

Keywords: Wearable Devices, Machine Learning, Healthcare, Decision Support System.

Abstract: In the last few years wearable devices are becoming always more important. Their usefulness mainly lies in the continuous monitoring of vital parameters and signals, such as electrocardiogram. However, such a monitoring results in an enormous amount of data which cannot be precisely analyzed manually. This recalls the need of approaches and tools for the automatic analysis of acquired data. In this paper we present MIPHAS, a software system devised to meet this need in a well-defined context: the monitoring of athletes during sport activities. MIPHAS is a system composed of several components: a smart t-shirt, an electronic component, a web application, a mobile APP and an advanced decision support system based on machine learning techniques. This latter is the core component of MIPHAS dedicated to the automatic detection of potential anomalies during the monitoring of vital parameters.

1 INTRODUCTION

Wearables that are able to monitor health parameters, such as electrocardiogram (ECG), are among the technologies that are going to change the world we live in. That was stated by Microsoft co-founder and billionaire Bill Gates at the 18th edition of the MIT Technology Review's annual roundup[1]. This feeling is supported also from the scientific literature that clearly shows an exponential trend in the number of publications per year with titles including wearable electronics (Khan et al., 2019). In the recent years the research community has devoted a lot of effort to the field of wearable technologies for the healthcare. Park et al. (2002) presented the "Georgia Tech Wearable Motherboard (GTWM)", which provides a versatile framework for the incorporation of sensing, monitoring and information processing devices. It involves the use of optical fibers and special sensors. The data bus integrated into the structure transmits the vital signs information to the monitoring devices such as an ECG Machine, a temperature recorder, a voice recorder, etc. Paradiso et al. (2005) designed WEALTHY, a system where breathing pattern, electrocardiogram, electromyogram, activity pattern or behavior, temperature can be listed as physiological variables to be monitored. The system is based on a wearable interface implemented by integrating fabric sensors, signal processing techniques and telecommunication systems, on a textile platform. Curone et al. (2010) devised a prototype system, based on a smart garment, which enables the detection of health-state signs of the users (heart rate, breathing rate, body temperature, blood oxygen saturation, position, ac-

[1]`https://cnb.cx/2XxF9XZ`

tivity, and posture) and environmental variables (external temperature, presence of toxic gases, and heat flux passing through the garments),to process data and remotely transmit useful information to the operation manager. Villar et al. (2015) introduced Hexoskin[2], a line of cutting-edge smart clothing that include body sensors into garments for health monitoring. Hexoskin monitors (i) ECG, and derived features such as: Heart Rate Variability (HRV), QRS events, and Heart Rate Recovery, (ii) Breathing Rate and Minute Ventilation (L/min), (iii) activity intensity, peak acceleration, steps, cadence, positions and (iv) sleep activity. Balestrieri et al. (2019) recently introduced ATTICUS, an Internet of Medical Things (IoMT) system for implementing personalized health services through the monitoring of ECG, respiration rate measurement, galvanic skin response estimation, skin temperature measurements, and activity classification and monitoring. Matias et al. (2018) presents a bracelet able to perform health abnormalities detection based on both vital signs, and accelerometer data collection from the user.

All such systems are designed to work in the health monitoring scenario, where physicians can remotely assist patients. However, monitoring vital signs would be greatly beneficial also when practicing sports. Indeed, many health problems can arise when a person is under specific stressful situations, such as running. Moreover, personal trainers could use the information acquired through a continuous monitoring of vital signs to keep track of the improvements of the athlete.

In this paper, we introduce MIPHAS (Military Performances and Health Analysis System), a hardware/software system able to detect and analyze the vital signs of an individual through the use of wearable systems when practicing sports. The novelty of the MiPHAS system lies in the ability to (i) adapt to the real conditions of the person, modifying the monitoring activity; (ii) analyze the data collected through the use of automatic learning techniques in order to suggest anomalous and/or critical situations both in the vital signs or in the performance of the athlete.

The remainder of the paper is organized as follows. In Section 2 we provide an overview of MIPHAS, while in Section 3 we describe in details the core component of MIPHAS, *i.e.,* the decision support system. Finally, in Section 4 we conclude the paper and outline directions for future works.

[2]https://www.hexoskin.com/

2 MIPHAS OVERVIEW

The MiPHAS project provides the monitoring of the electrical activity of the heart, respiratory activity, temperature and user “dynamics”, aiming at offering the following services of detection:

- **Cardiac Arrhythmia**, through an activity analysis of the electrical system of the heart, with particular focus on bradyrhythmia, tachyarrhythmia and on Atrial Fibrillation (AF). The focus on these specific kinds of disease is due to the fact that cardiovascular diseases are the leading cause of death in the world, and, in particular, atrial fibrillation is one of the most frequent types of cardiac arrhythmia (Fuster et al., 2001; Mathew et al., 2009; Petrutiu et al., 2006).
- **Heat stress and Heat stroke**, through an accurate estimate of body temperature obtained by a heat map. Exertional Heat Stroke (EHS) – a medical emergency defined as life-threatening hyperthermia with core body temperature $\geq$ 40.5°C and Central Nervous System (CNS) dysfunction (Navarro et al., 2017) – mainly affects individuals performing rigorous physical activities, such as athletes, soldiers, or laborers (Gaudio and Grissom, 2016).
- **Falls**, through the analysis of the user’s posture and movements.

MIPHAS is a project based on an innovative technology designed to monitor the vital signs of individuals during training sessions. Indeed, MIPHAS has been devised for athletes and specialized trainers, as final users of the system. The objectives of the system are therefore based on an individualistic approach (*e.g.,* personalized training strategies and techniques), thanks to the continuous and automatic analysis of the physical conditions of an athlete. The architecture turns out to be the composition of a multi-component technology, which includes:

- *a wearable sensor part*, in the form of a t-shirt equipped with innovative sensors able to detect and acquire vital signs;
- *a hardware component*, capable of transmitting the signals detected by the wearable sensors. This component is equipped with a smart hardware, which is also capable of modifying its behavior according to the needs identified by the software component;
- *a firmware and software platform*, able to analyze the vital signs detected in order to represent the health status of a person, the performance level

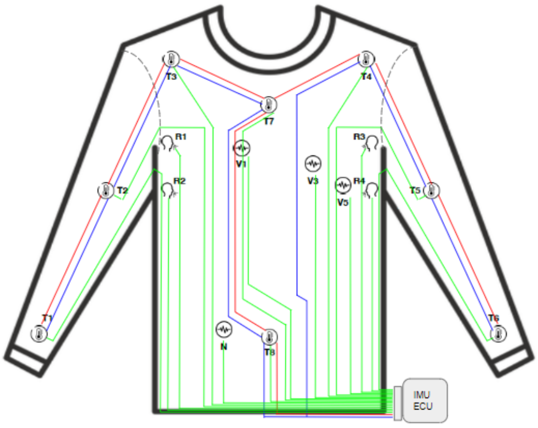

Figure 1: The MIPHAS wearable prototype with the placement of electrodes and sensors to detect vital signs. The prototype includes eight temperature sensors (from T1 to T8), four electrodes for the analysis of respiratory activity (from R1 to R4) and four electrodes for cardiac activity (from V1 to V5 and N). The IMU/central unit is inside the ECU (Electronic Control Unit) located at the height of the belt.

and any information deemed useful in order to offer significant data for monitoring the physical activity of the individual;

- *an Artificial Intelligence (AI) module*, able to analyze the data obtained from continuous monitoring and to identify any anomalies, classifying them according to their criticality level.

An overview on each component of MIPHAS will be described in the following subsections.

2.1 The wearable component

The wearable component in MIPHAS has been built to acquire (i) real-time three-leads ECG, (ii) thoracic bio-impedance, for the breath wave measurements, (iii) eight-points body temperature, and (iv) inertial data, basically used for activity recognition and fall detection. Figure 1 shows the preliminary prototype of the wearable.

The sensors positioning configuration follows these rules:

- ***Cardiac activity:*** The wearable allows the detection of the electrical activity of the heart through a three-lead ECG. The electrodes are arranged according to a typical standard Holter configuration (Dower et al., 1988), obtaining a continuous ECG relative to the precordial leads V1, V3, V5. The fourth electrode, embedded into the wearable, represents the neutral (N).
- ***Temperature acquisition:*** To obtain a complete thermal map of the upper body and maintain the non-invasive constraint, the MiPHAS system has 8 temperature sensors located in 8 distinct areas of the upper body, according to the model proposed by Wissler (1964) defined for the simulation of the human thermal system. To guarantee the non-invasive constraint, the MIPHAS system acquires the skin temperature of the individual through sensors integrated in the wearable.
- ***Respiratory activity:*** The MIPHAS system analyzes the patient's respiratory activity by measuring thoracic bio-impedance, a technique widely used for long-term monitoring. In fact, impedance pneumography (IP) signals can be used to assess respiratory variables such as volume and respiratory rate (Folke et al., 2003; Houtveen et al., 2003). Wang et al. (2014) carried out a study comparing the accuracy of the IP according to four different configurations (positioning) of the electrodes. From the comparison of the obtained IP signals it emerged that the most accurate and stable configuration appears to be the configuration shown in Figure 1, since being the electrodes far from the central area of the chest are less sensitive to the respiratory movement and are able to guarantee a better contact with the leather. Moreover, such a configuration of the electrodes is also less sensitive, compared to the others, to the assisted posture.
- ***Movement dynamics:*** The wearable is equipped with an Inertial Measurement Unit (IMU), aimed at detecting user activities and potential falls. The IMU is positioned close to the waist. Such a spot is largely considered preferable in application of automatic fall detection (Mao et al., 2017; Ranakoti et al., 2018).

The textile part of the wearable prototype shall meet key requirements. It has to be: (i) comfortable in order to fit prolonged activity intervals without affecting negatively the performances, (ii) stable when worn in order to favourite the stability of signals acquisition, (iii) customizable for different sizes as a common 'fashion' garment. To met these technical specifications we decided to adopt linear knitting techniques with three innovative yarns:

- *Bioceramic elastic yarn*: Used as a base for the wearable due to its technical characteristics, it is a decisive element for the perceived comfort of the garment. This material provides a positive side effect on peripheral circulation due to FIR (Vatansever and Hamblin, 2012) that is supposed to be part of the subjectively perceived comfort. Fur-

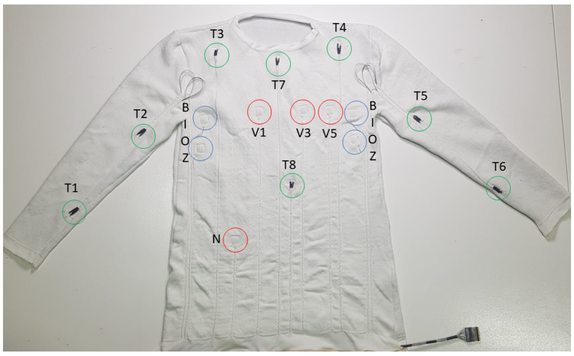

Figure 2: The MIPHAS wearable final prototype.

thermore, the material also provides the structure on which the sensors are applied and the other functional yarns incorporated;

- *High grip silicone yarn*: The highly deformable wire is used to obtain a "second skin" effect, necessary to keep the motionless sensors in their position and to minimize movement artifacts on the removal of the biomedical signal. This particular yarn considerably increases friction without elastic compression (elastic force of the thread itself). The high friction is due to the intrinsic properties implemented in the material);
- *High conductivity shielded stainless steel yarn*: For the creation of the electrical circuit, a high-performance stainless steel yarn made by capillaries coated with an insulated polymeric covering was adopted. This yarn has a high mechanical strength, good inertia to oxidizing agents and is suitable for being integrated into the wearable device as it maintains a softness that is not perceived as a foreign body. inside the garment;
- *Carbon-black based electrode*: a conductive cloth that acts as dry electrode. Considering the results obtained in the literature regarding the use of dry electrodes in electrocardiographic examinations (Chlaihawi et al., 2018; Guo et al., 2016), the electrodes must be carbon-based and each electrode must cover a surface of at least 2 cm^2.
- *IC thermal sensors*: specifically designed active sensors for superficial skin temperature estimation.

In Figure 2 is presented the first prototype of the wearable, built according to the above mentioned specifications.

2.2 The hardware component

This section contains the specifications related to the BIOX, the data acquisition board used to acquire the signals coming from the several sensors embedded in the MIPHAS's wearable. The board is connected to the internet via the NB-IoT interface and it can also connect to a local device through a Bluetooth (Low Energy) interface. A Generic Attribute Profile Server (GATT[3]) has been implemented with several services concerning the following measures: eight temperature measurements, heart rate, respiratory frequency and thoracic bio-impedance signal, pitch and roll angles and fall detection, SD memory status and battery level, data streams related to the ECG channels.

The following are the main types of measurements provided by the various sensors integrated on the data acquisition board and the minimum/maximum sampling frequencies that are used for the acquisition of:

- *Body Temperature*: mapping the body temperature to eight measurement points. The sampling frequency is approximately 1 Hz, while the ADC resolution is 12 bits.

  Electrocardiogram: acquisition of ECG signals from three synchronous channels. The sampling frequency is 320 Hz and the ADC resolution is equal to 16 bits;
- *Respiratory wave*: thoracic bio-impedance measurement at four terminals. Two currents and two voltages measured with a sampling frequency of 20 Hz. The ADC resolution is equal to 16 bits;
- *Dynamics*: (1) orientation measurements, expressed in terms of pitch and roll angles, acquired with a frequency of 1 Hz. The ADC resolution is 12 bits; (2) Fall Detection, the event is generated asynchronously. The accelerometer has a dedicated event-detection interrupt (fully configurable) which allows the identification of a *free-fall* episode.

The general architecture of the MIPHAS electronic component, with all the devices connected to the microcontroller and the interfaces that have been used for the data transport and transmission, is listed below:

- *ADS1294*[4], four-channel ADC with integrated front-end for the ECG signals conditioning; this device communicated with the microcontroller via SPI interface;
- *MAX30002*[5], chip for the thoracic bio-impedance measurement with four terminals, two for current driving and two for voltage reading; this device communicates with the microcontroller via SPI interface;

[3] https://bit.ly/2hIE3EB
[4] https://bit.ly/33J9sgt
[5] https://bit.ly/2nY15hX

- *Micro SD*, which communicates with the microcontroller via SPI interface;
- *Three LEDs*, one red, one green and one blue, which are used to define the battery status. The LEDs are connected to three digital microcontroller output pins;
- *Eight LMT70*[6] temperature sensors, which provide an output voltage proportional to the measured temperature. (The signals supplied by these sensors is acquired using the 12-bit ADC integrated on the microcontroller. Moreover, they are powered by an output pin of the microcontroller in order to reduce the energy consumption of the device);
- *Micro-USB*, for interfacing the board to a PC via USB;
- *SARA N211*[7], NB-IoT module; this module communicates via UART interface with the microcontroller;
- *BlueNRG-MS*[8], *Bluetooth module* this module communicates via SPI with the microcontroller;
- *LSM6DS3*[9], sensor containing triaxial accelerometer and gyroscope, which communicates via I2C with the microcontroller;
- *LIS3MDL*[10], triaxial magnetometer, which communicates via I2C with the LSM6DS3 module;
- *JTAG interface*, for microcontroller programming and firmware debugging;
- *The PDN (Power Distribution Network)*, which supplies the power to the microcontroller and to all the devices connected to it, based on the voltage supplied by the battery. The voltage supplied by the battery is measured by the microcontroller via ADC in order to estimate its state of charge.

The schematic is depicted in Figure 3.

In Figure 4 is depicted the preliminary hardware prototype of the BIOX board.

The schematic of the BIOX is depicted in Figure 3, while Figure 4 shows the preliminary hardware prototype. Figure 5 shows the 3D rendering of the case designed to house the BIOX board. In addition to the case, it is also shown the design of the sled housing to anchor the BIOX to the wearable of the MiPHAS system and to allow a reliable connection of the electrodes and sensors to the electronics.

[6] `https://bit.ly/2oSRsl3`
[7] `https://bit.ly/2iBsZsK`
[8] `https://bit.ly/2J1Nspi`
[9] `https://bit.ly/2Mq2Huf`
[10] `https://bit.ly/2J0rcMm`

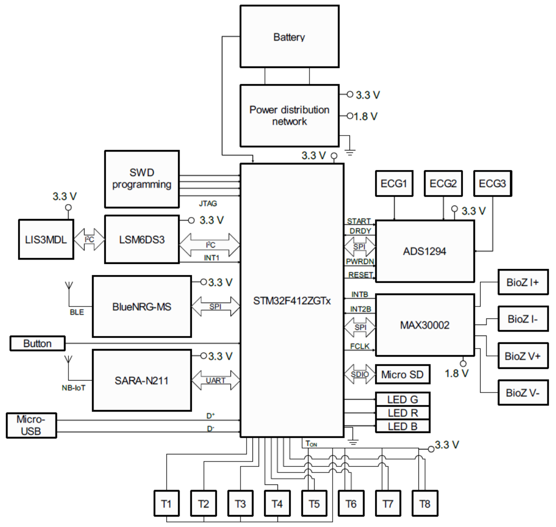

Figure 3: General architecture of the MIPHAS hardware component.

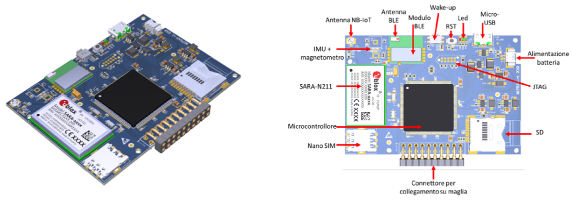

Figure 4: The preliminary prototype of MIPHAS hardware component

The MIPHAS firmware implements a GATT profile server Bluetooth Low Energy (BLE) with services and features according to the working principle depicted in Table 1.

We show in Figure 6 the system which integrates the MIPHAS's wearable, hardware and firmware. Moreover, it is shown how, with this configuration, it is possible to acquire a real-time multi-channel electrocardiogram.

2.3 The software component

Figure 7 shows the architecture of the MIPHAS' system. The server is mainly composed by three components:

- *Application server*: in the the MIPHAS system, it is the component that provides the infrastructure, the support and execution functions;
- *Decision Support System (DSS)*: it is the component that implements the decision support system of the MIPHAS system. Based on machine learning techniques, it has the task of making a first assessment of the alarms received;

Table 1: List of services implemented by the MIPHAS's firmware.

Feature	Transmission Frequency (via BLE)	Source
Measurement of body temperature	Sent every 1 s	Eight points located on the shirt
Measurement of the user's Heart Rate	Sent every 1 s	Evaluated on one of the three ECG signals acquired
Electrocardiogram	Sent every 31 ms, 10 samples per channel	Three ECG channels acquired through the electrodes in V1, V3, V5
Measurement of the user's Respiratory Rate	Sent every 1 s	Evaluated on the thoracic bio-impedance signals
Respiratory Wave (thoracic bio-impedance signal)	Sent every 500 ms, 10 samples	Acquired through the electrodes in R1, R2, R3, R4
Pitch and Roll angles	Sent every 1 s	Inertial Measurement Unit
Identification of falls	Sent in asynchronous mode	Inertial Measurement Unit
Estimation of the state of the battery [%]	Sent every 1 s	BIOX
SD memory occupied in percentage [%]	Sent every 1 s	BIOX

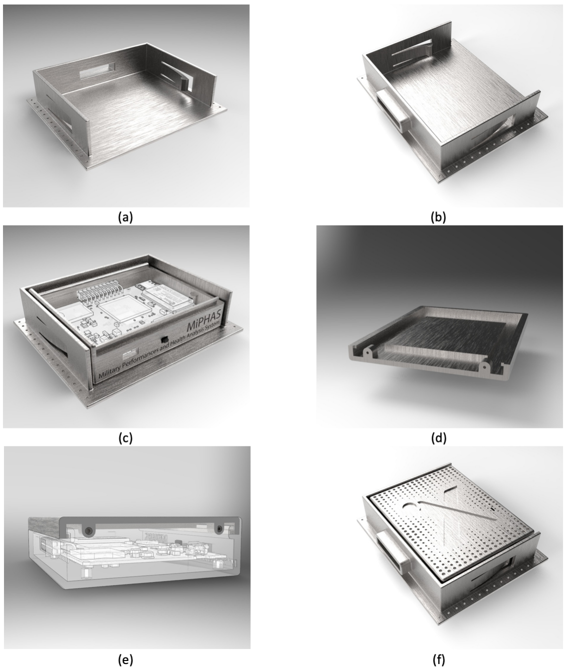

Figure 5: MIPHAS hardware case 3D Rendering

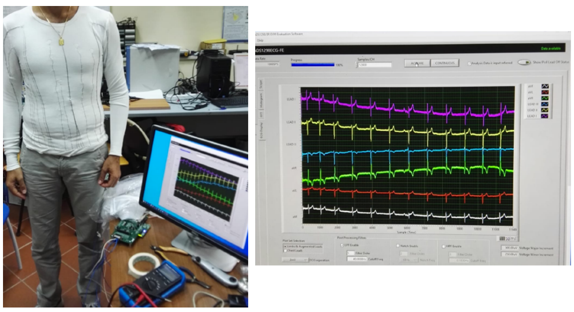

Figure 6: The preliminary test of MIPHAS and an example of the acquired ECG signals.

- *Alert manager*: it is the component that is involved in the process of notifying the medical specialists on the alarms received and confirmed by the DSS. The notification of the alarm is made only to the sport medical specialists who are in charge of the athlete for whom an anomalous situation has been found.

The users can interact with the system in two different ways:

- *active*: regards the interaction between the MIPHAS system and the all the actors. Especially, the "Personal trainer" and the "Manager" access to a web-based platform while the "Athlete" to a application for mobile devices;

- *passive* concerns the interaction between the MiPHAS system and the "Athlete" during a training session. These do not have access to any features of the MIPHAS system; they only supply data to the system thanks to the combined use of the wearable component and the BIOX. The wearable deals with the detection of vital signs, while the BIOX deals with its acquisition and sending, via Bluetooth Low Energy (BLE) protocol to a personal gateway. It is then the task of the personal gateway to send data, via the HTTPS protocol, to the MiPHAS server.

The sending of personal gateway data to the MiPHAS server is done *online*, *i.e.,* the vital signs of the individual are streamed every second during a training session.

Specifically, the structured data, *i.e.,* personal and clinical data of the athlete are stored in a relational database. The vital signs automatically monitored, instead, are stored in a document DBMS. The choice to store this data in a no-SQL database is motivated by two factors: (i) scalability, because given the large amount of data to be managed, a document database offers performances that are certainly superior to a report database as regards information retrieval and (ii) flexibility, because although the structure of a report has been defined to send the monitored vital signs, the latter could be modified, for example by changing the sampling frequency of a data (*e.g.,* the ECG) or by adding new sensors to the wearable. In this scenario, a document database offers greater flexibility than a relational database.

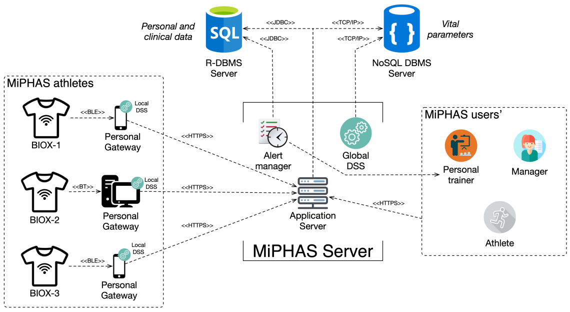

Figure 7: The architecture of MIPHAS.

Figure 8: MIPHAS Mobile App: (A) Home section (B) recap of the assigned training session (C) record of the completed training session.

2.3.1 The mobile application

The MIPHAS app is designed for the profile "Athlete". In the home there are two buttons (Figure 8 A) that allow, respectively, to start a new training session and to view the history of the workouts already performed. In case the athlete wishes to perform a new training session, she has to be submitted to a relaxation session, lasting one minute, in order to record and store her baseline heart rate and respiratory rate values. After the minute, the athlete displays a report of her baseline heart rate and respiratory rate values and the assigned training program (Figure 8 B). At this point the athlete can start the actual training session. When completed the training, the system requires the athlete to perform a new relaxation session, always lasting 1 minute, so as to be able to monitor the basal heart rate and respiration rate values again. After the post-workout relaxation time, the app shows the athlete a screen with the report of the training session just ended (Figure 8 C).

2.3.2 The web platform

The web platform has been devised for the other two profiles of the MIPHAS system: (i) the "Gym manager", responsible for managing personal and clinical data of athletes, (ii) the "Personal trainer", who takes

Figure 9: The Home section in MIPHAS web platform.

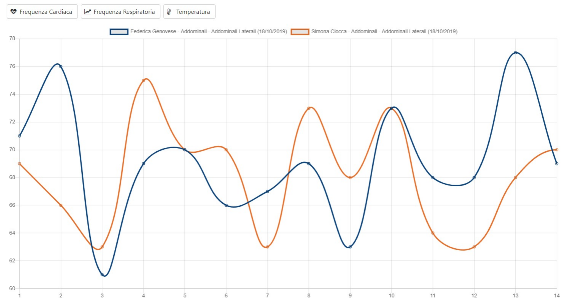

Figure 10: The Heart Rate comparison graph.

care of the athlete's training and is interested in monitoring vital signs during a training session in order to assess how the athlete is responding to the training protocol.

When accessing the homepage (Figure 9, the system shows a mask divided into 3 sections, the first two sections are displayed both to the "Personal trainer" and to the "Gym manager", the third section is shown only to the "Personal trainer". In the first section, the system shows four information boxes containing: (i) the number of total athletes registered, (ii) the number of red alarms in the last 30 days, (iii) the number of yellow alarms in the last 30 days and (iv) the number of white alarms in the last 30 days. In the second section a histogram is shown on the left with the alarms recorded in the last 30 days and to the right a pie chart containing the distribution of the alarms in the last 30 days. In the histogram for each day the system reports 3 different colored rectangles: red, yellow and white, representing respectively the number of red, yellow and white alarms occurred in the last 30 days.

The third section "Athletes" is visible only to the personal trainer and shows the list of all the athletes assigned to the personal trainer. The system gives also the possibility to view the progress and the details of the current training session (if any).

A very useful feature is represented by the *Compare Workouts* section. Here, the personal trainer can compare the training sessions obtained by an athlete on different days or compare the sessions carried out by two different athletes. Through this feature, the personal trainer can evaluate the progress and results of the athletes and choose whether to modify certain training sessions for particular athletes. The comparison is based on the data monitored during the training sessions. The *Data Summary* section displays some descriptors of the trainings, such as: (i) the effective duration, in minutes (ii) the average Heart Rate and Respiratory Rate during the relaxation before the training (iii) the average Heart Rate and Respiratory Rate obtained during relaxation after completing the training session (iv) the Cardiac, Respiratory and Thermal activity during the entire training session. Furthermore, in the *Details* section, the Personal Trainer has the possibility to check the graphs with the Heart Rate (an example in Figure 10, Respiratory Rate and Temperature waveforms based on the data acquired during the training sessions.

3 ARTIFICIAL INTELLIGENCE IN MIPHAS

The Decision Support System (DSS) is the core software for the automatic detection of potential critical situations. Intelligent decisions are made at different levels: part of the DSS is embedded in the personal gateway, while another part is deployed as a standalone service. The mobile gateway integrates - what we have defined - a MIPHAS Local DSS (MLDSS), considering that the data, automatically analyzed by this component, are related only to one athlete. On the other hand, we have defined as MIPHAS Global DSS (MGDSS) the one installed on the server because it is enriched with the data from all the MIPHAS system users.

When the electronic component detects an anomaly, the DSS is warned. Depending on the source of the warning (e.g. Heart, Respiration, etc.), a specific component of the - Global or Local - DSS is triggered. The DSS now can confirm or reject the warning. In case it is confirmed, an alarm (with a severity information) is forwarded to the personal trainer. The personal trainer can analyze *in near real-time* the anomaly and decide whether to confirm or reject the anomaly. The decision of the personal trainer is provided to the DSS that can use the (positive or negative) feedback to enrich its knowledge base.

3.1 Local Decision Support System

The local DSS has the duty to perform the automatic analysis of:

- ***Fall Detection.*** The process of fall detection in MIPHAS is managed in such a way that the electronic component, according to an algorithm internal to the sensor, detects (optimistically) a free fall event. Once a potential fall has been identified, the DSS of MIPHAS system has the task of rejecting a potential False Positive or confirming the episode, through a more specific elaboration than the one implemented by the electronic component. Specifically, for an accurate identification of falls, in MIPHAS it is integrated the method proposed by Mao et al. (2017). Basically, the authors propose a method based on the evaluation of a generalized instantaneous Root Mean Square (RMS) of the triaxial acceleration. To discriminate better a fall event from other rapid movements, in addition to considering the RMS of the acceleration of the human body, the authors also analyze the individual posture after the increase in acceleration. Posture is analyzed through an algorithm that uses the Euler angle, a quantity that represents the spatial orientation of a body;
- ***Heat Stress*** & ***Heat Stroke.*** Thanks to a continuous temperature analysis, the DSS needs to identify a particular situation of heat stress that could lead to a fatal heat stroke. This is done through the procedure described by Palma et al. (2017): an alarm is generated if the patient's heart rate is higher than a threshold f (in MIPHAS, the default is 100 bpm) and there is a change in body temperature at least equal to 0.1° C per minute for a defined period of time t (in MIPHAS, the default is 20 minutes).

3.2 Global Decision Support System

We have designed the global DSS in order to perform these automatic analyses:

- ***Atrial Fibrillation.*** When alerted, the MIPHAS DSS acquires a consistent portion of 3-leads ECG data. On these signals a well-known QRS detection method is applied, the Pan-Tompkins algorithm, according to the work of Pan and Tompkins (1985). The outcome of this last step, is used to trigger the detection algorithm. In MIPHAS, the algorithm embedded to automatically detect Atrial Fibrillation is the one proposed by Zhou et al. (2015). This method is one of the best approaches in the state of the art, showing highly precise results in the classification metrics (Sensitivity = 97.37%, Specificity = 98.44%, Accuracy = 97.89%).
- ***Respiratory disorders.*** When alerted, the MIPHAS DSS buffers a consistent portion of the

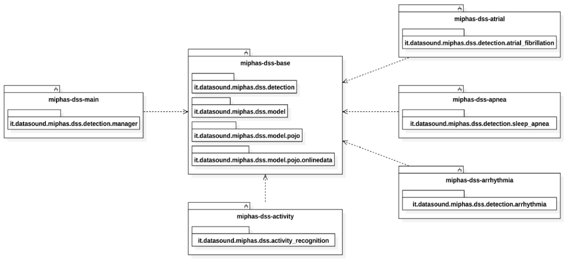

Figure 11: The MIPHAS MGDSS modular architecture.

bioimpedance signal. The offset is removed from the signal, by removing the mean. After this operation, a zero-crossing algorithm has been applied in order to derive the respiration frequency from the bioimpedance waveform. Once obtained a pattern of respiration frequencies, an algorithm inspects the presence of potential anomalous values in the pattern;

- ***Human Activity Recognition (HAR).*** The HAR component in MIPHAS is crucial because it allows the system to reject possible False Positive. If the respiration rate increases, it does not certainly indicate a respiratory disease if the athlete is running. Thus, the HAR is an information which helps the DSS to do a bivariate analysis, before confirming an anomaly. The algorithm works on a consistent section of the generalized RMS acceleration data: first, the method operates to remove the DC component from the accelerometer data. Once deleted, the FFT is computed. The fundamental frequency, resulting from FFT, provides the frequency range where the Human Activity belongs. At the moment, we have experimented a 3-classes identification (Standing, Walking, Running) method.

The MGDSS is designed to be reliable, safe and easily extensible. The MGDSS system defines a series of detectors, that are, components capable of detecting specific problems based on the measurements available. MGDSS is structured in different modules (see Figure 11). Some are basic modules, while others are plug-ins. There are two basic modules:

- ***Core module***: contains all the entities of the system and defines the abstract class Detector, which represents a generic pathology detector;
- ***Main module***: the entry point of MGDSS. It contains all the classes that allow you to manage the detectors, starts the system and provides services outside.

The plug-in modules currently defined are the following (see Figure 11): (i) *Atrial Fibrillation module* which contains the detector of atrial fibrillation and all the classes necessary for the identification of the pathology, (ii) *Breath Problems module* as container of the detector of respiratory diseases and all the classes necessary for the identification of such disorders and (iii) *Arrhythmia module* which contains the generic cardiac arrhythmia detector and the classes necessary for the identification of this pathology; (iv) *Activity Recognition module*: contains all the classes that allow to recognize the activity that the athlete is doing (*e.g.,* running or resting).

When the intervention of MGDSS is requested for a given athlete, all concrete detectors related to the warning are instantiated. For example, if the warning concerns the fall, the heat stroke detector will not be started in order to optimally allocate the available resources. An instance of a detector refers to a specific athlete: in other words, if several athletes are monitored simultaneously, it is possible that several instances of the same detectors are running at the same time. MGDSS periodically checks for new data for the patient in question and provides this data to all the detectors installed for it.

The detectors access a patient's data and, based on these, they decide if there is any anomaly. If at least one of the detectors reports an anomaly, it is registered and sent back to the MiPHAS backend, which, in turn, alerts the physician. Some of the detectors can be just a *support* for other detectors: they are not intended to report anomalies, but to provide additional information to help the other detectors to take a decision. At the moment, the only support detector implemented is the Human Activity Recognition (HAR) detector. Periodically, such a detector is called in order to update patient activity. Like the other detectors, the HAR detector also has an instance for each patient.

Finally, a Detector Manager (DM) orchestrates all the detectors. This component provides operations that allow data to be forwarded to all the detectors of an athlete and to perform a global detection in a transparent way (without necessarily know which detectors have been instantiated and in which moment).

4 CONCLUSIONS

In this paper we have presented MIPHAS, a telemonitoring system aimed at continuously monitoring athletes during their training sessions and offering support to the trainers in their decision-making processes. MIPHAS is basically composed of three components: a smart t-shirt, an electronic device, called BIOX, and several software components.

The wearable - made of specific fabrics for the tele-healthcare applications - embeds several sensors.

The electronic device is the component dedicated to the data acquisition of vital parameters. This unit is also in charge of transmitting data in real-time to the software components. These are mainly composed of a web application, a mobile app and a DSS.

We have an interesting agenda for future works. First of all, we plan to exhaustively experimenting MIPHAS. The experimentation will involve professional athletes. We also plan to enrich the DSS with more refined algorithms, in order to reach a fully functioning phase of *Continuous Learning*. Finally, we also plan to reduce the invasiveness of the electronic component by dividing it in distinct physical modules.

REFERENCES

Balestrieri, E., Boldi, F., Colavita, A. R., De Vito, L., Laudato, G., Oliveto, R., Picariello, F., Rivaldi, S., Scalabrino, S., Torchitti, P., and Tudosa, I. (2019). The architecture of an innovative smart t-shirt based on the internet of medical things paradigm. In *Proc. of 2019 IEEE Int. Symp. on Medical Measurements and Applications*.

Chlaihawi, A., Narakathu, B., Emamian, S., Bazuin, B., and Atashbar, M. (2018). *Development of printed and flexible dry ECG electrodes.* Sensing and Bio-Sensing Research, 20, 9–15.

Curone, D., Secco, E. L., Tognetti, A., Loriga, G., Dudnik, G., Risatti, M., Whyte, R., Bonfiglio, A., and Magenes, G. (2010). *Smart garments for emergency operators: the ProeTEX project.* IEEE Transactions on Information Technology in Biomedicine.

Dower, G., Yakush, A., Nazzal, S., Jutzy, R., and Ruiz, C. (1988). *Deriving the 12-lead electrocardiogram from four (EASI) electrodes.* Journal of Electrocardiology.

Folke, M., Cernerud, L., Ekstrom, M., and Hok, B. (2003). *Critical review of non-invasive respiratory monitoring in medical care.* Medical & Biological Engineering & Computing, 41(4), 377–383.

Fuster, V., Ryden, L., Asinger, R., Cannom, D., Crijns, H., and et al., R. F. (2001). *ACC/AHA/ESC Guidelines for the Management of Patients With Atrial Fibrillation: Executive Summary A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the European Society of Cardiology Committee for Practice Guidelines and Policy Conferences (Committee to Develop Guidelines for the Management of Patients With Atrial Fibrillation) Developed in Collaboration With the North American Society of Pacing and Electrophysiology.* Journal of the American College of Cardiology, 38(4):1231–1265.

Gaudio, F. and Grissom, C. (2016). *Cooling Methods in Heat Stroke.* The Journal of Emergency Medicine, 50(4), 607–616.

Guo, S., Han, L., Liu, H., Si, Q., Kong, D., and Guo, F. (2016). *The future of remote ECG monitoring systems.* Journal of Geriatric Cardiology, 13(6):528-30.

Houtveen, J., Groot, P., and de Geus, E. (2003). *Validation of the thoracic impedance derived respiratory signalsusing multilevel analysis.* International Journal of Psychophysiology, 59(2):97–106, 2006.

Khan, S., Ali, S., and Bermak, A. (2019). Recent developments in printing flexible and wearable sensing electronics for healthcare applications. *Sensors*, 19(5):1230.

Mao, A., Ma, X., He, Y., and Luo, J. (2017). *Highly Portable, Sensor-Based System for Human Fall Monitoring.* Sensors, 17(9), 2096.

Mathew, S., Patel, J., and Joseph, S. (2009). *Atrial fibrillation: mechanistic insights and treatment options.* European Journal of Internal Medicine, 20(7):672–681.

Matias, I., Pombo, N., and Garcia, N. (2018). Towards a fully automated bracelet for health emergency solution. In *Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security*, pages 307–314. INSTICC, SciTePress.

Navarro, C., Casa, D., Belval, L., and Nye, N. (2017). *Exertional Heat Stroke.* Current Sports Medicine Reports, 16(5), 304–305.

Palma, O. A., Ceballos, M., Rocio, R. V., Basto, C., and Barzallo, B. (2017). Heat stroke detection system based in iot. In *Proc. of 2017 IEEE Second Ecuador Technical Chapters Meeting*.

Pan, J. and Tompkins, W. J. (March 1985). A real-time qrs detection algorithm. *IEEE Transaction on Biomedical Engineering*, bme-32(3).

Paradiso, R., Loriga, G., Taccini, N., Gemignani, A., and Ghelarducci, B. (2005). *Wealthy-a wearable healthcare system: new frontier on e-textile.* Journal of Telecommunications and Information Technology.

Park, S., Mackenzie, K., and Jayaraman, S. (2002). The wearable motherboard:a framework for personalized mobile information processing (pmip). In *39th Annual Design Automation Conference (ACM).*

Petrutiu, S., Jason, N., Nijm, G., Al-Angari, H., Swiryn, S., and Sahakian, A. (2006). *Atrial fibrillation and waveform characterization.* IEEE Engineering in Medicine and Biology, 25(6): 24–30.

Ranakoti, S., Arora, S., Chaudhary, S., Beetan, S., Sandhu, A., Khandnor, P., and Saini, P. (2018). *Human Fall Detection System over IMU Sensors Using Triaxial Accelerometer.* Advances in Intelligent Systems and Computing, 495–507.

Vatansever, F. and Hamblin, M. R. (2012). Far infrared radiation (fir): its biological effects and medical applications. *Photonics & lasers in medicine*, 1(4):255–266.

Villar, R., Beltrame, T., and Hughson, R. L. (2015). Validation of the hexoskin wearable vest during lying, sitting, standing, and walking activities. *Applied Physiology, Nutrition, and Metabolism*, 40(10):1019–1024.

Wang, H., Yen, C., Liang, J., Wang, Q., Liu, G., and Song, R. (2014). *A Robust Electrode Configuration for Bioimpedance Measurement of Respiration.* Journal of Healthcare Engineering, 5(3), 313–328.

Wissler, E. (1964). *A mathematical model of the human thermal system.* The Bulletin of Mathematical Biophysics, 26(2), 147–166.

Zhou, X., Ding, H., Wu, W., and Zhang, Y. (2015). A real-time atrial fibrillation detection algorithm based on the instantaneous state of heart rate. In *Plos One Journal*.