Wearable devices and medical monitoring robot software to reduce costs and increase quality of care

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***Abstract*—Wearable devices are increasingly used in healthcare and sports. Most wearables (74%) in a literature search record cardiorespiratory variables. A prototype to allow coaches to guide sportsmen during training, a mobile application to share physiological data in the cloud during exercise, a hospital risk detector based on tags, wrist and card IDs (CAMACUA) as well as a cardiac failure follow-up application with artificial intelligence (SIMIC) are described. Modern Medicine and Sports now benefit from wearable technologies to lower risks of in-training injury, drug dispensing errors and accidents secondary to proximity of objects not meant to be close to each other.**

Keywords—wearable devices, health care, chronic disease follow-up, medical informatics.

I. Introduction

Evolution of technology in recent years has contributed to the creation of ever smaller and more agile computers [1]. Likewise, the miniaturization of electronics has contributed to the creation of small transducers, now included in what is known as "wearable devices". In general terms, personal computing became available in the 80's, internet came about in the 90's, mobile computing in the 2000 decade and only in the last decade did wearable computing come along [2].

Wearable devices are clothing, footwear or accessories to be worn so as to transmit physiological variables [2]. This technology has drawn the attention of industry and academia where new devices are developed [3] to be used in the health care and sports sectors.

In the 1980s, Steve Mann started the area by creating a small computer coupled with a backpack to control a photographic device [4]. Mann [5] was the first to define wearable computing as the practice of inventing, building or using computers and components or devices with sensors, all of which were carried by the user, i.e. "wearing" them.

Wearable device refers to small sensors that are normally attached to the user's body [4] and allow its use while the user carries out his/her activities. A wearable device is usually integrated into common objects, such as clothes, shoes, watches, bracelets, glasses, among others [6].

The technological advances that made possible the miniaturization of sensors and the embedded processing have brought new challenges and opportunities to the area of wearable computing [7]. In this area, most of the times, it is important to create devices capable of recognizing, adapting and reacting to either the user, the location or the task performed. To perform these tasks, it is necessary to include sensors into the wearable device [2]. The type of sensor identifies the stimulus as well as its use. For example, a mechanical sensor can provide position, acceleration, force, mass, displacement and can be used to detect the height of a jump or a sudden drop. A physiological sensor can capture information from the user's body such as heartbeat, body temperature, brain activity, respiratory rate, providing basic data to help evaluate health conditions.

In health applications, the sensors-derived data can be transmitted by WiFi communication [8] or Bluetooth [9], among other wireless links. This information is of great value for both later processing (such as Holter recorders) [10] or on-line reaction, as will be presented in the following sections.

Organ	Function recorded	Number of papers
Heart	Heart rate, ECG and BCG	11 studies
Lung	Respiratory rate, oxygen saturation, respiration, and pulmonary ventilation	9 studies
General	No specific organ or several	7 studies

Research on wearables devices concentrates on cardiovascular and respiratory applications, with 75% of the papers read [11]. In terms of cardiology, maximum and resting heart rate is addressed in one paper [12], while other authors use heart rate in general, as obtained from wearables [13], [14], [15], [16], [17] and [18]. A few authors [19], [20] and [21] go further and mention the EEG (Electrocardiogram) [22] and the BCG (Ballistocardiogram).

In terms of respiratory rate, experiments are being carried out using wearables [18] [23]. Oxygen saturation [13] is also studied. Other authors[14], [24], [16], [25], [26] refer generally to breathing variables. An ambitious goal such as pulmonary ventilation acquisition by a wearable device is also mentioned [27].

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The wrist watch wearable [15], [22], [17], [28] is used for the acquisition of physiological and physical signals, as well as spectacles [29], [9], [30] and bracelets [31], [32].

In terms of sensors, the accelerometre was used in more than 60% of the articles (17/27) followed by the gyroscope (33% of the articles) and the magnetometer (20%) [15].

In terms of diseases, the main applications mentioned refer to chronic conditions such as lung, diabetes [27], Parkinson´s disease [35] and ultimately cancer.

Due to its high competitiveness, sports medicine (and by extension sports training and performance optimization) has adopted the concept of wearables to record physiological variables and to analyze data both in real time and later.

II. Wearable Devices Development

This section refers to our development of wearable devices and the preliminary results of their application.

A. Wearable for Athletes in Individual and Collective Sports

The high performance required in the area of sports creates the need for affordable alternatives for performance evaluation. Thus, we designed a wearable prototype to capture the data of the athlete by means of sensors. The aim was to monitor athletes using wearable technologies, so that trainers could make decisions from the observed signals. Figure 1 shows the outline of the architecture and the information flow.

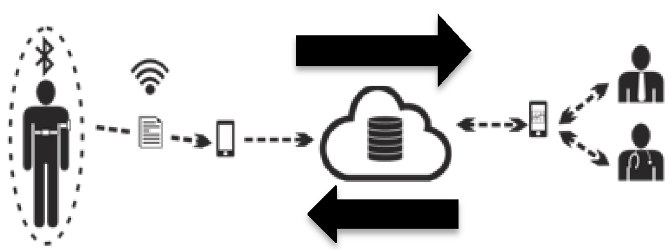

Fig. 1. Wearable device architecture for athlete and trainers in real time [36].

The sportsman is monitored as he wears the wearable. Subsequently, the data obtained from the sensors are transmitted using the wireless network connection. Finally the trainer and physician receive information and may feedback the system with advice or commands displayed by our smartphone application.

The choice of the Raspberry Pi model Zero W plate [37] was based on its small size and compatibility with available sensors. In addition to the Raspberry Pi Zero W plate, sensors were incorporated into the prototype for monitoring athletes: GPS [38] and heart rate [39]. The sensors collect data that is later transferred to a Trainer´s system.

The prototype includes the EM-506 [40], a GPS signal receiver (dimensions 30 mm on each side and 10.7 mm in height and weighing 16 g). Its discreet and efficient cable help its adherence to wearables without disturbing the individual.

The Polar H7 monitor [39], which communicates via Bluetooth natively with the Raspberry Pi Zero W plate, was used to monitor the heart rate. Complementing the platform for monitoring athletes' activities, computer systems were developed, acting in parallel to the proposed wearable device. First, there was a need for software to be run by Raspberry Pi Zero W, responsible for receiving the data from the sensors and performing their storage on the memory card of the prototyping plate. Besides that, a smartphone application was created to display the information of the athletes and their management.

Preliminarily, the system used to collect the data coming from the sportsman has no need of interaction with the end users. Its function is to specifically read the signals sent by the wearable sensors and organize them so that they are correctly available to be sent to a new phase, in a mobile device. The data obtained, in its turn, are sent to a cloud database and can be synchronized with several other devices.

Obtaining athlete training data is an important task, however, being able to provide this data in the form of efficient information that can bring contributions to both athletes and professionals involved, is fundamental. For this, the application was designed to be a tool used by the technicians/professionals involved with the athletes' training routines, such as physicians, physiotherapists, nutritionists, among others. In this way, those responsible for evaluating the athletes' performance access the information they need to prepare athletes quickly and efficiently, since thay can pass on their opinions, as on-line feedback, to individual sports practitioners.

With this design, the data is obtained by a wearable used during training sessions by the athlete. Subsequently, as this information is passed to the device plate, it can be parsed by an application, and finally actions can be planned. These plans, in turn, are shared with the sportsmen involved so that new data can be analyzed again.

To validate the prototype, a health professional was interviewed after he used it with five athletes. The experiment consisted of using the Polar H7 strap by the volunteer, athlete communicating via Bluetooth with the Raspberry Pi Zero W, found in a training bracelet, which also accommodating a portable 2200 charger for power. Therefore, no data were collected regarding the sensor, and only heart beats from Polar H7 were measured.

The heart rate data obtained and sent to the plate, where it was included in a file and stored in its secondary memory. After a set time, the file is transmitted to the mobile phone where, through the developed application, import is carried out.

The volunteer, wearing the bracelet with the prototype and the Polar H7, performed a predefined course in which his heart rate would be measured. This trip in the first week was limited to a short space, with a flight of stairs. For the second measurement, the exercise was greater, 5 minutes long, with two flights of stairs, in order to verify possible variations when going up and down floors of the building. For the third experiment, a path of 10 minutes was defined.

From the experiment carried out, it was concluded that the platform operated correctly, capturing data, storing them and making them available to the health professional. New experiments are now performed with athletes using the equipment for longer periods of time carrying out sequences of activities, following research protocols.

B. *Vital Signs Monitor for Volleyball Athletes with **e-Health***

A novel Monitor was developed as a prototype in Arduino with the *shield e-Health*, to collect vital signs in the cloud (*Thingspeak* data repository). This prototype is intended as a first step towards the design of a wearable device. The technologies we used are 3g for wireless communication, Open-Hardware (Arduino) platform prototyping plates, the *Shield e-health* [41] and the Thingspeak data repository.

The Shield e-Health (Fig. 2) allows, in conjunction with a prototype plate such as Arduino or Raspberry Pi, to run applications where vital sign monitoring is required, using up to 10 different sensors: blood oxygenation (SpO2), air flow (breathing), body temperature, electrocardiogram (ECG), glucometer, galvanic skin response (GSR - sweating), blood pressure (sphygmomanometer), patient position (accelerometer), and muscle / electromyography (EMG) sensor. These vital signs can be used to monitor a user's condition in real time or to obtain more user-sensitive data [41].

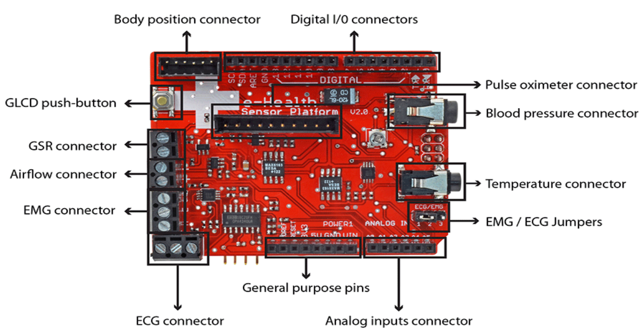

Fig. 2. Shield e-Health platform architecture (Aranda, Bez, Carvalho, 2017).

The eHealth plate is connected to the Arduino so that it may receive codes developed in Arduino, because the IDE interprets that the Arduino and the plate are the same device.

The validation was done by measurement of vital signs of a volleyball team. Three vital signs in *Shield e-Health* were selected: heart beat, temperature and blood pressure, taken at two times: before and after training.

The first two vital signs (heartbeats and temperature) were collected, which were promptly sent to Thingspeak and then the athletes' blood pressure was collected. The next athlete was transferred. Data transmission from the third sensor (blood pressure) was performed after the collection of all the athletes.

This approach was chosen in order to ensure ease of use during collections. Once all collections were completed, the blood pressure sensor was connected to the prototype to send the data to Thingspeak. After the training of the athletes, the collections were carried out again in the same way.

Once the measurements were completed, the data were made available to the coach of the volleyball team to be analyzed and, from this information, to eventually take measures regarding the training of the athletes, seeking a better optimization of their performance. We also asked athletes and coach to answer questionnaires, to detect any discomfort during the measurements and to evaluate satisfaction of the trainer using the app.

The questionnaire consisted of three questions on a like scale. The ages of the athletes ranged from 21 to 23 years. When asked if there was any kind of discomfort or discomfort in vital signs measurements, 100% of the respondents stated that there was no discomfort. 90% answered the vital signs measurement can help improve sports performance. The coach also responded a questionnaire consisting of three questions. The first was if there was any difficulty accessing the vital signs of the athletes. The coach considered the app easy to access. He pointed out that having this information on his cell phone is much more practical than on a computer, for example.

The second question referred as to whether this Monitor could help improve athletes' performance. The coach believed he could adjust training according to the athlete's fatigue, and thus in some cases, reduce the risk of injury.

The vital signs data obtained during the experiment were made available to the trainer through the developed application. In addition to allowing the athlete's vital signal to be tracked as soon as the value is updated on Thingspeak, it is also possible to track the history of the athlete's vital signs.

There were some problems during the experiment, nevertheless. Out of the 60 measurements made, five errors occurred, whereby the collected value was not sent to the repository in the cloud, that is, in 8.33% of the collections. This error occurred because of a possible lack of 3G signal from the cell at the measurement site.

We also observed that at times sending data to the cloud was slower than usual. We believe this problem also occurred due to the instability of the 3G network. More experiments must be carried out in order to confirm the problem is in the internet connection, rather than any other possible reason.

C. *Medication Error Reduction using wearable patient ID*

In clinical settings, medication errors must be controlled in order to be part of a high standard of care, as stated by the National Coordinating Council for Medication Error Reporting and Prevention [42]. Some errors are indeed preventable because they are derived from a lack of information at the precise time and place when and where the correct medication is to be administered. The event that may cause harm to the patient is in the control of the health care professional or patient. This is usually associated with information on tags, labels or a person´s memory when objective data is unavailable. Leaving aside professional skills, prescribing, product labeling, packaging, and nomenclature, medication errors events may be related to the last ring of the chain, i.e. dispensing to the hospitalized patient. When administering medication to a patient, (i) it must belong to the patient,

(ii) dose and route must be that of the prescription and (iii) it must be administered in due time. A survey of US hospitals concluded that 34% of the medication error occurred at the administration phase and only 2% are intercepted (near misses). An additional 10% occurs while the prescription is transcribed and medication dispensed [43]. Some of the errors could be life-threatening [44]. These reports [43],[44] conclude that information and communication technology (ICT) can help reduce medication risks. Despite the efforts to prevent medication errors, they are still reported in 2016 [45]. Other risky situations are related to patients and visitors wandering within hospital corridors or non-authorized zones. In some occasions wrong patients can even be operated on [46]. To reduce these potential hazardous situations, innovative designs can be considered, putting ICT to work with its full potential.

Our recent design, named CAMACUA [47], addresses these issues with a mixture of wearable devices and markers on both fixed objects and mobile elements. Upon admission, patients are provided with an ID barcode wristband. All equipment, furniture, medication trays and unidose containers are marked (either barcode or other ICT technologies). Radio Frequency Identification (RFID) readers are mounted in room entrances and corridors to receive signals from passing tags. All employees carry mobile devices equipped with barcode reader, which they are asked to use to check entities at any time, in passing. Visitors are given cards with passive RFID and bar codes. All event data are recorded in an "event database" for immediate scrutiny and later log analysis. If the CAMACUA system detects risky situations, an immediate alert is created to prevent damage, either centrally or locally at the employee´s mobile device. For instance, if a person or object is identified (by a sensor or an employee) in a forbidden zone, an alert is triggered to security staff, notifying the event. Medication trays standing for more than a set time in the vicinity of a different patient than the recipient, warn nearby employee mobile phones, in addition to be recorded in the CAMACUA database.

To prevent medication administration errors, the nurse scans both the patient barcode and the unit-dose QR code. If CAMACUA detects a mismatch of the unit-dose and the ID of the patient it is being administered to, a warning is displayed and sounds at the right time to stop a possible error being committed. Information on drugs and patient is also shown at the bedside, including a photo, observations and dosages.

Patients and objects may also be located based on reports created from the "last seen" zone. CAMACUA is freely configurable, using a flexible "event specification language" to alert in case entities-locations match, which include drug mis-administration risks.

CAMACUA components are (1) the back-end application, (2) mobile application, (3) web client and (4) RFID sensor middleware. The back-end application is the key component, which executes all the event processing logic and notifies when a risk situation is detected. It is composed of the event engine and the alert system, and provides a lightweight interface, used by client side components. Web client for administrative staff manages such functions as entity registration and zone permission assignment. The mobile application runs on devices carried by medical and security staff. It is used for entity identification and to display notifications according to predefined priorities. Nursing staff uses it as an assistant for unit-dose administration to prevent errors.

Events are classified as primitive or complex. Primitive events are generated by external actors, such as the identification in time and space of a patient, a unit-dose or any marked object. Complex events are combinations of primitive events according to a set of operators applied to both primitive and complex events. CAMACUA uses the basic operators described by Wang et al. [48]: Logical operators (such as AND, OR, NOT) and Temporal operators (such as SEQ, WITHIN , etc.). The basic syntax of CAMACUA allows to define events and actions of the type "ON event ; IF condition ; DO action".

By putting CAMACUA in operation, it is possible to envision a reduction of medication errors and a lower number of situations defined as ***risky coincidences in time and space*** of people, instruments and drugs.

D. Cardiac Failure Follw-up & Artificial Intelligence Mobiles

Self care is of paramount importance for persons with cardiac failure (CF) [49]. Their quality of life, the progression of the disease and ultimately their survival rate greatly depend upon life style, nutrition, medication and exercise, all enforced on a daily basis. Recommendations by Health Personnel are periodically fine tuned and adapted, which is the essence of follow-up. Traditionally, the health system is expected to assume responsibility for follow-up, which in turn is based on patient behavioural compliance and medication adherence. The growing number of persons with CF in modern societies, as the epidemiological transition evolves, challenges the effectiveness of follow up activities. This is why we developed an automated and intelligent system to help manage CF, called SIMIC (for the Spanish Sistema Informático de Manejo de la Insuficiencia Cardíaca) [50]. Active and personalized follow up is coded as a set of recommended clinical routines, under the formalization of an expert system (ES).

During the medical visit, the physician "prescribes" SIMIC to suitable patients, either living alone or with the help of a family member or home assistant. The prescription is recorded in the SIMIC web platform and typically put in practice outside the physician's office by teaching the patient to install the SIMIC app in his/her mobile terminal. From that instant on, the SIMIC app will be active asking questions and capturing data from the patient, in a very sparse and civilized way, never becoming intrusive nor insisting unnecessarily. According to the type of follow up set by the physician, SIMIC will statistically ask questions on life style, exercise, diet and medication, as well as general mood and common family activities. This information is managed by the ES included in the SIMIC app to eventually trigger a local answer or a comment. The SIMIC ES is set in such a way as to behave as an intelligent wearable system because only meaningful combinations of data and absence of data are reported to the SIMIC web system. The patient feed-back is received under the form of an alert, informing Health personnel that the patient is behaving in a way which is frankly outside the physician's recommendations. This alert is planned to be active only for a fraction of the CF population and can be the starting point of an active human contact seeking with the patient to find out more and to see whether the Health System can do anything to help. By doing so a high quality of care can be offered, as only a fraction of the persons under follow up will require a personalized call, to bring back the person's behaviour to normal CF management style.

Just as a wearable device is read in the physician's office after a Holter recording or some other evidence, in the case of SIMIC all information gathered since the previous visit is available in the SIMIC web system under the Doctor´s control. The information recorded by the patient during normal life is displayed contributing to a richly informed conversation, based on recorded facts, weight variations, exercise and diet enforcement data. The physician may decide to include all this information, along with his notes, in the Electronic Clinical Record (ECR), managed by SIMIC and available for interoperability, according to the CDA standard. [51]

To define the behaviour of SIMIC for CF follow up, a special language was developed [52] with formal production rules. SIMIC behaviour rules can be specified or modified by the physician with no programming skills, using a SIMIC wizard interface. SIMIC implements natural language processing, lexical verification and includes a compiler to allow the SIMIC app to enforce the follow up profile during the person's life.

By ensuring a continuous communication in both directions of the CF person in his/her home environment with Health Personnel, unwanted situations may de detected in time to actually prevent them from doing irreversible harm. Along with hardware wearable devices, SIMIC may contribute to a more efficient public health. This would be the result of a personalized care, of the kind only very expensive settings allow, such as a personal physician devoted to a monarch or other privileged person in the past. SIMIC is the combination of a specialized ECR platform gathering sparse patient life style data, events and physiological variables (weight, mood, diet) with counseling and alert capacity. By relieving Health Personnel from active follow up tasks (such as periodic telephone calls, as part of an excellent medical care), SIMIC allows personnel to devote their professional time to CF persons counseling during visits. By using SIMIC, if patients show good follow up behavior, visits may be less frequent, an additional efficient contribution of personal intelligent data capture, an implementation of the wearable concept.

III. Discussion and Conclusions

The growing availability of technical devices which are able to detect, measure and react to environmental and personal physical changes over time, along with scores of technologies to transmit and receive such simple and yet numerous data, is changing our life style, worldwide. At the same time, a considerable processing power is now available in the vicinity of every element which detects physical magnitudes. In this paper we have described physical sensors located on the human body and we have presented software elements which react to physical conditions reproducing specialized human caregivers´ behaviour. Wearable devices are those sensors that can go undetected in people´s clothes. Now consider data capture and analysis devices that are included inside any user´s mobile device software. The mobile phone or tablet is a device we are adopting as a general life enhancement "*accesoire*". Since we need our mobile device for routine communication and information, its use to run health monitoring, follow-up or alert may also be considered a wearable technology, since its presence is hardly perceived, in very much the same way as a temperature sensor goes undetected in the sports tee shirt used by an athlete while training.

We have shown here that athletes can wear data capture devices in order to dispatch information to their coaches in real time, so that feedback messages can be used for better training. We have shown a software enquiry and counselling device (SIMIC) for chronic condition patients. Using psychology and artificial intelligence concepts, SIMIC detects whether the user is either wise enough to be left alone or rather is asking for help due to his/her irresponsible behaviour. The feedback is here the responsibility of the "wearable device", not the sports trainer.

Simple ID labels become "wearable devices" provided they are read frequently by mobile phone readers to populate long lists of time-stamped vicinity observations. The analysis of such data can be that of detecting risk situations in advance and therefore avoid accidents. Labels become wearable devices since no one feels their sensing capability, left to personnel active readers, powered by CAMACUA.

Miniaturization of components and new data capture technology is putting in the hands of manufacturers the possibility to record all what is physically happening on a living person. Software implementation of follow-up, advice or alert capabilities, left to health personnel until now, will enhance even further our living experience under learned tutorship. A path that was probably started when Hippocrates separated diagnosis from therapeutic decision: wearables can now detect variables, and help make simple decisions, repeatedly and consistently, to ease our lives.

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