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UCEMEPA: Ubiquitous Computing Environment for Monitoring and Evaluating Physical Activity

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ABSTRACT

The physical inactivity has been indicated by the World Health Organization (WHO) as one of the main risk factors for the incidence of Chronic Non-Communicable Diseases (CNCDs). To change this scenario WHO has stimulated regular practice of physical activities because they play an important role in preventing CNCDs. In Brazil, these activities are performed by health units which generate a large amount of data that need treatment. To deal with this problem we developed UCEMEPA, an environment that employs Ubiquitous Computing technologies and wireless communication networks, in order to monitor remotely and evaluate in real-time participants of physical activity groups. This environment automatically collects physiologic data, and provides indicators which will support and direct public policies for promoting physical activity. In this sense the UCEMEPA will contribute for the promotion of health and quality of life, and for the conduction of longitudinal studies aiming to establish correlations between the practice of physical activity and CNCDs prevention.

Keywords

Healthcare System, Health Information Management, Ubiquitous Computing and Wireless Body Sensor Networks.

INTRODUCTION

Reports from WHO has indicated that the sedentariness in developed and developing countries has becoming a big problem for the global public health, since it has contributed to the quick increase of CNCDs cases linked to physical inactivity. Only in 2005, CNCDs such as hypertension, obesity, diabetes mellitus and cancer, were indicated as the cause of 35 million of deaths in the world, which corresponded to about 60% of mortality in that year. Besides this alarming index, projections performed by WHO have shown that the number of deaths aroused from these diseases would increase by 17% until 2015 (WHO, 2008).

In order to hold this progress, WHO has created and divulgated interventionist actions aiming at controlling and preventing CNCDs. These actions are based mainly in a set of non-medicated and low-cost actions with the purpose of reducing the risk (e.g., sedentariness, obesity) which exposes the world's population to these diseases. Promoting regular physical activity is one of these actions and performs an important role to prevent CNCDs. (Warburton, Nicol and Bredin, 2006) presents a study in which men and women who keep active, if compared to sedentary individuals, present a reduction of 30% to 40% in the risk of colon cancer and women physically active present a reduction of 20% to 30% in the risk of breast cancer. (Miles, 2007) reports that the regular practice of physical activity can provide benefits over the body capacity to form and destruct blood clots. According to (Miles, 2007), physical activity improves blood transport in coronary arteries and promotes beneficial neurological and immunological alterations, reducing considerably the risks of cardiac diseases.

In Brazil, many of the promotion and maintenance actions of physical activity programs recommended by WHO are under responsibility of Family Health Units (USFs) or Basic Health Units (UBSs). USFs and UBSs are small regional health units which, integrated, compose the municipal health system. The physical activity programs promoted by these units include physical exercises sessions which are developed in work groups, also called Physical Activity Groups (PAGs). These programs provide a huge amount of data which are not submitted to any kind of evaluation and monitoring.

Besides stimulating the physical activity, WHO highlights the necessity of participating countries to adopt ways of monitoring the performance of these activities, since it is important to gather physical information about the population in order to direct public policies to fight against the sedentariness and CNCDs. In order to support this monitoring, WHO recommends the use of information systems and computational technologies which help health professionals to manage the information.

The Ubiquitous Computing (Weiser, 1991) can contribute to this monitoring recommended by WHO, since it employs many types of technologies, such as mobile devices, wireless networks and sensors, which are often used in the development of mobile applications and smart environments monitoring. In health domain, these technologies have been employed to support the Hospital Information Systems (HISs) and for the development of new healthcare models, such as Distributed Healthcare, Mobile Healthcare and Pervasive Healthcare (Bardram, Mihailidis and Wan, 2006).

In this context, this paper presents the Ubiquitous Computing Environment for Monitoring and Evaluating Physical Activity, which was developed for the collective monitoring of PAGs. Using integrated technologies from Ubiquitous Computing and from wireless communication networks, physiologic data from participants are automatically collected and sent to a remote monitoring server. This environment provides indicators which will support and direct public policies for promoting physical activity and allow the conduction of longitudinal studies aiming to establish correlations between the practice of physical activity and CNCDs prevention.

RELATED WORKS

The literature presents some works which employ ubiquitous technologies to monitor individuals during the performance of physical activity. In (Ho and Chen, 2009) the Exertrek is presented, a personal cardiac monitoring system able to help the practice of physical exercises. Based on cardiac data monitored by electrocardiogram sensors (ECG), the system helps the individual to adjust himself during the physical exercise. Another work developed for the similar purpose is presented in (Postolache, Girao, Pinheiro, Madeira, Pereira, Mendes, Postolache and Moura, 2001). Using sensors such as accelerometer (ACC) and ECG, data from elder patients are continuously collected in order to monitor the individuals' motor activities. In (Ketabdar and Lyra, 2010) the ActivityMonitor, a system to monitor physical activity over the internet, is presented. This system uses ACC sensors to identify physical activity patterns of a user and employs GPRS or Wi-Fi networks to send the collected data to a remote server.

Among the works developed to monitor physical activity, there are those with a focus on CNCDs control. Seto *et al.* present in (Seto, Giani, Shia, Wang, Yan, Yang, Jerret and Bajcsy, 2009) a system formed by movement sensors (e.g., ACC, gyroscope), position sensors (GPS) and air pollution sensors (particles measure) to identify correlations between the practice of physical activity and the environmental conditions which intensify the asthma symptoms. Portacarrero *et al.* present in (Portocarrero, Souza, Demarzo and Prado, 2010) the Physical Activity Information System (SIAF) in order to obtain, treat and evaluate data related to physical activity. The SIAF offers management functionalities over UBSs/USFs, PAGs, participants and physical activity sessions.

In related works presented and which use Ubiquitous Computing technologies for monitoring, each individual monitored needs to have a set of sensors and a mobile device, which is responsible for sending data collection. This one-to-one approach is adequate to individual monitoring, but becomes costly if applied on collective monitoring.

The physical activity programs conducted by UBSs/USFs are composed of aerobic activities (e.g., walking, gymnastic), developed in groups of 5 to 15 participants. These activities are performed in 40 to 90 minutes sessions, and are followed by a health professional who conducts the participants and evaluate their physical conditions. For this UCEMEPA scenario, where the presence of a health professional in physical activity sessions is mandatory, the one-to-one approach, represented in Figure 1(a), was replaced by a one-to-many approach, represented in Figure 1(b), where the health professional holds the mobile device. Besides the economic advantage, since a single device is used to monitor several individuals, this new approach brings the following benefits: a less intrusive monitoring, since the participants will not need to have devices apart from the sensors; the management of all sensors can be centralized; and the communication between the mobile device and the server is facilitated.

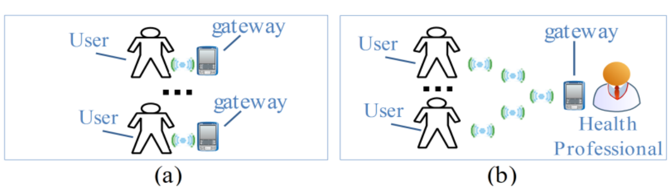


Figure 1. One-to-one (a) and one-to-may (b) approaches

UCEMEPA

UCEMEPA was designed to collect data either indoors (i.e., covered sport court, recreation salons) or outdoors (i.e., walking lanes, open courtyards) places. This environment is formed by three modules: Wireless Body Sensor Network (WBSN); Collective Monitoring Server (CMS); and Physical Activity Information System (SIAF). Figure 2 shows a general view of the functional diagram with UCEMEPA modules.

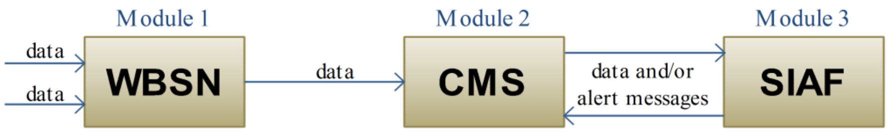


Figure 2. UCEMEPA functional diagram

The interaction between the modules illustrated in Figure 2 can be classified according to the following phases: in the first phase the sensors are placed on the participants in order to form the WBSNs; in the second phase the CMS identifies all the active WBSNs and starts the communication with them in order to collect data, analyze and send it to the SIAF; and in the third phase the SIAF performs the persistence of the data obtained from the physical activity sessions, providing them for visualization. Once critical health conditions which offer risk to the participants are identified, alert messages can be showed either by CMS or SIAF. Figure 3 shows a general view of UCEMEPA architecture and the arrangement of its modules.

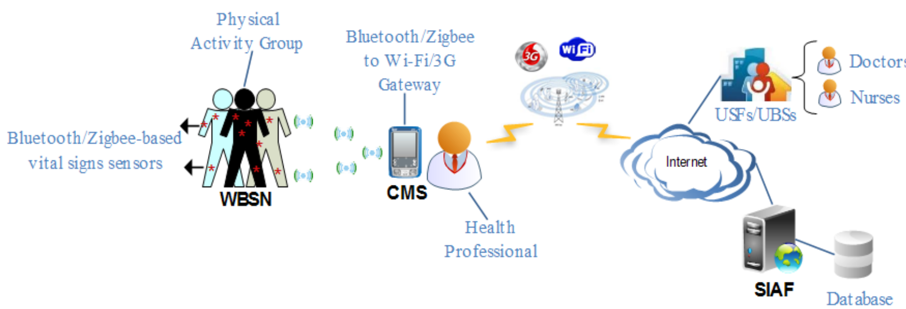


Figure 3. UCEMEPA architecture

Wireless Body Sensor Network

The latest technological advances on sensors and wireless communication networks have enabled the development of intelligent sensing miniaturized devices. When some of these devices are interconnected and are applied to monitor one individual, a WBSN (Latré, 2011) is formed.

The development of the WBSN for the UCEMEPA relied on requirements such as: the sensors must be small and light so they do not impair the physical activity practices; the transmission of data collected by sensors must be performed through wireless communication networks in order to provide the participants the freedom of movement; and the configuration of the sensors must be easy. The open-source platform Arduino (Arduino, 2011) was chosen for the creation of the WBSN because it allows attaching the sensor in pieces of clothing, such as gloves, shirts and pants, allowing the construction of Wearable Computing architectures (Bonato, 2010), which make the sensors increasingly "imperceptibles" to users. Table 1 shows the sensors used in UCEMEPA.

Sensor	Purpose
ECG	To read heartbeat
PPG	Detection of cardiovascular pulse waves
BP	To read blood pressure
ACC	To measure the proper acceleration

Table 1. WBSN of the UCEMEPA

For the wireless communication between the sensors described in Table 1, the literature recommends the use of two types of protocols: Bluetooth, which has low power consumption, supports ad hoc networks and allows data rates up to 3 Mbps at a range of up to 10 meters; and ZigBee, which has power consumption and cost reduced, supports ad hoc networks and allows data rates up to 250 kbps at a range of up to 75 meters (Kim, 2007).

Collective Monitoring Sever

The CMS was developed to run in a smartphone or tablet with Android (Android, 2011) platform, which will be carried by the health professional who follows the physical activity session. The main CMS functionalities are presented in Figure 4.

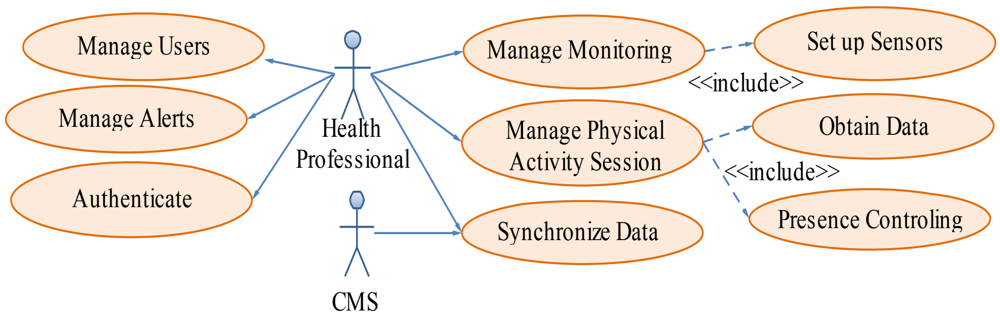


Figure 4. CMS use case diagram

The sensing network data are collected automatically in regular time breaks which can be set in the CMS, according to the health professional's interests. The CMS acts as an environment gateway and makes use of wireless communication interfaces in order to perform this role. Using Bluetooth or ZigBee interface the CMS provides communication with WBSNs, through which the physiologic data are collected. These data are processed and sent to SIAF through Wi-Fi or 3G interfaces.

Physical Activity Information System

In order to have the management and persistence of the information collected during the physical activity sessions, the UCEMEPA uses the SIAF. Therefore, this system was adapted by including new screens of monitoring and automated mechanisms for data collection, since in (Portocarrero *et al.*, 2010) all data are manually entered.

The SIAF automation provides some benefits for physical activity monitoring: improved efficiency in collecting physiological data of the participants; increased accuracy and reliability of collected data; and allows real-time assessment of participants' physical conditions, ensuring that the participant's health will not be compromised. Figure 5 shows the use cases diagram of SIAF with the main functionalities and users involved with this module.

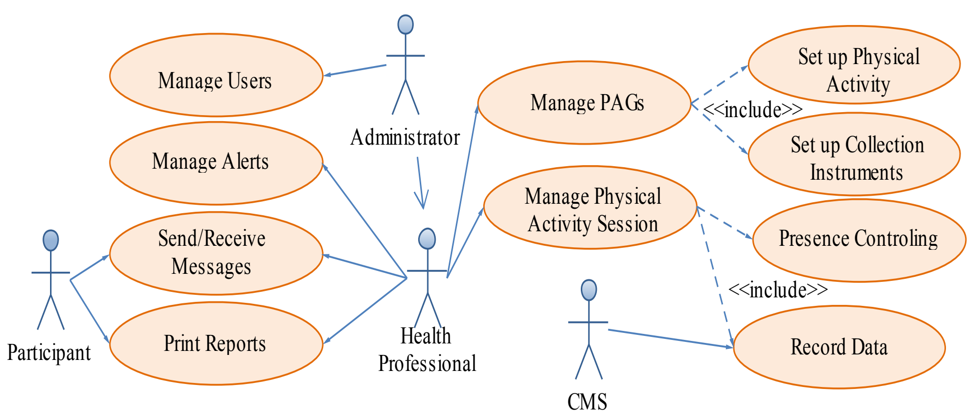


Figure 5. SIAF use case diagram

EXPERIMENTAL RESULTS AND EVALUATION

In order to provide subsidies for the choice of communication technology to be employed between the CMS and WBSN, this has been simulated and analyzed via the Network Simulator 2 (NS-2) version 2.34 (NS-2, 2010). NS-2 is a discrete event simulator which offers great flexibility in investigating the characteristics of the networks. To compose the simulation scenario of the WBSNs, a PAG with 10 participants was created, and for each participant, a personal WBSN with 3 physiological sensors (ECG, PPG, and BP) and an acceleration sensor (ACC) was created. As physical activities are developed in groups of 5 to 15 participants, the simulation scenario created is very close to the real environment. Figure 6 presents the WBSN simulation scenario in NS-2 and the Table 2 presents the parameters employed in this scenario.

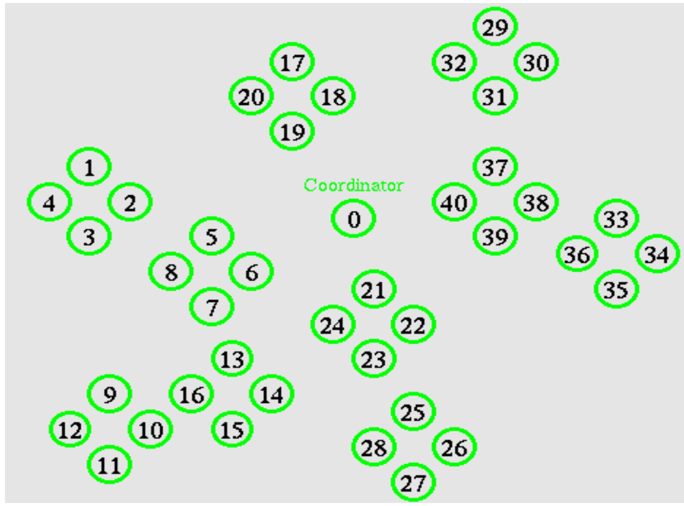


Figure 6. WBSN simulation scenario in NS-2

Parameter	Value
Traffic type	UDP
Packets size	100 bytes
Number of sensors	41
Movement of the sensor networks	Yes
Average speed of displacement	1.5 m/s
Area of movement of the sensors	25x25 meters
Simulation time	60 minutes

Table 2. WBSN simulation parameters

In the simulations conducted, the Bluetooth protocol was employed in part of time and the ZigBee protocol was employed in other part of time. For the assessment of these simulations, two metrics were considered: Average Power Consumption of the Sensor Network; and Delivery Rate of the Packets.

The simulations were performed for the following situations: continuous monitoring; and periodic monitoring, with data collection being carried out every 1 minute, 5 minutes, 10 minutes, 20 minutes and 30 minutes. These variations were applied in the same scenario and simulated for both Bluetooth and ZigBee. Each value plotted on the graph in Figure 7 and Figure 8 was obtained by the average of 10 simulations.

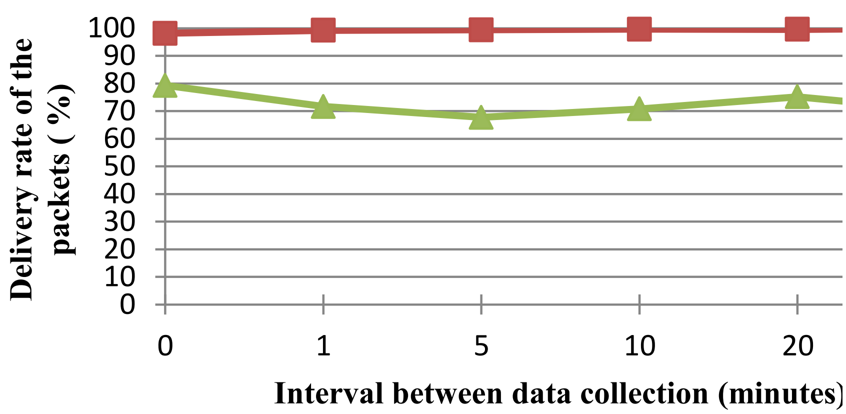


Figure 7. Delivery rate of the packets

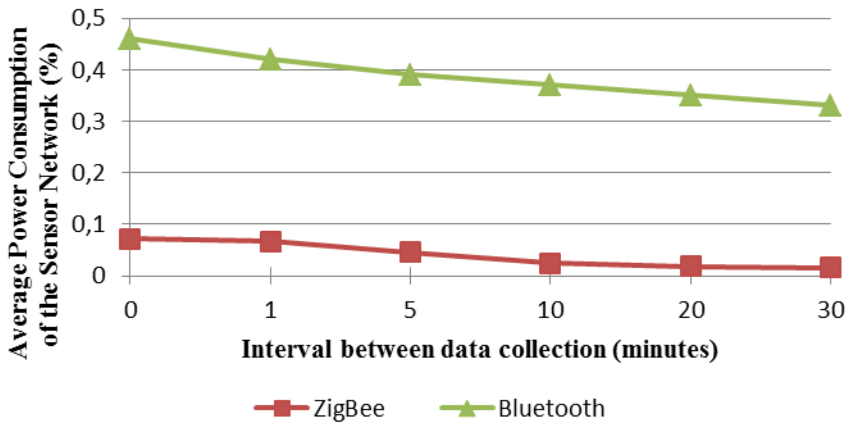
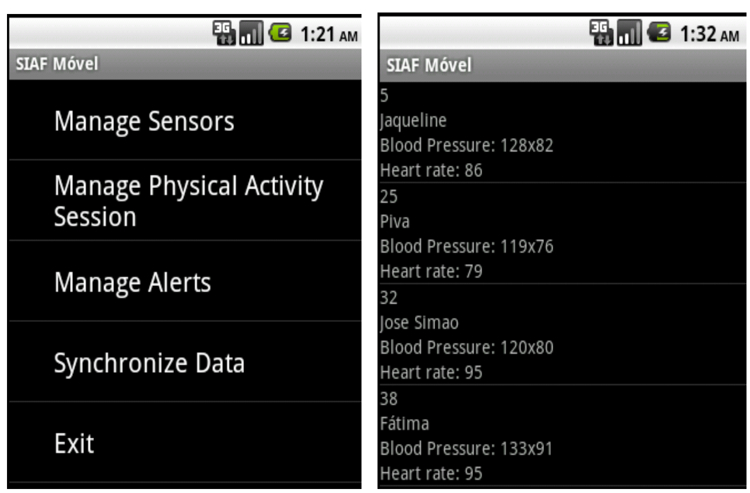


Figure 8. Average power consumption of the sensor network

From the results presented in Figure 7, it was possible to observe that, for the Delivery Rate of the Packets metric, the ZigBee protocol proved to be more appropriate. In simulations with Bluetooth, it was found that some sensors moved out of range from the WSBN coordinator radio waves, generates many losses in communications and consequently, in the packets. Meanwhile, with the ZigBee, the low rate of lost packets was not enough to compromise the operation of the environment.

From the results presented in Figure 8, it was possible to observe that, for the Average Power Consumption of the Sensor Network metric, the ZigBee protocol also proved to be more suitable for one-to-many approach. Although both wireless communication protocols have been designed for applications which require low power consumption, in UCEMEPA scenario the ZigBee proved to be the most efficient solution. The higher efficiency of this protocol, if compared to Bluetooth, is due to its lower energy consumption in data transmission and reception, and when the sensors are in a hibernation state.

To evaluate the CMS, a prototype of this module was developed in Java. This prototype was configured on a Motorola A953 smartphone device with Android 2.2 operational system. Figure 9 shows the main menu (a) and the mobile monitoring center (b) screens of the CMS.



(a) **(b)**

Figure 9. CMS: main menu (a); mobile monitoring center (b)

The screen in Figure 9 (a) allows the health professional to access the management and data synchronization functionalities while Figure 9 (b) shows a list of active participants during the monitoring of a Physical Activity session. The values in the last screen are continuously updated and analyzed.

In order to test the SIAF, it was implanted in a computer with Ubuntu operational system, containing AMD dual-core processor of 1.73 GHz, 3 GB of RAM and 120 GB of HD. The SIAF screen presented in Figure 10 allows following remotely and in real-time a participant's blood pressure signs, which are received during a monitored session. The data presented in this Figure were collected in regular intervals of 10 minutes. The yellow and dark blue lines indicate values of control for systolic and diastolic blood pressure respectively.

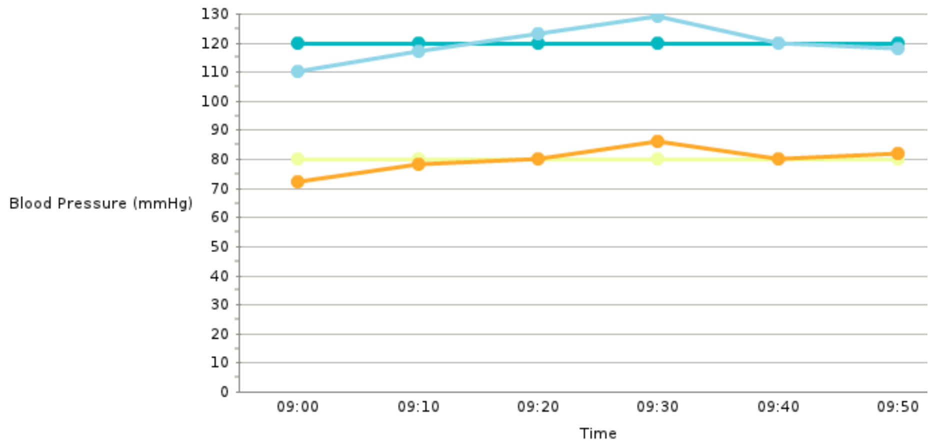


Figure 10. SIAF: online blood pressure report

Besides allowing the online monitoring, illustrated on the screen in Figure 10, SIAF provides reports on evaluation indicators to measure the effectiveness of the promotion of physical activity in the CNCDs prevention. For example, Figure 11 shows a report on the Weight indicator.

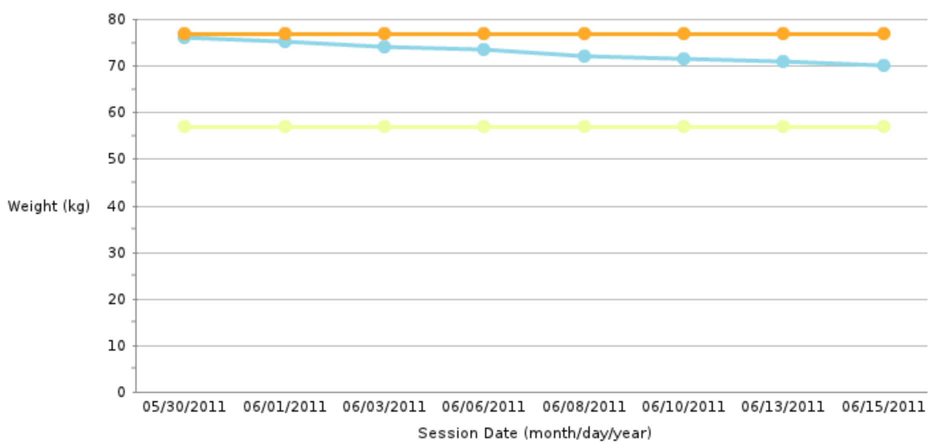


Figure 11. SIAF: weight indicator

In the previous Figure it is possible to notice that along the 8 physical activity sessions, the participant had a reduction of 8% in his weight (blue line). The upper and lower control lines indicate limit values of normality. Values above the orange line indicate overweight, while values below the yellow line indicate that the participant is under the ideal weight. Besides the report on the Weight indicator, the SIAF prints reports on the Adhesion, Adherence, Blood Pressure and Physical Activity Level indicators.

CONCLUSION AND FUTURE WORKS

This article presented UCEMEPA, a computational environment which employs mobile devices, sensors, and wireless communication networks to monitor remotely and evaluate in real-time individuals who practice physical activity in group.

UCEMEPA was explicitly designed to support WHO global strategy to fight against the sedentariness and to prevent CNCDs. This environment allows the generation of health indicators and indicators for the physical activity programs which help UBSs and USFs to evaluate PAGs longitudinally and direct public policies to promote physical activity.

Once the results of the simulations showed that the ZigBee was the most appropriate protocol to provide wireless communication between the sensors of the WBSN and the CMS, this was adopted in UCEMEPA. The low power consumption of this protocol provided greater operational autonomy to the WBSN, and its low rate of packet loss on the communication was not enough to compromise the operation of the environment.

Although the one-to-one approach with Bluetooth can be employed in the construction of environments for collective monitoring, from an economic point of view, the implantation of these environments in large-scale becomes very expensive. On the other hand, the construction of environments for collective monitoring using the one-to-many approach and ZigBee protocol reduces the implantation costs and makes the environment more scalable than the previous one.

Continuing this work, the next step will be the use of real monitoring sensors in UCEMEPA and the implantation of this environment in UBSs and USFs. After that, it will be possible to evaluate the usability perceived by health professionals while they are using the environment. It is planned also the integration of the environment with other information systems, such as HISs, so that these systems can access the data from UCEMEPA.

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