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A mobile system for sedentary behaviors classification based on accelerometer and location data

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ABSTRACT

Background: Sedentary behaviors are associated to the development of noncommunicable diseases (NCD) such as cardiovascular diseases (CVD), type 2 diabetes, and cancer. Accelerometers and inclinometers have been used to estimate sedentary behaviors, however a major limitation is that these devices do not provide enough contextual information in order to recognize the specific sedentary behavior performed, e.g., sitting or lying watching TV, using the PC, sitting at work, driving, etc.
Objective: Propose and evaluate the precision of a mobile system for objectively measuring six sedentary behaviors using accelerometer and location data.
Results: The system is implemented as an Android Mobile App, which identifies individual's sedentary behaviors based on accelerometer data taken from the smartphone or a smartwatch, and symbolic location data obtained from Bluetooth Low Energy (BLE) beacons. The system infers sedentary behaviors by means of a supervised Machine Learning Classifier. The precision of the classification of five of the six studied sedentary behaviors exceeded 95% using accelerometer data from a smartwatch attached to the wrist and 98% using accelerometer data from a smartphone put into the pocket. Statistically significant improvement in the average precision of the classification due to the use of BLE beacons was found by comparing the precision of the classification using accelerometer data only, and BLE beacons localization technology.
Conclusions: The proposed system provides contextual information of specific sedentary behaviors by inferring with very high precision the physical location where the sedentary event occurs. Moreover, it was found that, when accelerometers are put in the user's pocket, instead of the wrist and, when symbolic location is inferred using BLE beacons; the precision in the classification is improved. In practice, the proposed system has the potential to contribute to the understanding of the context and determinants of sedentary behaviors, necessary for the implementation and monitoring of personalized noncommunicable diseases prevention programs, for instance, sending sedentary behavior alerts, or providing personalized recommendations on physical activity. The system could be used at work to promote active breaks and healthy habits.

1. Introduction

Sedentary behavior is frequently defined as any waking activity characterized by low levels of energy expenditure (≤1.5 METs) while sitting or reclining [1]. Epidemiological evidence shows that sedentary behavior is associated to the development of non-communicable diseases (NCD) such as cardiovascular diseases (CVD), type 2 diabetes, and cancer [2]. Furthermore, some studies have demonstrated that high levels of sedentary time and low levels of moderate or vigorous physical activity are strong and independent predictors of early death from any cause [3].

A major future research topic identified in the literature is the improvement of the technology currently used for the objective measurement and characterization of sedentary behavior [3–6]. Methods for assessing sedentary behavior are typically classified as subjective and objective ones: subjective methods include self-report questionnaires, interviews and diaries; while objective measures include the use of devices such as accelerometers, inclinometers, heart rate (HR) monitors, etc. [4]. Subjective methods, especially self-report questionnaires, are widely used,

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feasible, cost-effective, and could obtain information about the context in which sedentary behaviors occur. However, reliability and validity limitations have been reported in the literature, caused among others, by the difficulty for a person to recall and recognize sedentary behaviors because they are sporadic, incidental and may occur in different locations [4,7]. As an example, the International Physical Activity Questionnaire (IPAQ), which is one of the more accepted instruments for measuring physical activity and sitting behavior has shown moderate reliability but moderate to poor validity compared to accelerometers [7].

Accelerometers and inclinometers are, typically, electronic devices used to estimate sedentary time based on the identification of low movement counts (the frequency and amplitude of acceleration of the body) at specified cut points [3]. These devices overcome some of the limitations of subjective methods, providing a more accurate and objective estimation of sedentary time [3,7]. However, as identified by a recent systematic review [7] and a Meta-Analysis [6], the main limitation of inclinometers and accelerometers for measuring sedentary behaviors is that these do not provide contextual information to recognize specific sedentary behaviors e.g., using computers, tablets, cellphones, TV viewing, sitting at work, driving, transportation, relaxing, etc. Geolocalization (e.g, using Global Positioning Systems – GPS) combined with accelerometry has been recognized as an alternative method to improve the accuracy of information about the context of sedentariness [3]. In this direction, Loveday et al. performed a systematic review of technologies for assessing location of physical activity and sedentary behavior, concluding that despite GPS was the most widely used location-monitoring technology, its precision and availability in indoor locations (where most of sedentary behaviors occur) is not enough to provide an accurate measure of sedentary behavior location [8]. Radio-frequency identification (RFID) and Bluetooth Low Energy (BLE) beacons (iBeacons), as emerging technologies for "tagging" objects in the context of Internet of things (IoT), are mentioned in the review as technologies with the potential to be used for indoor location (here referred as symbolic location).

The objective of this paper is to propose and evaluate the precision of a mobile system for objectively measuring sedentary behaviors using accelerometer and location data collected from nearby BLE beacons. Two experiments were performed separately: one using accelerometer data from a smartwatch attached to the wrist and location data from BLE beacons, and another using accelerometer data from a smartphone put into the pocket and location data from BLE beacons. Finally, the precision of the classification is compared in two scenarios: one using accelerometer data only, and the other adding location data collected from the BLE beacons.

1.1. Related work

There is a large number of studies using accelerometers and other motion sensors for activity classification, fall detection, gait analysis, rehabilitation, balance training and identification of psychological states [9]. Some of them include the classification of sedentary behaviors as a type of low intensity physical activity, but the task of classifying specific sedentary behaviors such as watching TV, using PC, sitting at work, driving, etc.; has been little studied. In order to identify relevant studies providing the classification of specific sedentary behaviors, we performed a literature search on Pubmed, IEEE Xplore and Science direct databases. Our inclusion criteria were: 1) Papers published in English or Spanish languages. 2) Papers describing a system based on a physical activity monitor or other devices used to classify at least one sedentary behavior including its posture. The search query used was the following:

(*sedentary lifestyle OR sedentary activity OR sedentary behavior*) *AND* (*classification OR tracking OR monitoring OR recognition*) *AND* (*physical activity monitor OR wearable OR wearable monitor OR activity monitor OR system OR technology OR RTLS OR camera OR accelerometer OR indoor positioning system OR RFID OR RTLS OR PALMS OR BLE OR Bluetooth OR NFC OR location measurement system OR indoor tracking system*)

The search resulted in 91 papers. After applying the inclusion criteria, only 5 papers met the requirements. The selected papers are summarized in Table 1.

Most of the papers analyzed were based on traditional physical activity devices such as Actigraph, ActivPal, GENEActive, Actical, Actiheart, and Stepwatch, commonly used to recognize one or more typical postures such as lying, sitting or standing. However, only the study performed by Spinney et al. [14] included one of the emerging location technologies described above. The authors implemented a system composed by two modules: an ActivPal sensor for classifying walking, standing and sitting postures; and the OpenBeaconSystem, an RFID-based location system used to register where these postures occurred. The baseline precision level of that system was 86.1%, which is the precision related to the recognition of the place in which the person is located within the indoor environment. In [10], a precision of 100% was reached when classifying three body postures: sitting, standing and lying, but reached using simultaneously an inclinometer and an accelerometer on the hip and thigh, respectively. In [11], GENEActiv and ActivPAL devices worn in the wrist and thigh were used, in order to identify sitting and standing postures. A better precision was obtained when wearing the ActivPAL on the thigh to classify between sitting and standing. The IDEEA project [12] used a combination of 6 accelerometers which were located in different parts of the body. This study, unlike [10], recognized low-level postures such as lying on the side or face up, and tried to recognize when the person was reclining, but not obtaining good results. The study described in [13] did not report the precision of the classification of postures; instead, the data was used to infer the time the person was sitting.

2. Material and methods

The main component of the proposed system is a Classifier system, which automatically recognizes six sedentary behaviors: sitting watching TV, reclining watching TV, having breakfast/lunch/dinner, using a computer, driving a car, and being transported by car. These sedentary behaviors were selected based on the taxonomy of sedentary behaviors proposed by Chastin et. al [15]. A data mining process was carry out using supervised machine learning algorithms. To this end, labeled data from 15 people, 8 men and 7 women, performing sedentary behaviors were collected. Participants did not have physical limitations to carry out the requested tasks. The volunteers' average age was 44 years, ranging from 25 to 87 years.

Another important component of the system is the technology used for collecting user's location data. Based on the review presented in the introduction, RFID and BLE were considered. The two factors taken into account when choosing the type of indoor location technology were its required accuracy and its total cost of implementation. In our scenario, a very accurate indoor location system is not necessary, because obtaining the user's symbolic location is enough in order to identify his/her activities based on nearby objects (TV, Couch, desk, etc.).Regarding costs of the implementation infrastructure, the implementation of an RFID-based indoor localization system involved the use of several components (active tags, readers and their antennas, controller and its software) making it more complex and costly compared to a system based in BLE. In a BLE beacons system, the smartphone