# Mobile Acquisition Platform for Sleep Assessment

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**Abstract**

With sleep being a physiological need essential in every individual's life, the current prevalence of sleep disorders is a serious issue. Although *polysomnography* (PSG) is the preferred tool for monitoring and diagnosing of such disorders, for it acquires a large amount of relevant data, it is an expensive exam, uncomfortable for the patient, which usually must be performed in clinical facilities.

The scope of this work is to provide a highly portable system, an alternative to existing sleep assessment tools, called *Mobile Acquisition Platform for Sleep Assessment* (MAPSA), supported by a physiological monitoring belt and a mobile phone connected via Bluetooth®. This system allows extended time monitoring, acquiring a limited set of physiological data, but also sleep related information, through sleep and dream electronic diaries. The MAPSA takes advantage of a light hardware and user-friendly interface, which should aid sleep physicians in the diagnosis of other types of disorders not easily detectable by the PSG.

**Key Words**: Sleep disorders, Physiological Monitoring Belt, Mobile Phone, Sleep e-Diary, Dream e-Diary.

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## 1 Introduction

Sleep has persisted as an essential physiological function throughout all mammalian evolution [13]. Nonetheless, sleep deprivation has become pervasive in society, with special relevance in the developed countries, where a significant number of people reports less than seven hours of sleep most nights. Such numbers explain the high prevalence of sleep disorders, which are related with reduced quality of life, increased morbidity and higher mortality risk, thus representing a significant economic and social burden to society [10]. Therefore, it is imperative to diagnose sleep disorders early and accurately.

While there are several diagnostic methods available in sleep laboratories, it is clear that *polysomnography* (PSG) represents the benchmark for diagnosing this type of illnesses. However, some of the most common sleep disorders do not require as much data as the PSG provides, being actually diagnosable with lighter systems [8], such as combinations of actigraphy, temperature, ECG and sleep diaries [2]. This subject arises the motivation of this work, which is to develop a highly portable system for aid in the diagnose of sleep disorders, hereby defined as *Mobile Acquisition Platform for Sleep Assessment* (MAPSA).The system consists of essentially two parts - a physiological acquisition belt and a mobile phone. The MAPSA is an easy-to-use and interactive system, which monitors several physiological signals and stores relevant sleep related information, through sleep and dream electronic diaries. All these parameters are intended to be used as a whole to elaborate a complete sleep journal over an extended period of time. This system was implemented in *Python* and developed in both Portuguese and English versions.

The following section provides a short background on the subject, describing some sleep assessment tools and the technology supporting the proposed system. Then, a section is dedicated to the problem definition and subsequent conceptual model and computational implementation. Section 4 depicts illustrative examples on how to use the tool and what outputs are to be expected, while the last section presents the main conclusions, as well as some possibilities of further work.

# 2 Physiological and Technological Background

Sleep is a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment [3]. Two separate states define sleep - *Non-Rapid Eye Movement* (NREM) and *Rapid Eye Movement* (REM) sleep, which alternate cyclically across a sleep episode [11]. Sleep interferes with many biological processes, such as immune system function, metabolism, gene expression and learning/memorizing capability [4]. Conversely, there are many factors modulating sleep, namely age and ethnicity [4].

## 2.1 Sleep Assessment Tools

The first step towards the diagnose of a certain sleep disorder by a physician is always the analysis of the patient's history and clinical findings, based on which the physician makes a preliminary diagnosis [7]. Naturally, for an accurate diagnosis, further evaluation is often required, which can range from subjective assessment, such as specific questionnaires and sleep diaries, to more thorough exams such as actigraphy or polysomnography.

*Polysomnography* (PSG) represents, with no doubt, the benchmark for diagnosing sleep disorders. This exam is indicated in the following diagnoses: sleep related breathing disorders, narcolepsy, parassomnias, sleep related seizure disorders, *Restless Leg Syndrome* (RLS), *Periodic Limb Movement Disorder* (PLMD), depression with insomnia and circadian rhythm disorders [9]. PSG is a multi-parametric test that thoroughly evaluates the bio-physiological changes that occur in the human body while the person is asleep, thus is usually performed at night. This exam monitors, namely, EEG, EOG, ECG, respiratory airflow, chin muscle tone, oxygen saturation and movements of legs, eyes, chest and upper abdominal walls. To measure all the these parameters, PSG naturally requires highly complex hardware [17].

A sleep diary is a registry of a person's quotidian activities, such as sleeping, meals and work-outs. For sleep disturbs diagnosis purposes, a sleep diary is usually maintained over a period of several weeks and is self-recorded by the patient [12]. Similarly, a dream diary is a journal in which dream experiences are recorded. Though nightly dreams recorded immediately after waking up, are the most important type of entries, personal reflections or waking dream experiences are also valuable for the study of dreams, psychology or, ultimately, sleep disorders evaluation [14].

## 2.2 Heart Rate Variability Biofeedback

Biofeedback is a procedure supported by machinery that translates physiological processes into audio or visual real-time signals, with the goal of controlling central nervous system activity. A particular biofeedback protocol deals with *Heart Rate Variability* (HRV), defined by the amount of heart rate fluctuations around the mean heart rate. HRV measurements are easy to perform, noninvasive and have good reproducibility, and are achievable monitoring either heart rate alone, or heart rate plus respiration. Most common protocols involve the displaying of cyclic heart variations on a video screen, while the subject observes the trace and uses it as feedback for regulating the breath and, consequently, the emotional state [18].

## 2.3 Physiological Monitoring Belts

Cardiac belts are devices designed to be worn around the thorax, below the chest area, and to monitor some physiological activity. Although traditionally these devices only monitor heart rate, modern cardiac belts were redefined as physiological monitoring tools. In fact, some of the marketed chest straps monitor not only ECG, but also breathing rate, temperature and activity [15].

## 2.4 Mobile Phones

Nowadays, mobile phones are a very attractive application platform, as most of them endue a lot of interesting characteristics, namely significant computing power, long battery life, many built-in sensors and wireless connectivity capabilities, such as Wi-Fi and Bluetooth® technologies. Plus, such mobile phones are becoming more and more a common tool among the general population [1]. While there are several *Operative Systems* (OS) for mobile phones available in the market, the *Symbian mobile OS* is widely spread, reaching low-cost devices, but still possessing a broad range of options and a user-friendly approach [5]. In particular, *Python for S60* (PyS60) is officially suported by Nokia®, hence providing access to most available phone functions [1].

# 3 System Framework

First, the need for alternative sleep assessment tools is exposed. Furthermore, the features such tools need to incorporate are depicted. In this particular work, after some bibliographic review and sleep experts consultation, the need for innovative, less expensive and portable exams arose. These exams should assist physicians in their daily practice, simplifying the diagnosis task.

The second step in developing the platform was establishing the system's architecture, the devices supporting it, and what tasks these devices should perform, in order to reach the designated purpose. The system hereby presented intends to offer an alternative supported by only two devices, a physiological monitoring belt and a mobile phone, comprising three interconnected main features: the acquisition of physiological data, a *Sleep electronic-Diary* (SeD) and a *Dream electronic-Diary* (DeD). The architecture of the *Mobile Acquisition Platform for Sleep Assessment* is presented on Fig. 1.

For the physiological monitoring belt role, the *Zephyr® BioHarness Bluetooth* was chosen as an adequate fit. This chest strap comprises two parts: a smart fabric chest strap and the *BioHarness Module*. The

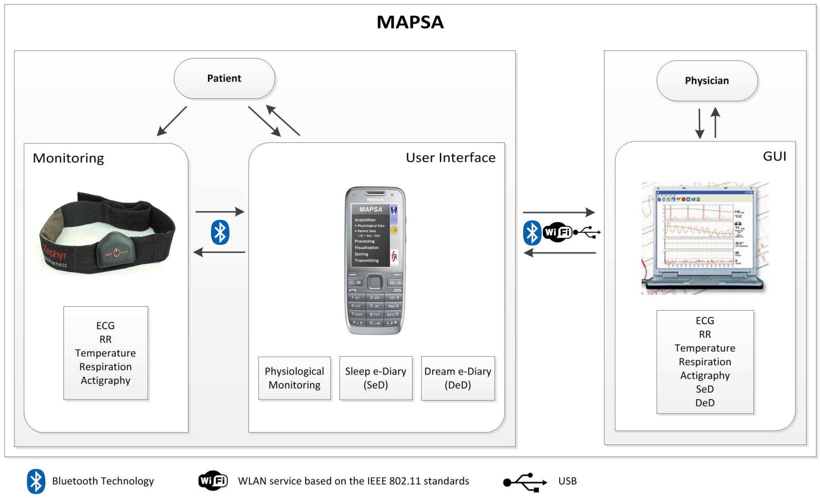



Figure 1: MAPSA system architecture.

subject wears the chest strap which incorporates sensors to monitor heart ECG signals and respiration rate. On the other hand, attached to the strap is the *BioHarness Module*, which includes an infrared temperature sensor, for monitoring skin temperature, and a tri-axial accelerometer, for monitoring attitude (subject posture) and activity (acceleration). Raw sensor data is acquired and transmitted by Bluetooth® over a ten meter range to a corresponding device, thus allowing physiological data monitoring [16].

The second device supporting the MAPSA is a mobile phone. Considering the architecture presented in Fig. 1, the mobile phone terminal application focuses on three areas: the connection to the physiological belt, the *Sleep electronic-Diary* (SeD) and the *Dream electronic-Diary* (DeD). As soon as the *Zephyr® BioHarness Bluetooth*'s power button is pressed, the device starts transmitting data. However, the physiological monitoring belt must also have established a Bluetooth® connection with a receiving device before data can be relayed to any application software [16].

In the context of the *Sleep electronic-Diary* (SeD), there are three actions available to the user in the main menu: *Insert Event*, *Show Calendar* and *Delete Event*. Although this suggests a simplistic approach, one must look at the structure of the SeD as a whole to understand that all the necessary features are present (Fig. 2 A). All the interaction is done through mobile phone selection menus, which schedule the registered events in the mobile phone's native calendar, providing a user-friendly approach to the visualization of events. Considering the *Dream electronic-Diary* (DeD), the tool must provide the user with five main options: *Record*, *Listen* and *Delete* dreams. Additionally, the DeD must be able to transcript the dreams, using an external speech recognition platform, as well as transfer the dreams to the physician's computer terminal. Bearing this in mind, the DeD design is structured as follows in Fig. 2 B. The recording of the dreams is achieved using the built-in microphone, while the dreams play using the built-in speakers. At the same time, the application automatically associates each recorded dream with an entry in the mobile phone's native calendar, enabling the observation of the subject dreams' frequency.

The *Graphical User Interface* available in the physician's computer terminal, is designed as a complete and interactive visualization tool. In fact, the high amount of data transmitted by the mobile phone demands a highly adaptable application, with chosen time spans and information parameters.

This last step explains the necessary computational implementation undertaken. Although such imple-

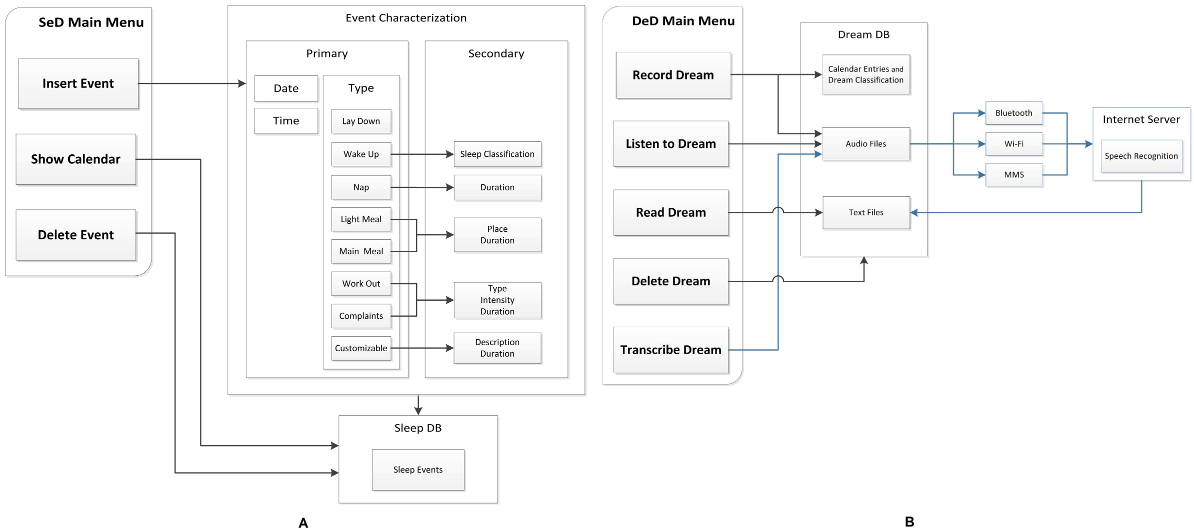



Figure 2: (A) *Sleep electronic-Diary* (SeD) and (B) *Dream electronic-Diary* (DeD) tool design.

mentation was only necessary for the applications associated with the mobile phone and the computer, the physiological monitoring belt is also referred, for its functioning and transmitting processes determinedly influenced the development of the mobile phone's *BioHarness Monitoring Tool*.

Considering the *Zephyr® BioHarness Bluetooth* handles a considerable variety of data, this information is monitored recurring to several individual packets. In this context, a packet is a segment of hexadecimal text containing a determined type and length (samples) of information, which is periodically sent to the receiving Bluetooth® device. Once all the desired data packets are activated, the mobile phone acquires, processes and records the information contained in all the data packets sent by the *BioHarness Module*, updating the user with relevant outputs. For this particular system, PyS60 was chosen as a developing language, for it is freely distributed, easy to both learn and use, yet still highly powerful. Using PyS60, the monitoring of the physiological belt, subsequent data processing and a user-friendly interface are possible on the mobile phone.

For convenience, the *Graphical User Interface* was developed in the computer version of PyS60 and its predecessor, *Python*. In particular, a GUI toolkit extension was used, *wxPython*, which allows the design of highly functional graphical user interfaces sparing the time-consuming need of writing all the associated code, which is automatically generated. Nevertheless, it provides the necessary connection with external Python modules such as *Matplotlib* or user created Python functions, representing a highly powerful tool.

# 4 Application Outputs

This section describes the features the developed system provides as outputs, subsequent to the computational implementation depicted in the previous paragraphs. Two applications to this system are presented. While the first is sleep disorder's focused, presenting the graphical user interface developed for the physician's use, as well as the role of sleep and dream diaries in insomnia diagnosis, the second, on the other hand, refers the possible use of this system on a different scope - heart rate variability biofeedback.

## 4.1 A Sleep Assessment System

From the patient's point of view, the MAPSA system entails two devices: the *Zephyr® BioHarness Bluetooth* and the mobile phone. The first (Fig. 3 A) represents a passive tool, for the patient only needs to adequately position the chest strap and press a button. All the necessary interaction involves the mobile phone, which both ensures the Bluetooth® connection with the belt and the required user interface for the registry of sleep related events, via *Sleep e-Diary* (SeD) and *Dream e-Diary* (DeD).


Figure 3: (A) Physiological monitoring tool for mobile phone, (B) Sleep and dream application selection, (C) SeD's main menu, (D) SeD's primary event characterization, (E) SeD's primary event characterization detail.

While the acquisition elapses, the patient undergoes his regular routine, using the *Sleep e-Diary* (SeD) to schedule the relevant activities or events (Fig. 3 B), such as meals or complaints. The main menu for this specific tool is presented in Fig. 3 C, in which the key option is definitely the first. This option enables the user to easily select the occurring event (Fig. 3 D), as well as its associated date and time, which are by default the current local time. The selectable events are shown in the detail illustrated in Fig. 3 E. In this SeD, *Lay Down* and *Wake Up* events are related. In fact, the tool imposes *Sleep* as an event each time consecutive *Lay Down* and *Wake Up* activities are inserted. Furthermore, the tool detects if the patient forgets the registry of either one of them, arising an error message, inquiring the number of sleep hours and creating the associated event.

All the registered events are scheduled in the native mobile's calendar, and thus can be consulted using a familiar interface. In addition to the regular possibility of deletion of events using the native calendar's interface, the SeD also provides such a possibility as a specific option. In fact, the tool depicts the list of events filtered by user selected day and type to simplify the selection of events to delete.

In the context of MAPSA system developed, the *Dream e-Diary* (DeD) presents three main menu options (Fig. 4 A): *Record Dream*, *Listen to Dream* and *Delete Dream*. The patient should select the first each time he intends to report a dream, usually immediately after waking up to ensure no details are forgotten. With the selection of *Record Dream*, the mobile phone starts recording an audio file until the patient finishes the report and chooses to stop the process (Fig. 4 B and C). Additionally, an associated event designated *DeD* is entered in the sleep calendar, which can be viewed as previously explained (Fig. 4 D). The two remaining options are *Listen to Dream* and *Delete Dream*. The selection of either one of these options returns a list of previously recorded dreams, from which the patient might select the ones to listen or to delete (Fig. 4 E).

Furthermore, sleep and dream classification are provided by the system. Considering the SeD, a sleep classification system was implemented. In fact, following the registry of each sleep event, a sleep quality

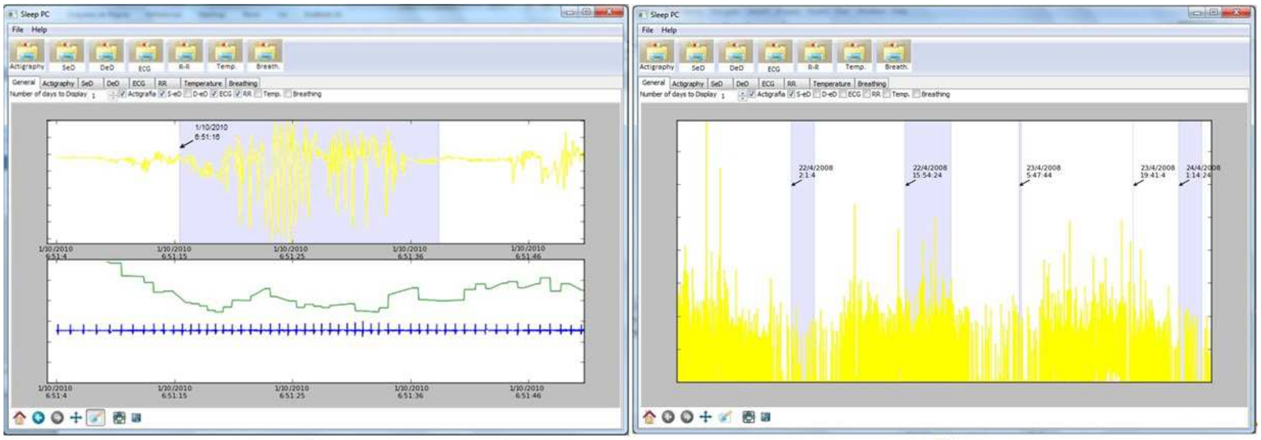

Figure 4: DeD's characteristics: (A) main menu, (B) start recording dream message, (C) stop recording dream screen, (D) dream event in calendar and (E) listen or delete dreams list.

questionnaire arises (Fig. 5), which is based on the one currently under use in CENC. As illustrative examples, two types of questions are portrait in Fig. 5 A and B, one which the user answers with a number and other with an associated Likert scale of classification. In the context of the DeD, a dream classification scale was also associated with the diary. Therefore, each time a dream is reported, the scheduling of that event in the associated calendar is followed by an informative message and four questions. These questions intend to assess the type of dream in question and can be useful when related to other sleep events such as early awakenings, reported in the sleep questionnaire.


Figure 5: Sleep quality assessment integrated in SeD: (A) initial message, (B) question 1 and (C) question 7 and associated classification scale.

On the other hand, from the physician's point of view, the mobile phone interaction is not at all relevant. In fact, the important features are the connection between the mobile phone and a computer terminal and the visualization of the collected data in a proper interface, which aids in the diagnosing of sleep disorders. Once all the monitoring files are at the computer terminal, the visualization of the physiological parameters acquired by the chest strap, as well as the sleep and dream diaries events can be achieved in the developed GUI (Fig. 6 A). This monitoring depicts a short span of time so that variations in variables such as ECG, breathing waveform or activity could be observable. In yellow, the actigraphy data collected is represented, while in green are the R-R intervals and in blue the ECG waveform.

The possibility of an adaptable platform, in which the number and type of parameters to visualize is adjustable, is even more relevant for special types of analysis which do not require the physiological monitoring belt. In the developed GUI, actigraphy information collected previously to this work with a wrist device is also




A B

Figure 6: Visualization of physiological parameters and sleep and dream events in computer environment.

considered, aiming at the simultaneous display of this data and both SeD and DeD events. In Fig. 6 B, the result of a simultaneous wrist actigraph and SeD monitoring is depicted. In yellow the magnitude of the acceleration derived from the patient's movements is shown, while the light blue spans of time indicate the events registered in the SeD.

The SeD was a tool idealized and patented in the context of a previous thesis [6]. In the present approach, however, numerous improvements were made. On the other hand, the DeD as it was designed required support by an external and web based speech recognition platform, which was not achieved, and thus a more feasible DeD was implemented. This approach to sleep assessment is considered to be valid in the context of this thesis, as it provides the groundwork necessary to a more complete and interesting future approach.

The development of a complete interactive visualization system, in which the physician might select the desired time spans and physiological parameters, is definitely a valuable tool. Altough the development of a complete, multiple patient prepared platform is not yet a reality, highly important progress was achieved, and the mobile phone accompanied monitoring over extended periods of time is now a tool able to generate data appropriate for long term sleep assessment analysis.

## 4.2 Heart Rate Variability Biofeedback

This section suggests a wider range of possible uses for the MAPSA system, with the application of the combo monitoring belt - mobile phone in biofeedback. In fact, considering the variety of parameters monitored by the physiological belt, the mobile phone might serve the purpose of displaying biofeedback relevant information, in an attempt to achieve brain control activation.

In the utilization of the developed platform in biofeedback, the chest strap and the mobile phone are the only tools required. The subject wears the physiological monitoring belt,while the mobile phone handles the Bluetooth® connection, which will trigger the beginning of the physiological acquisition. Once the acquisition starts, each time a R-R packet is processed by the mobile phone, a bar graph is displayed to the user, in which the corresponding real-time values are presented above each bar. In Fig. 7, three real-time monitoring examples are displayed, in an attempt to show the adaptation capability inherent to the system.

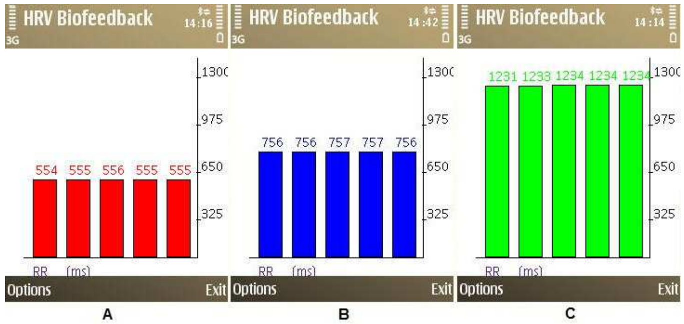



Figure 7: R-R interval bar graph representation in three different moments in time: (A) stress situation, (B) average situation and (C) extremely relaxed situation.

The system as it is enables the subject to perceive the physiological changes undergoing as he tries to perform brain control activation. Furthermore, to a layman, the RR-intervals or breathing rate observation are probably more intuitive and, thus, adequate than two bars representing the sympathetic and parasympathetic contributions, which require some insight into the matter. In conclusion, although this methodology was not extensively tested, considering protocols which point out that brain control activation is only possible after several sessions, evidence suggests that this system has the potential to be a valid fit for HRV biofeedback.

# 5 Conclusion

In the present work a system called *Mobile Acquisition Platform for Sleep Assessment* (MAPSA) was developed, which aimed at contributing to the sleep medicine field. In fact, the MAPSA should help physicians in their daily practice, providing a innovative and highly portable system to aid in sleep disorders diagnosis, an alternative to existing assessment exams. This platform took into account the available literature in sleep diagnosis, attempting to answer the multiple need expressed by sleep specialists.

The MAPSA is an evolving system. In fact, despite the current usefulness associated with MAPSA, in a near future this system might represent a much more complete and useful tool, which should be developed to meet both current needs and future challenges associated with the field. As intelligently as machines might be programmed, in this particular case mobile phones, they do not personify the knowledge acquired over years of experience by the physicians. Nonetheless, tools like MAPSA should be seen as helpful devices, highly relevant in the early and accurate assessment of sleep-disturbed patients.

# References

[1] Adelmann, R., Langheinrich, M.: Spark rapid prototyping environment - mobile phone development made easy. Intelligent Interactive Assistance and Mobile Multimedia Computing pp. 225–237 (2009)

[2] Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., Pollak, C.P.: The role of actigraphy in the study of sleep and circadian rhythms. american academy of sleep medicine review paper. Sleep 26(3), 342–392 (2003)

[3] Carskadon, M.A., Dement, W.C.: Normal human sleep: An overview. Principles and practice of sleep medicine pp. 15–25 (2000)

[4] Foster, R.G., Wulff, K.: The rhythm of rest and excess. Nature Reviews Neuroscience 6(5), 407–414 (2005)

[5] Harrison, R.: Symbian OS C++ for Mobile Phones: Vol. 1. Symbian Press, 1 edn. (2003)

[6] IST, Pires, P., Sanches, J.M.R., Paiva, M.T.S.A.: Metodologia de registo de eventos em diário electrónico, implementado em telemóvel, para auxília no diagnóstico de distúrbios do sono. Patente de Invenção Nacional Nº 104157 (2008)

[7] Korpinen, L., Frey, H.: Sleep expert - an intelligent medical decision support system for sleep disorders. Informatics for Health and Social Care 18(2), 163–170 (1993)

[8] Kushida, C.A., Chang, A., Gadkary, C., Guilleminault, C., Carrillo, O., Dement, W.C.: Comparison of actigraphic, polysomnographic, and subjective assessment of sleep parameters in sleep-disordered patients. Sleep Medicine 2(5), 389–396 (2001)

[9] Kushida., C.A., Littner, M.R., Morgenthaler, T., Alessi, C.A., Bailey, D., Jr, J.C., Friedman, L., Hirshkowitz, M., Kapen, S., Kramer, M., Lee-Chiong, T., Loube, D.L., Owens, J., Pancer, J.P., Wise, M.: Practice parameters for the indications for polysomnography and related procedures: an update for 2005. Sleep 28(4), 499–521 (2005)

[10] Martin, J.L., Fung, C.H.: Quality indicators for the care of sleep disorders in vulnerable elders. Journal of the American Geriatrics Society 55(2), S424–S430 (2007)

[11] Oswald, I.: The function of sleep. Postgraduate Medical Journal 52(603), 15–18 (1976)

[12] Perlis, M.L., Jungquist, C., Smith, M.T., Posner, D.: Cognitive behavioral treatment of insomnia: a session-by-session guide. Springer Verlag, 1 edn. (2005)

[13] Rechtschaffen, A.: Current perspectives on the function of sleep. Perspectives in biology and medicine 41, 359–390 (1998)

[14] Schredl, M.: Dreams in patients with sleep disorders. Sleep Medicine Reviews 13(3), 215–221 (2009)

[15] Technology, Z.: Bioharness bluetooth api guide (2010), version 1.9

[16] Technology, Z.: Bioharness bluetooth developer kit user manual (2010), version 1.12

[17] Togeiro, S.M.G.P., Smith, A.K.: Diagnostics methods for sleep disorders. Revista Brasileira de Psiquiatria 27, 8–15 (2005)

[18] Yucha, C., Montgomery, D.: Evidence-based practice in biofeedback and neurofeedback. Association of Applied Psychophysiology and Biofeedback (2004)