Real-time Monitoring of Occupational Stress of Nurses

Emil Jovanov, Karen Frith, Faye Anderson, Mladen Milosevic, Michael T. Shrove
University of Alabama in Huntsville, Huntsville, Alabama, U.S.A

***Abstract*—Prolonged exposure to stress has been associated with chronic diseases, depression, and immune disorders. Stress perception is highly subjective. Assessment of occupational stress requires personalized physiological monitoring and timely collection of individual characterization of sources of stress. We implemented a wearable system for monitoring of occupational stress of nurses – UAHealth. Personal monitors are implemented on iPhone smartphones with Ant+ wireless interface. Interbeat intervals are collected from a chest belt, and step count and cadence from foot pod sensor. All data are processed in real-time on the phone to assess stress index. A 30-minute personalized maximum over predefined threshold initiates a questionnaire to collect assessment of sources of stress. In this paper we present system organization and preliminary results.**

I. Introduction

Stress, strain responses, and chronic illnesses such as hypertension, cardiovascular disease, depression, and immune disorders are widely believed to be related [1][2]. Researchers and theorists believe that the hypothalamic-pituitary-adrenal and sympathetic-adrenalmedullary responses to stress over long periods of time are the physiological process responsible for chronic illnesses [3]. However the intermediate consequences of stress are not clearly understood.

McVicar described a continuum of psychological and physiological outcomes of stress including eustress, distress, and severe distress [4]. Although eustress is considered a helpful response to stress resulting in excitement and increased mental acuity and physiological signs (increased heart rate, blood pressure, and cortisol levels), stress too great for an individual's resources can create a disruption in homeostasis of the body. McEwen further explains that individuals can marshal physiological resources to short, stressful situations, resulting in elevations in heart rate and blood pressure. After the stressful situation passes, an individual's heart rate and blood pressure will typically return to baseline. However, under multiple stressful situations or unresolved stress, the heart rate and blood pressure may fail to return to baseline resulting in a new baseline called allostasis [5].

Appelhans and Luecken describe two theories (polyvagal theory and neurovisceral integration) that connect emotional responses to the activation of the autonomic nervous system and cardiac activity, specifically heart rate variability (HRV) [6]. In general, in healthy emotional responses to social situations, HRV is greater; however, reduced HRV is seen when coping is insufficient to the demands of the situation. This insufficient coping results in anxiety or depression. Studies of occupational stress have shown that HRV is a reliable measure indicative of strain from insufficient coping to stress [7][8][9]. Early detection of allostasis and interventions to reduce the strain responses could interrupt the progression to chronic illness.

Workload, leadership/management style, professional conflict, and emotional cost of caring have been described as the main sources of distress for nurses [4]. However, precise assessment of stress depends on personalized physiological monitoring and assessment of influence of personal and workplace factors. Promising tools in stress research are wearable sensors that can record continuous heart rate, blood pressure, and heart rate variability. When recordings of physiological parameters are paired with subjective measurements of stress, new information about intermediate indicators of strain can be developed.

Wearable monitoring has been revolutionized by advances in smartphone technology. The need for ubiquitous connectivity and integration of multiple devices on a single platform created the need for smartphones as a single universal platform. Mass market created a push for ever increasing performance of smartphones, where recent smartphones use high performance embedded processors.

Smartphones are designed to be used anytime, anywhere. Wide area connectivity using a cell phone network provides opportunities for immediate upload of critical health information and events to medical providers or specialized service. In addition, location capabilities implemented through integrated GPS or cell phone network localization can provide information about the current location of the person in need. Available memory allows smartphones to store physiological data for days and months at the time, even in the case of limited connectivity. Once connection is reestablished, all locally stored data may be uploaded to the medical server.

In this paper we present the development and

Manuscript received April 15, 2011. This work was supported in part by the University of Alabama in Huntsville under Grant UAH234343.

E. Jovanov is with the Electrical and Engineering Department, University of Alabama in Huntsville, Huntsville, AL 35899 (Phone: 256-824-5094; fax: 256-824-6803; e-mail: emil.jovanov@uah.edu).

K. Frith and F. Anderson are with the College of Nursing, University of Alabama in Huntsville, Huntsville, AL 35899, USA (e-mail: karen.frith@uah.edu and faye.anderson@uah.edu).

M. Milosevic and M. T. Shrove are with the Electrical and Computer Engineering Department, University of Alabama in Huntsville, Huntsville, AL 35899 (e-mail: mladen.milosevic@uah.edu and shrovet@uah.edu).

experimental evaluation of the UAHealth system for personalized physiological monitoring and assessment of occupational stress. The purpose of the study was to examine the physiological responses and identify episodes of occupational stress in nurses. Three aims are relevant to the study: (1) Develop software and database requirements for wireless physiological monitoring, (2) Identify occupational stress during simulated nursing activities, and (3) Develop software on mobile devices to show physiological indicators of stress and integrate these with subjective assessments of stress.

II. METHODS

We implemented a wearable monitoring system to monitor nurses throughout the work day and collect their responses about the source of stress. We decided to monitor heart rate, heart rate variability and physical activity using wearable sensors and a smartphone. Collected records are processed in real-time on smartphone, in our case iPhone, to create a custom, personalized, stress-index. All personalized measurements are processed relative to the personal baseline recorded at the beginning of the day. Possible long-term changes caused by the prolonged occupational stress are assessed using post-activity monitoring. Baseline (pre-activity) and post-activity physiological states are recorded in the quiet area, in a comfortably sitting position, with the legs uncrossed, for 8.5 minutes. The measurement time has been selected to provide length of record sufficient to assess baseline and post-activity heart rate variability and blood pressure variability [10]. Baseline physiological parameters are collected using non-invasive continuous monitoring to monitor beat-to-beat heart rate, SBP (systolic blood pressure), DBP (diastolic blood pressure), MAP (mean arterial pressure), SV (systolic volume), CO (Cardiac Output), SVR (Systemic Vascular Resistance), and dP/dt (maximum first derivative of the pressure). We use Nexfin monitor from BMEYE in Real-time Physiological Monitoring Laboratory at the University of Alabama in Huntsville [11].

During normal daily activities, subjects use UAHealth monitoring system to collect and store RR intervals and physical activity. UAHealth is an integrated mobile health monitoring system designed to monitor physical activity and heart activity, and collect response from the user. The System architecture of the UAHealth is presented in Figure 1. Users wear a standard heart monitoring belt and a foot pod sensor. Both sensors communicate with the personal monitor in a wireless body area network (WBAN) using Ant+ low power wireless standard. Personal monitor is implemented on iPhone with Ant+ gateway –Wahoo Fisica key [13]. A typical example of the heart rate calculated from interbeat (RR) intervals and step count in 15 second epochs is presented in Fig. 2. The experimental protocol has been approved by the UAHuntsville IRB committee (FWA00016967).

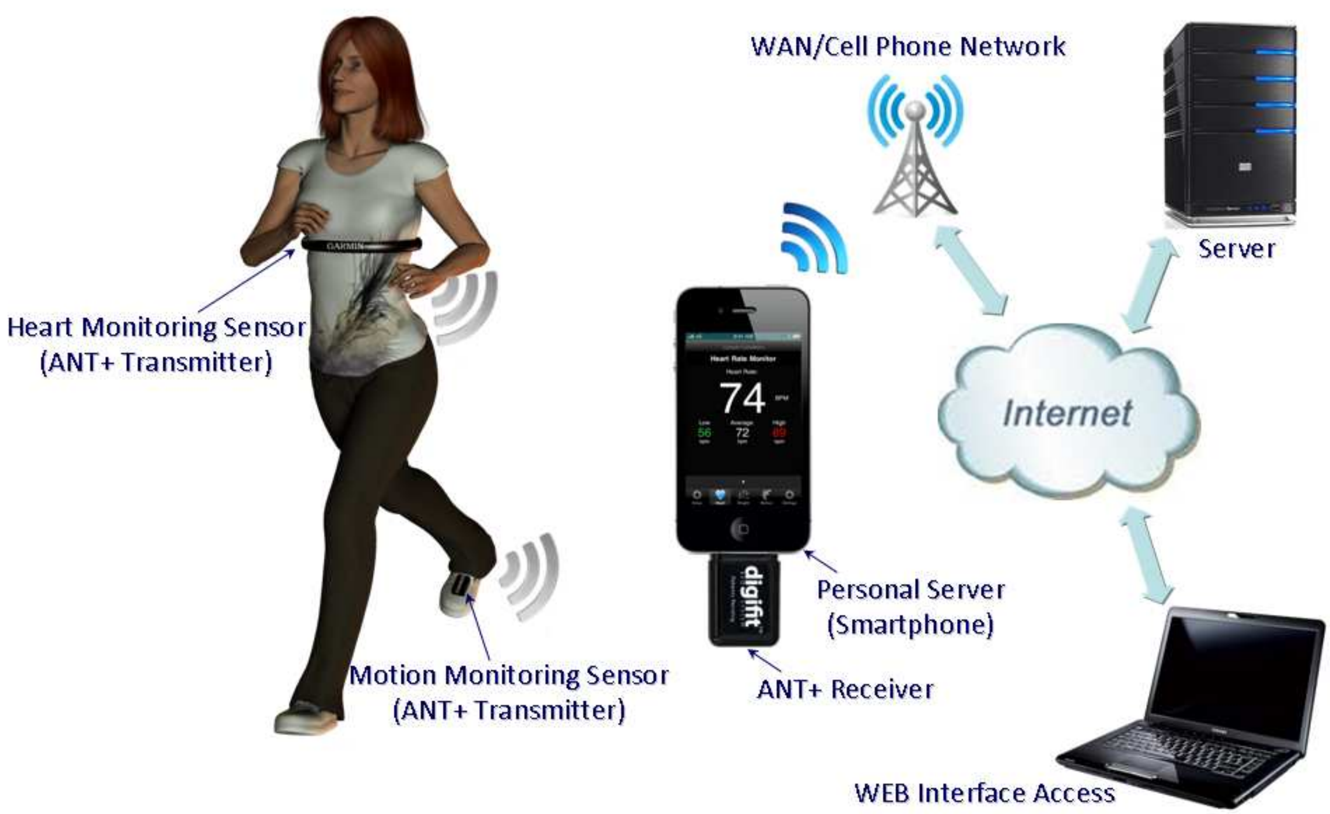

Fig. 1. System organization of the monitoring system

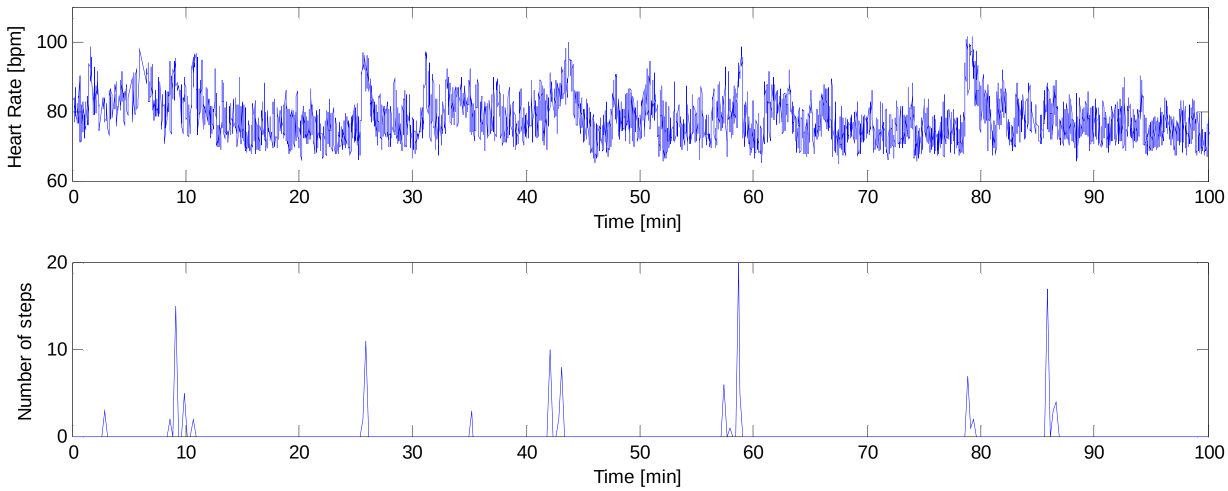

Fig. 2. Heart rate and step count during daily activities

Step count is collected in 15 second intervals with cadence. Both parameters are used to assess change of heart rate caused by physical activity. The typical example is presented in Fig. 2 at time t=26 min, when small physical activity (12 steps in 30 seconds) increased heart rate from 69 to 96 beats per minute.

The user can also monitor their own physiology on mUAHealth application on iPhone (e.g. heart rate monitoring on personal server presented in Fig. 3).

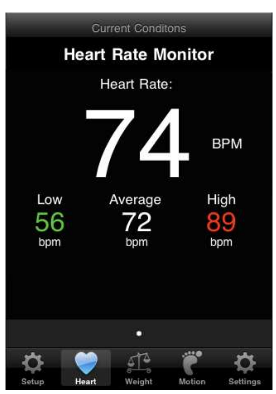

Fig. 3. *mUAHealth* – Heart rate monitoring

A personal server communicates with the UAHealth medical server using cell phone or WiFi network. The medical server was designed to be flexible and support variety of sensors and experimental scenarios. The server uses MySQL database for storing data received from the smartphone.

The personal server can monitor patients remotely at all times and store collected records for future upload; this organization implements a robust ubiquitous solution for health monitoring.

Our WBAN uses low power ANT+ wireless standard with commercially available off-the-shelf sensors, such as Garmin [12] chest belt and Garmin foot pod..

Collected data is uploaded to the personal health record on a server. Personal medical records on the server can be accessed by the user, medical professionals, or other individuals approved by the user.

Ubiquitous monitoring systems have to adapt to intermittent communication. Therefore *mUAHealth* is designed to work both online and offline. Subjects are not always monitored near an Internet connection, consequently, *mUAHealth* monitors Internet connectivity to determine when to submit health related information to the remote medical server. That is why it is essential for smartphone medical applications to have a local and remote database.

Personalized physiological response is assessed as a change of heart rate and heart rate variability, compensated for physical activity. Resulting stress index is calculated in real-time on the smartphone. Mean heart rate and heart rate variability are calculated in one-minute windows every 15 seconds.

All local maximums in a 30 minute window are declared as a stress episode. If no other maximums are detected, the program initiates a study specific questionnaire to collect information about current causes of stress, as represented in Fig. 4.

All results are stored in the database for postprocessing and analysis. We decided to collect events as maximums in the 30 minute window to minimize interference with their regular work. Please note that the questionnaire is activated after 30 minutes if no other stressful events with higher stress index have been detected. We believe that 30-minute period provides good trade-off between the need to avoid interference during critical (and stressful) events and the need to collect response from nurses as soon as possible after apparent stressful event affecting physiology of the subject.

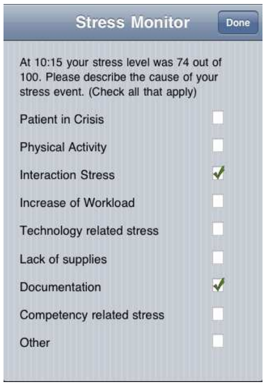

Fig. 4. Stress related questionnaire on iPhone.

III. Discussion and Conclusion

Personalized wearable monitoring of occupational stress of nurses may facilitate objective assessment of physiological changes and facilitate collection of subjective responses about the source of stress in the workplace. Our initial experiments included five subjects monitored during regular work.

In this paper we present system organization and preliminary results from a pilot study. The results from the pilot study will be used to refine calculation of stress index and minimally intrusive initiation of the questionnaire. After modifications, we plan to run the experiment on a larger group of nurses for prolonged period of time.

Acknowledgment

We are grateful to Ms. Greer Eleazer, Director of the Learning Resource Center in the College of Nursing, University of Alabama in Huntsville for help with organization of experiments and participant recruitment.

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