TERVA: Wellness Monitoring System

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***Abstract*-- Long-term monitoring of physiological and psychosocial variables would be beneficial to investigate slowly developing deterioration in wellness status of a subject. We designed a personal wellness monitoring system (TERVA), which allows monitoring wellness-related variables at home for many weeks or even months. The TERVA system runs on a PC computer and interfaces with different measurement devices through serial interface. Measured variables include beat-to-beat RR intervals, activity level, blood pressure, weight, temperature, respiration, ballistocardiography, movements, and sleep stages. In addition, self-assessments of daily wellbeing are stored by keeping a behavioral diary. To test the system, one healthy man was monitored for 10 weeks and an aged woman was monitored for 2 weeks. The data allows conclusion that the TERVA system provides a method to investigate wellness-related data over several weeks or even months in out-hospital conditions.**

Keywords: Long-term, home monitoring, wellness.

I. INTRODUCTION

Long-term monitoring of physiological and psychological variables at home would be beneficial to investigate slowly developing deterioration of the wellbeing of a subject. So far, the most widely used home monitoring systems are designed mainly for monitoring a single variable, such as blood pressure, blood glucose, ECG, etc. Consequently, the applications have been concentrated on monitoring of the development of chronic diseases, such as hypertension, diabetes, asthma, etc. However, monitoring a number of variables at the same time, would be of interest in various groups of subjects, e.g. patients discharged from hospital after a major operation or serious illness, risk-pregnant women, athletes, weight-watchers, elderly living independently or in institutional care, etc. In this case, the variable of interest is the subject's wellbeing (*wellness*), which is determined by various physiological and psychological factors. Hence, monitoring of more than just one variable over periods of weeks or months would clearly be of interest.

Few attempts have been made for home monitoring of multiple variables over periods of several weeks or months. Probably the closest relative to the present approach is made by Finkelstein et al [1,2], who developed a system for monitoring and interpretation of several different kinds of variables for cystic fibrosis patients. They demonstrated that multiparametric home monitoring is feasible and provides useful information for patients with cystic fibrosis.

The objective of the present study was to develop a system for long-term monitoring various wellness-related physiological and psychosocial factors at home. The functioning of the system was evaluated by pilot studies with one healthy middle-aged man and one aged woman.

II. METHODS

A. Monitoring system

The main criteria for the measurements and devices to be included in the monitoring system were:

1. *information*: the measurements should provide useful information that may be easily interpreted,
2. *easiness*: the measurements must be simple to perform independently, requiring minimum technical skills and co-operation,
3. *convenience*: the measurements should minimally disturb daily life, and
4. *price:* the measurement devices must be inexpensive.

The TERVA system (Fig. 1) was designed following these principles. The hardware design of the system and functioning of each device is described below.

1) Laptop computer

A laptop computer (Compaq® Contura 410C) controls the system, provides a user-interface for the measurement devices, records the data and displays the results.

2) Serial multiplexer

A custom-made software-programmable 8-to-1-channel serial (RS-232) multiplexer expands the serial port of the laptop computer to interface maximum 8 devices simultaneously. Only one device is active at a time. The active device is selected by software.

3) Blood pressure monitor

Dynapulse 200M (Pulse-Metric Inc, CA, USA) is a semi-automatic blood pressure monitor based on the oscillometric method. Special software delivered with the device guides the user in the measurement and computes systolic and diastolic blood pressure from the cuff pressure.

4) Thermometer

A custom-made thermometer is based on an electric thermistor, which is mounted at the end of a plastic pipe and equipped with RS-232 interface. The body temperature is measured from armpit in about three minutes.

5) RR-interval and activity monitor

RR-interval and activity monitor (prototype, Polar Electro Corp, Kempele, Finland) records beat-to-beat heart rate and activity in ambulatory conditions. RR-interval is automatically detected from ECG [3], which is measured with a special belt-electrode (no electrode pasta needed). Activity is measured by counting accelerations exceeding a certain threshold level within a minute.

6) Scale

A standard digital scale with a custom-made serial (RS-232) interface is used to measure body weight.

7) Static Charge Sensitive Bed (SCSB)

SCSB (Biomatt System, Biorec Inc, Helsinki, Finland) is used to record heart rate, ballistocardiography, respiratory rate and amplitude and movements when the subject is in bed [4]. The SCSB sensor is placed on the subject's bed under a special foam mattress. It performs its measurements fully automatically without any physical contact to the subject and is in that sense optimal for long-term home use. It is capable to sleep stage classification [5,6]. The device computes minute averages for the measured variables and sends them to the computer for further analysis.

8) Diary

A structured behavioral diary is kept on paper (one sheet / day). The subject assess his/her emotional and psychosocial wellbeing by answering thirteen questions, like 'During the day, I have felt myself: happy … unhappy'. The answers are scaled from 1 to 7. In addition, he/she writes down

Fig. 1. TERVA system. Laptop computer (1) is observing data via serial port from blood pressure monitor (2), thermometer (3), RR-interval and activity monitor (4), scale (5), and SCSB (6). The SCSB is positioned under a special foam mattress in the subject's bed and the scale is positioned on the floor next to the bed. For easy transportation and compact installation at home, everything (except the SCSB and the scale) is packed in a suitcase.

TABLE 1
DAILY MEASUREMENT SCHEDULES

Measurement	Healthy man				Aged woman			
	M	D	E	N	M	D	E	N
RR-interval & activity	├──	────	──┤					
Blood pressure	x	x	x		x		x	
Body temperature	x	x	x		x		x	
Body weight	x				x			
SCSB				├┤	├──	────	────	──┤
Diary	x	x	x		x	x	x	

M – morning (5:30 a.m. – 10:00 a.m.), D – day (10:00 a.m. – 6:00 p.m.), E – evening (6:00 p.m. – 12:00 p.m.), N – night (0:00 a.m. – 5:30 a.m.)

his/her daily consumption of alcohol, tobacco, coffee and tea. The results are afterwards transferred to the computer.

B. Software

The TERVA application software is running continuously on the laptop computer under MS-Windows 3.1®. The software and the computer settings are built so that the software loads automatically whenever the computer is switched on. This ensures that e.g. in the case of operating system crash the system may be easily re-started.

The subject initializes a measurement by measurement software. When a measurement is activated, software automatically selects the correct multiplexer channel as active and then starts a measurement-specific sub-program to guide the user through the measurement and to acquire and store the data. An exception is the SCSB measurement, which is automatically started whenever the pre-programmed measurement period starts. The software analyzes the SCSB data online and starts data storage whenever the subject goes to bed during the pre-programmed recording period.

The software has a built-in watch dog application, which continuously compares the pre-programmed measurement plan with the measurements performed, and alerts whenever a measurement should be made. When a measurement plan is followed as it stands, a single key press activates the pre-programmed measurement. Extra measurements can be activated from pull-down menus. The measurement plan may be adapted to the weekly rhythm of each subject so that the disturbance to the daily living is minimized.

The user-interface of the software is graphical. To ease the daily use, the normal lines of actions were analyzed and set as defaults in each window/display. Hence, normal daily routines do not demand use of mouse but may be performed by repeated pressing of the 'Enter'-button. The software provides simple feedback to the user so that he/she can confirm the success of the measurement and also get some immediate information, such as body temperature or blood pressure level. This feedback serves also as a motivating factor for the subjects to continue with the study. However, in this phase of the project, no advanced data reviewing capabilities are offered to the user e.g. for reviewing long-term trends or processed variables.

The data is time-stamped and stored on a database. Special search routines may be performed to display or export the selected variables for the defined time range.

C. *Subjects and protocols*

A healthy 46-year-old working man volunteered the study (Subject 1). He used the TERVA system for 10 weeks at home. He was familiar with the basics of using computers. Prior to the study, he was trained to use the system. During the study, a research nurse was continuously available for phone-consultation. In addition, she visited him weekly, verified the system functioning, and took backups of the data. The daily measurement plan is presented in Table 1.

Subject 2 was an 82-year-old female living in a rest home volunteering the study. She was monitored for 14 days. She had a reduced functional capacity and needed support in daily living. Due to this, the measurement plan had to be slightly adapted (Table 1). A trained nurse measured blood pressure, body temperature and body weight, and filled in the diary for her. In addition, RR-interval and activity monitor was not used. The SCSB measurement, in turn, was active throughout the day because the subject tended to spend a lot of time in bed even during the daytime.

D. *Data analysis*

For further analysis, the data was exported to Matlab®. To make the different variables comparable to each other despite the different sampling frequency, all the data were transformed into a single matrix, which had one representative value from each variable for each time of day (time-of-day, or TOD matrix): morning, day, evening and night. To construct this matrix, the following steps were taken:

1. Based on the *a priori* knowledge and statistical distribution of all the data points, reliability of each single data point was assessed. Based on this assessment, a reliability index (range from 0 – totally unreliable, to 1 – reliable) was then associated to each data point.
2. TOD matrix values for each time span were computed by searching the data points, which fell on that time span, and computing their reliability-weighted average. If no data fell in some time span, a *visibility* defined for each variable parameter was used to extend the time span for averaging. The visibility defines the time span during which the variable value may be considered relatively unchanged. In the present study, visibility for body weight was [–18.5 hours, 5.5 hours], and [0,0] for other variables. By this way, it was possible to get near-equally sampled estimations for each variable, which eased the visual analysis

All together 76 variables were computed for the TOD matrix from the measured data. In addition to TOD averaged measured variables, extra variables were derived from RR-interval (18 heart rate variability related variables) and SCSB (33 variables) data.

The analysis was carried out graphically by plotting the data as a function of time. Only a sub-group of variables are presented here for clarity.

III. Results

The measurements succeeded well in both subjects (Table 2). There were some technical problems during the recordings due to software and hardware but these were solved and they did not affect the recordings too much. Subject 1, the healthy man, who had the system installed at home and performed all the measurements by himself, had some complaints about the usability of the system, mainly associated with the limited feedback that the system provided about the results. Still, he considered the system easy-to-use and the results provided interesting and useful

TABLE 2
SUCCESS RATE OF MEASUREMENTS

Measurement	Number of Measurements Made (Executed / Planned, %)	
	Healthy man	Aged woman
RR-interval & activity	63 (90 %)	-
Blood pressure	152 (72 %)	29 (104 %)
Body temperature	148 (70 %)	29 (104 %)
Body weight	64 (91 %)	15 (107 %)
SCSB	64 (91 %)	56 (100 %)
Diary	156 (74 %)	33 (79 %)

In both subjects, the results showed large day-to-day and within-day variations in all the parameters (Figs 2-3). Still, the monitored variables may be associated with the wellness of the subject. For example, the Subject 1 had a period of flu between March 26^{th} and 30^{th}. This may be seen in various different parameters (Fig. 2). In fact, this period may be clearly distinguished from the data. In Subject 2, a general survey of the data shows that the subject has an exceptionally low body temperature and she is continuously fatigued despite sleeping well. This arouses a suspicion for hypothyresis, alarming for more specific investigations.

IV. Conclusions

A system was developed for monitoring wellness-related data in out-hospital conditions. The result, the TERVA system, was found to function satisfactorily well both at home and in institutional environment (rest home). The system provides information related to the wellness of the subject, and it may be used to trend exceptional episodes or general level of wellness. Graphic presentation makes the results easier to review and allows providing feedback to the subject or addressing a need for further investigations.

The TERVA system is the first general-purpose wellness monitoring system, which allows monitoring several variables over weeks or months in out-hospital conditions. Further developments should be concentrated in improving the usability of the system, especially in providing immediate feedback and review utilities to the subject him/herself, and in increasing the reliability and accuracy of the measurements. The future studies should assess the validity of the method in larger population. The exceptionally long monitoring time and large spectrum of monitored variables allows also studying totally new aspects, such as existence of weekly rhythms in the monitored variables, long-term interaction of different variables, or recovery from a severe illness.

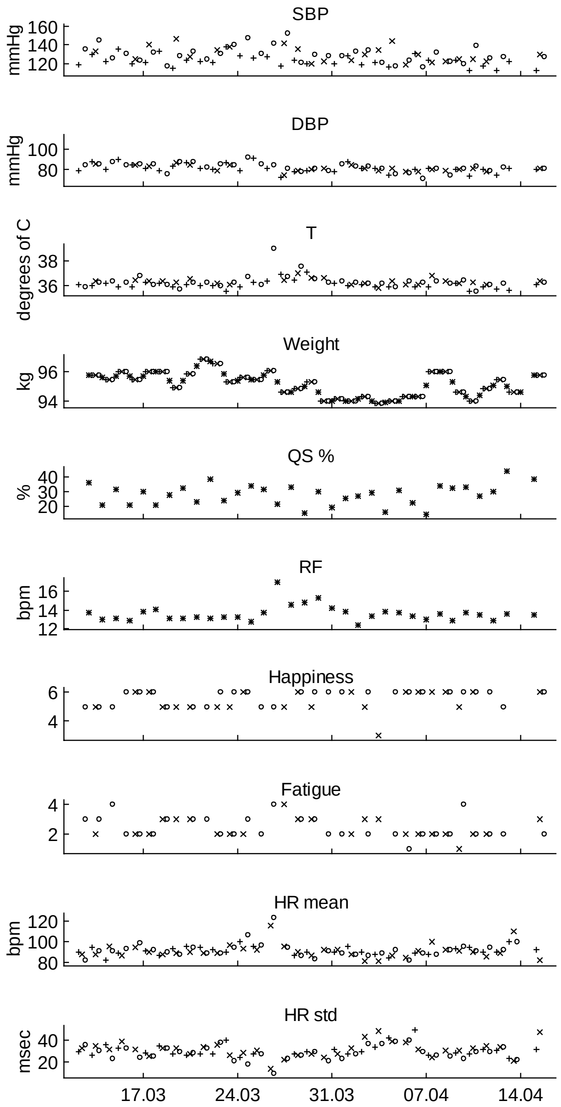

Fig. 2. An example of recordings from a 46-year old man (subject 1). Variables from top to bottom are: systolic (SBP) and diastolic (DBP) blood pressure, body temperature (T), body weight (Weight), percentage of quiet sleep from time in bed in the night (QS %), respiratory frequency (RF), and self-assessed happiness (from 1 – unhappy to 7 – very happy), self-assessed fatigue (from 1 – not tired to 7 – very tired), mean heart rate (HR mean), and heart rate variability (HR std). x-axis ticks stand for Sundays. Different symbols denote time of a day: '*' – night, '+' – morning, 'x' – day, 'o' – evening. Note a period of flu between March 26th -30th: the body temperature rises together with respiratory frequency in the night, heart rate and fatigue, and the body weight decreases as well as heart rate variability. The relative amount of quiet sleep and happiness are not affected.

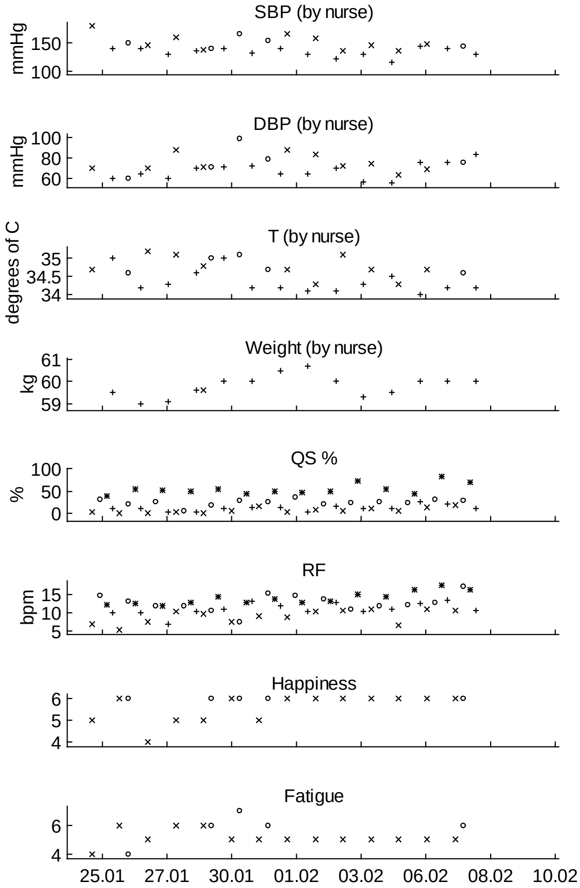

Fig. 3. An example of the recordings from a 82-year old woman (Subject 2). The subject is having continuously low body temperature and she feels herself fatigued. However, both her own assessment of the quality of sleep and high percentage of the quiet sleep during the night show that she sleeps well and her fatigue is due to other factors. The results arouse suspicion for hypothyreosis. For explanations of symbols and abbreviations, see text and Fig. 2.

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