Tango™ Wellness Motivator for Supporting Permanent Lifestyle Change

Antti Vehkaoja[1], Jarmo Verho[1], Mikko Peltokangas[1], Teppo Rantaniva[2], Vala Jeyhani[1], Jari Råglund[2]

[1] BioMediTech Institute and Faculty of Biomedical Sciences and Engineering, Tampere University of Technology, Tampere, Finland

[2] Health Care Success Ltd. Helsinki, Finland.

antti.vehkaoja@tut.fi

Abstract. We present a system designed for assisting people in obtaining healthier lifestyle. The system includes a monitoring device worn on the chest and a web portal that visualizes the measured parameters and provides the user motivating tips for healthier lifestyles. The monitored parameters include heart rate, step count, calorie consumption, activity level, heart rate variability and sleep quality. A unique feature of the system is that the communication from the wearable unit to the backend server is arranged via direct mobile network connection, thus avoiding the need for a separate gateway device. The measured data can be viewed with a web browser user interface. We evaluated the beat-to-beat heart rate estimation performance with ten subjects in a controlled exercise protocol and with three subjects in 24-h free-living conditions. The average mean absolute error of the R-R interval estimation was 8.0 ms and 6.4 ms in the two test scenarios, respectively and the corresponding coverages of the obtained R-R intervals 76 % and 94 %.

Keywords: Wearable Monitoring, Lifestyle Coaching

1 Introduction

Lifestyle has the single most important role in maintaining or affecting general health condition of a person. Sedentary lifestyle and poor dietary habits are the main causes of increase in prevalence of cardiovascular diseases, obesity, type-2 diabetes, and metabolic syndrome in Western countries and recently also in Middle East and Asia [1].

While general health awareness is increasing and there is a growing trend of self-monitoring of wellness, these trends only touch a small portion of the people, i.e. the ones who are already active and interested in their wellbeing. Those people who suffer from the aforementioned problems and who would really benefit from a lifestyle change are easily left out and do not get support for it. Wellness trackers and activity monitors coming on the market are mainly designed for people who are already active. The devices are not designed from the perspective of a person who is just trying to start a lifestyle change and who would need external motivating and encouraging. Some motivating systems exist for facilitating physical rehabilitation, such as the one described in [2] but what has been lacking are tools that the patients could use on their own and that would provide coaching in several aspects of life habits.

Healthy lifestyle consists of three main pillars: activity, sleep, and nutrition. All these together affect the overall wellbeing of a person. There are technological solutions developed for assisting in quantifying the behavior of the user with respect to any of these three areas. Activity is the one that has been gained the biggest attention from users and technology developers and the range of functionality of activity tracking devices has increased from the first ones that just used to show the average heart rate or count steps. For example, many of the newer wrist-worn devices also include sleep monitoring and sleep quality assessment in their service. In addition, there are devices dedicated exclusively for sleep monitoring and a lot of research has been done with different monitoring methods. One example of a commercial solution that uses a flexible mattress sensor has been developed by Beddit company [3].

Current solutions for nutrition monitoring are mostly based on food diary applications, where the user manually enters the meal content and the application breaks it up into nutrients. Automatic image based solutions for the detection of food content and computation of the energy and nutritional content have been studied and developed, too [4]. Another approach for assisting in changing one's dietary habits is not to try to quantify of what is eaten but rather try to directly assist in making better dietary choices by providing educative tips towards healthier diet.

In this paper we present our solution named Tango™ wellness motivator, which is intended for people who have not paid attention to their living habits earlier but are looking for a lifestyle change. The Tango™ system is based on a holistic approach considering all the three pillars that affect on physical welfare and gives support on improving them.

2 Tango™ Wellness Motivator System

The proposed system consists of a chest-worn monitoring device that is attached to a regular heart rate monitoring belt, a back-end server system for storing the measurement data, and a front-end user interface that is accessed through a web browser. A special feature of the system is that the monitoring device communicates with the back-end directly using the GSM cellular network, thus avoiding the need for a separate gateway device.

As said earlier, the purpose of the system is not to work as a basic activity monitor, but rather as a lifestyle coach that motivates the user to pay attention on his/her daily habits; i.e. generally encourages to move more, adjust the amount of sleep, and optimize dietary choices. Therefore, a decision was made not to provide the user real time information to e.g. a wrist device but to encourage the user to use the dedicated web portal to see the daily activity results and at the same time be provided with tips on how to improve the general wellbeing. The components of the system and their most important features are presented next.

2.1 The monitoring device

The heart of the chest-worn monitoring device is nRF52832 SoC (System on a Chip) that includes an ARM Cortex M4F processor core and several versatile peripheral devices, e.g. Bluetooth Low Energy (BLE) radio. The monitoring device uses an ADS1292R analog front-end from Texas Instruments for measuring the ECG signal and an MPU-9255 9D motion sensor from TDK Invensense for detecting steps and monitoring sleep. Communication with the cellular network is handled with SARA-G350 2G GSM modem from u-Blox. The device is charged with a custom charging dock powered by a normal micro USB charger. The BLE connection provided by the SoC could be used for transmitting the measured information to a local, e.g. a wrist-worn device but this has not yet been implemented and is reserved for future use.

Operating modes

The monitoring device has two operating modes. In the daytime mode it measures the ECG signal and calculates beat-to-beat heart rate from it, detects step counts and measures activity and posture of the user. The other operating mode is low-power sleep monitoring mode or nighttime mode. In nighttime mode, the device is worn on the wrist with in a dedicated wrist cradle. The ECG measurement and step counting are disabled and an algorithm for detecting sleep/wake states based on acceleration measurement is used. The presence of the nighttime measurement cradle is detected by the signal obtained from the ECG measurement channel.

Communication with the back-end server

The communication with the back-end is initialized and executed in a following way: the device initializes the GSM modem on start-up, sets up a GPRS data connection, obtains the IP address of the back-end server via DNS, opens a TCP socket connection to it and then requests the initial configuration using a simple custom protocol. The configuration contains the initial time; the daytime mode data transmit interval (one minute by default) and information about the latest available firmware.

Assuming the device is in the daytime mode (measuring ECG and counting steps), it keeps the socket connection to the back-end server alive and sends new data periodically in one minute intervals by default. The server, in turn, acknowledges each received data block. The acknowledges are not strictly necessary, but they make the detection of data loss simpler and more reliable. The main drawback of this is the increased current consumption, which is, however, minimal in comparison to the power required simply to keep the GPRS data connection open. The monitoring device has on-board memory for storing up to two hours of data in case of a loss of network connection.

When the device is in the nighttime mode (measuring sleep quality), the GPRS data connection is normally shut down. The device registers to the GSM network every 15 minutes, sends the collected sleep quality data and then deregisters from the network. While the network registration and deregistration are slow operations consuming lots of power, the net effect is still a significant reduction in average power consumption.

The average current consumption of the device was measured to be 16 mA in daytime operating mode and 4.4 mA in nighttime mode.

2.2 Signal processing

Some of the monitored parameters are computed on the device in order to decrease the amount of transmitted data and the rest, which are derived from the previous ones, are calculated in the back-end system. The heart rate and step counting algorithms were developed specifically for this system and for the other parameters, algorithms proposed in the literature were used. Minute by minute energy expenditure is estimated through the average heart rate by using method proposed by Keytel et al. in [5]. The model-based estimation algorithm considers the age, weight, and the gender of the person. The energy expenditure values are calculated in the back-end side, which is a natural choice, as the user information is stored there. Sleep/wake detection is based on the algorithm proposed by Cole et al. in [6].

The developed step counting algorithm exploits a two-phase approach by first classifying the type of activity, and then, if walking or running activity is detected, the steps are being counted. This approach enables using simple, adaptive threshold approach in the step counting phase. Proprietary heart rate estimation algorithm uses the slopes and the amplitude of the R-peak as features and compares the features of new R-peak candidates to the already detected R-peaks. The algorithm does not report an R-peak if the signal has too much noise. A relatively low 100 Hz sampling frequency is used for the ECG to minimize the computational load of the microprocessor. This sampling rate has still been found adequate for beat-to-beat interval estimation [7].

2.3 Web portal user interface

User can observe the recorded data via a web browser user interface partially shown in Fig. 1. When signing-in, the UI first provides the user with an intuitive summary view of user's activity status. This summary view takes into account the user behavior from the past seven days and presents the status with changing background color. All the monitored parameters are presented below the summary view. These are divided in four categories: activity, heart, rest and nutrition.

Heart rate tachogram is shown from a desired period together with a heart rate variability (HRV) index (not shown in Fig. 1). The HRV parameter displayed is the RMSSD (root-mean-square of successive differences) and features an automated function for obtaining comparable values of this index i.e. recognizes when the user is still and in relaxed orientation for long enough.

Daytime activity levels are categorized in four classes based on the heart rate and the activity information obtained with the movement sensor. The commonly used definitions of 55 % and 70 % of the maximum heart rate are used as thresholds between low and moderate, and moderate and high intensities. Sedentary time is indicated when the heart rate and activity level stay low for too long time. Activity category also includes steps taken and calories burned during the day.

Other features of the user interface, not shown in Fig. 1, include sleep/wake hypnogram and other derived sleep parameters: sleep latency, sleep efficiency and total sleep time. In addition, the dietary and nutrition section is not shown in Fig. 1. Due to the lack of convenient and easy-to-use solutions for food intake, we have currently taken the approach of providing the user with motivational dietary tips and recommendations.

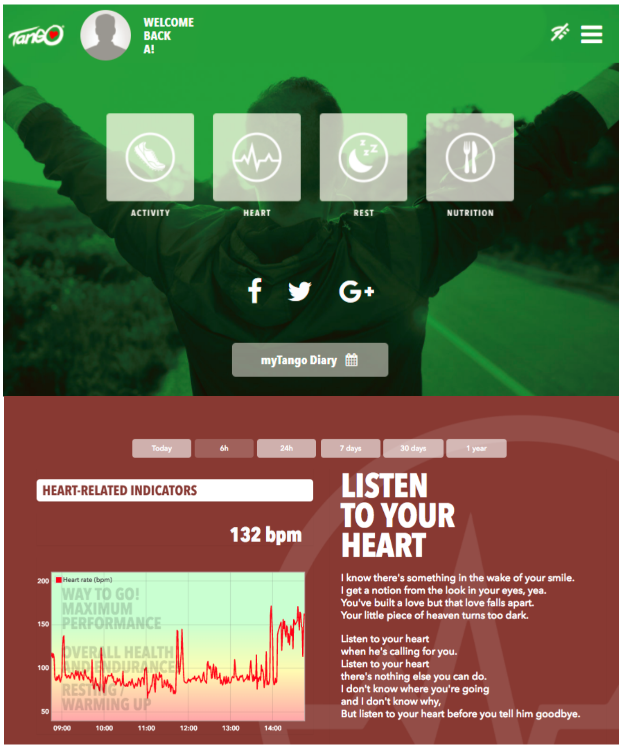

Fig. 1. Tango™ web portal user interface.

3 Validation of the Heart Rate Algorithm

We evaluated the performance of the beat-to-beat heartrate estimation algorithm in two tests. The first HR test setup had a controlled test protocol of approximately 30-minute duration and the other one was a 24-hour recording in free-living conditions. The following test protocol was implemented in each controlled measurement: 1) normal walking and going stairs up and down, 2) laying on a bed, 3) riding an exercise bike (12–16 km/h), 4) running on a treadmill (speeds of 3, 5, 8 and 11 km/h), and 5) standing up. The duration of each phase was 3 min, and there was a break of 30 s between each phase. The data were analyzed for 10 subjects in controlled measurements and for 3 subjects in 24-hour measurements. The heart rate belt was not moisturized before the beginning of the tests to mimic the intended usage condition, which is long-term use throughout the day not just when going for a walk or to do some other exercise.

The subjects were young healthy adults. The subjects were informed about the study and they signed informed consent forms. The principles outlined in the Helsinki Declaration of 1975, as revised in 2008, were followed in the study. Reference data was recorded with Ambu Blue Sensor R-00-S disposable stress test electrodes placed under the right clavicle and on the left hip to measure approximately the Lead II ECG signal. The signal was recorded with Faros 360 ECG monitoring device from Bittium Biosignals Ltd. Faros is certified as Class IIa medical device. The reference ECG data was analyzed with professional Holter ECG analysis software, Cardiac Navigator from Bittium Biosignals. The detected R-peaks were visually verified and corrected. Some periods of the measurement had so high noise level in the reference ECG that the true R-peaks were not visually observable. These segments were marked as noise. In this algorithm evaluation test the reference results were compared to our own heart rate algorithm by loading the data to Matlab and running the algorithm.

R-R-intervals were found in both signals and the corresponding intervals were assigned to each other. The assignment was visually verified and corrected. If an extra beat was detected in the belt ECG, this R-R-interval was compared with the previous detected R-R-interval of the reference ECG. In case the belt ECG was missing an R-peak, the erroneous (too long) R-R-interval was assigned to both of the corresponding intervals in the reference ECG.

4 Results and Discussion

Table 1 shows the results of the algorithm evaluation. The performance of the system was approximately equal during both, the controlled test and the free-living conditions in terms of RRI estimation error. The coverage was significantly better during the 24-hour test due to generally smaller amount of movement during the recording. In the controlled measurement, two test subjects had the coverage of the belt ECG less than 30% due to the high-amplitude artefacts in the measurement signal. They both had the largest R-R estimation error as well. With the other subjects, the belt ECG coverage was higher than 72% with mean absolute error less than 10.3 ms and rot mean square error less than 26 ms. In one test subject, the belt ECG provided higher coverage (82.88%) than the reference ECG (68.64%). The majority of the large beat detection errors occurred during short periods of RRI-series interrupted by bad-quality ECG or just before or after a break caused by bad-quality ECG. The sweating during the treadmill exercise improved the skin-electrode contact: all subjects had good-quality ECG at the end of the measurement, even though some of them had major artifacts in the ECG during the other phases of the measurement. The choice of not moisturizing the heart rate belt before starting of the recording was made on purpose for trying to mimic the intended usage conditions of the system. We assumed that the users would not be moisturizing the heart rate belt electrodes when putting the device on for a day. However, it can be concluded based on the test results that moisturizing the electrodes is needed to obtain signal with adequate quality, at least if there will be excessive amount of movement before the skin-electrode contact improves naturally by sweating.

Table 1. R-R-interval estimation performance during the two test protocols

	Controlled measurements (average (range)), (N = 10)	**24-hour measurements (average (range)), (N = 3)**
Mean absolute error (ms)	7.99 (4.69…26.34)	6.34 (5.79...7.30)
Root mean square error (ms)	19.10 (6.00…61.56)	20.67 (11.88…23.84)
Mean error (bias) (ms)	-0.53 (-10.34…1.83)	1.33 (-1.49…3.53)
Coverage (%)	76.24 (24.19…99.67)	94.17 (90.61…99.82)
Reference coverage (%)	95.64 (68.64…100)	99.84 (99.53…99.99)

5 Conclusion

We have presented a system intended to be used as a motivator tool for people trying to improve their living habits. In wellbeing point of view, the system addresses the three main components of health: activity, sleep, and nutrition by supporting healthier lifestyle and providing tips for improving it. The future work will include evaluation of the system with subjects belonging to the actual target group. Also, the subjective perceptions will be evaluated with interviews. Technical development of the future will include implementing the respiration monitoring to gain better insight to users' fitness.

Conflict of Interest

JR and TR are employees of Health Care Success Ltd, producer of Tango™ system.

References

1. Ramahi T M: Cardiovascular disease in the Asia Middle East region: global trends and local implications, Asia Pacific Journal of Public Health 22,83S–89S (2010).
2. Vehkaoja A et al: System for ECG and heart rate monitoring during group training, Proc. 30th Annu Int Conf IEEE Eng Med and Biol Soc, pp. 4832–35, Vancouver, Canada (2008).
3. Paalasmaa J et al: Unobtrusive online monitoring of sleep at home, Proc. 34th Annu Int Conf IEEE Eng Med and Biol Soc, pp. 3784–88, San Diego, USA (2012).
4. Hassannejad H et al: Automatic diet monitoring: a review of computer vision and wearable sensor-based methods, Int. J Food Sci and Nutr, 68(6),656–670 (2017).
5. Keytel L R et al: Prediction of energy expenditure from heart rate monitoring during submaximal exercise, J Sports Sci, 23(3),289–297 (2005).
6. Cole R J et al: Automatic sleep/wake identification from wrist activity, Sleep, 15(5),461–469 (1992).
7. Mahdiani S et al: Is 50 Hz high enough ECG sampling frequency for accurate HRV analysis?, Proc. 37th Annu Int Conf IEEE Eng Med Biol Soc, pp. 5948–51, Milan, Italy (2015).