Addressing the healthcare cost dilemma by managing health instead of managing illness

An opportunity for wearable wireless sensors

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***Abstract*— The cost of healthcare is increasing worldwide. Without disruptive changes, a large part of the population in many developed countries will no longer be able to afford healthcare by 2040. Part of the solution will come from focusing on prevention. Having personal tools at everyone's disposal, which will help people to monitor their health and to change their behavior, can enable disease prevention. Managing weight and managing stress are two societal challenges where a behavioral change can have huge cost savings. In this paper, it is shown how wearable sensor devices are able to detect energy expenditure as well as monitor stress levels. System aspects and validation are discussed. Because convenience and user acceptance are key for making these tools a success, smaller form factors and more convenient sensor locations on the body are required.**

Keywords*— *wireless sensors, body-area networks, healthcare

I. INTRODUCTION

While healthcare is continuously getting better at treating and curing people, the overall healthcare system itself is ailing [1]. The cost of healthcare is increasing worldwide, and without disruptive changes, a large part of the population is at risk for no longer being able to afford healthcare in 2040. Curbing this trend while ensuring that everyone receives at the least the same quality of healthcare as today is one of the greatest challenges of our time. To solve this challenge, disruptive changes are needed. Healthcare is focusing on managing illness. It is doing an ever-better job, partly thanks to technology. In the future, healthcare should be focusing on managing health, which is predictive and preventive and therefore will be saving cost as well as lives.

To tackle the formidable challenge of preventive healthcare, people must have tools at their disposal that will help them change their behavior and take control of their own health. Managing fitness and managing stress are two of the key challenges that need to be tackled.

II. MONITORING FITNESS THROUGH ENERGY EXPENDITURE

Lack of physical activity is one of the major health problems in most of the Western world. 31% of all people are insufficiently active.

978-3-9815370-0-0/DATE13/©2013 EDAA

With over 1 billion overweight people on the globe, and 300 million obese, weight is the 4th biggest risk factor for global mortality leading to 3.2 million deaths each year. However, it is not straightforward to combine our daily work and life with healthy active living, as most of us spend the better part of a workday doing sedentary activities. As a result, there is an imbalance between the calories burned due to physical activity and those accrued by food intake and this leads to a weight increase. The accurate quantification of habitual physical activity in ambulatory day-to-day settings is a starting point to provide people with tools to monitor their energy balance. Furthermore, it is also an essential tool to further quantify the relationship between such activity and health. Determination of calorie intake on the other hand is currently very qualitative, and similarly tools for quantitative calorie intake are needed. Imaging or hyperspectral imaging of food using smartphones is being explored [2]. This paper focuses solely on the calorie expenditure measurement tools.

Fig. 1. Single-lead ECG necklace and ECG patch for determining energy expenditure.

An accurate measurement method for energy expenditure is indirect calorimetry [3]. Because this is a very cumbersome technique, accelerometers and heart rate monitors are being used by epidemiologists for objectifying physical activity [4, 5]. However, because the extraction of energy expenditure from these single data is not accurate, improved sensing methods are needed. We have shown that a wearable multi-parameter patch is able to accurately measure energy expenditure [6] in a pilot study of 19 subjects. A wearable necklace or a patch with skin adhesive (see Fig. 1) measured single lead ECG and acquired 3-axis accelerometer data across 48 activities per person. Activity clusters of sedentary and non-sedentary activities were created and modeled. The six clusters of daily activities are: lying, low whole body motion (e.g. sitting, writing, working on a PC, watching TV, …), high whole body motion (e.g. cooking, cleaning, stacking groceries, …), walking, biking, and running. A feature selection model recognized six clusters of activities independent of the subject in 52.6 hours of recording from the 19 participants. Compared to state-of-the-art, the achieved improvement in energy expenditure accuracy ranged from 18-31% (see Fig. 2).

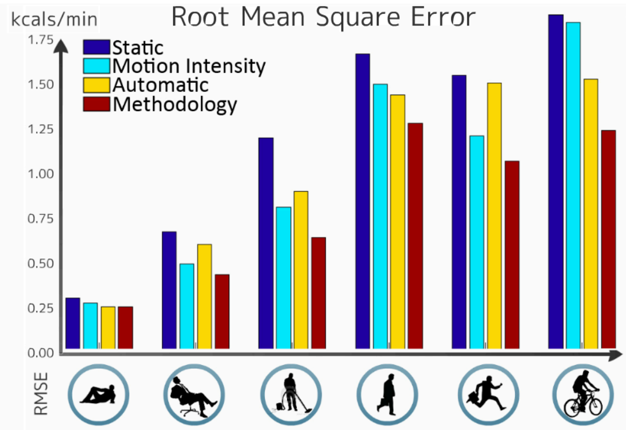

Fig. 2. By using our energy expenditure tracking methodology from [6], the error margin of monitoring energy expenditure is significantly reduced for typical clusters of daily activity.

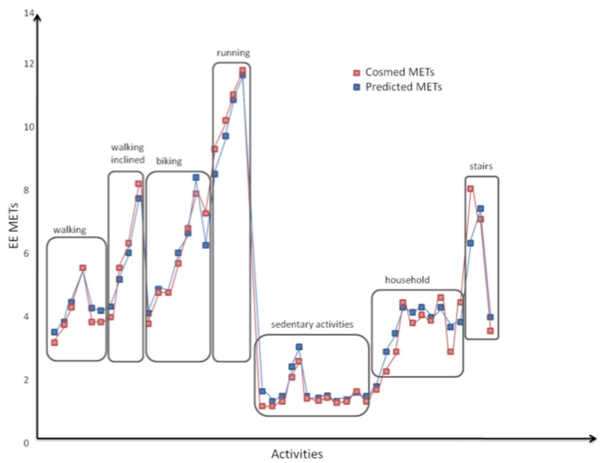

Fig. 3. Side-by-side comparison of indirect calorimetry with a wearable wireless device featuring heart rate and accelerometer sensing.

A side-by-side comparison of indirect calorimetry (using a COSMED device) and our single lead ECG patch with built-in multi-axis accelerometers gives further insight in the obtained accuracy (see Fig. 3). The overall error is below 10%. While these results are amongst the most accurate achieved to date, a chest-worn patch does not appeal to all consumers. Armband-type devices have attracted significant attention [7] but currently lack the added functionality of accurate heart-rate measurement, thereby leading to an error margin of 30% in energy expenditure assessment. Similarly, wrist-watch type devices have increased inaccuracy because the movement of the wrist is not representative for whole-body energy expenditure. This requires further work into algorithms that can extract energy expenditure by performing multi-sensor fusion from data gathered at one convenient body location. Aside from heart rate and motion/acceleration, additional sensors may be needed such as skin, ambient temperature and perspiration.

III. MONITORING STRESS

Stress is the second-most reported work-related health problem [8]. Between 30 and 40% of all employees consider their job as stressful. 25% of all sick days are due to stress. Four of the top ten causes of death are directly linked to stress: cardiac disorders, stroke, musculoskeleton disorders, and suicide or homicide. The total disease burden due to stress amounts to almost 300B$ a year in the US alone. While stress is also a positive force, a stress balance is needed and this requires objective methods for assessing stress levels. However, for stress monitoring, the number of tools is even more limited than for energy expenditure. Today, stress is still predominantly assessed from questionnaires instead of by acquiring individual physiological information.

Stress is known to activate the sympathetic nervous system (SNS) [9]. Much work has been done on the detection of stress by monitoring physiological parameters that are influenced by the SNS. Examples are muscle activity, heart rate variability, skin conductance, pupil dilation.

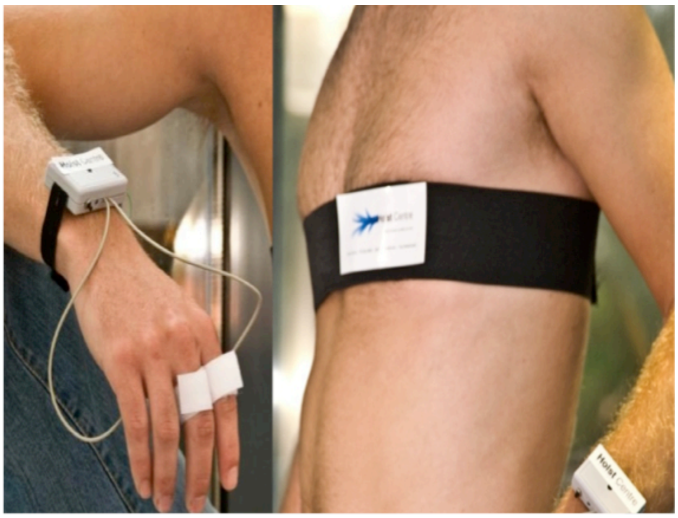

Fig. 4. First-generation tool for monitoring SNS expression using skin conductance, skin temperature, single-lead ECG, respiration.

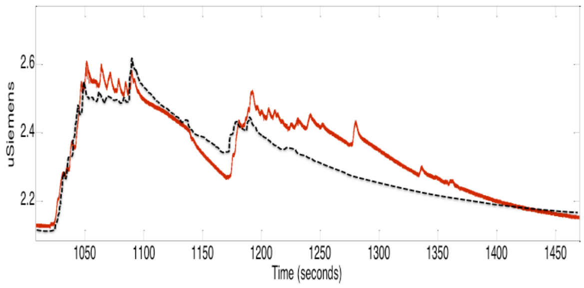

Fig. 5. Second-generation tool from monitoring SNS expression from skin conductance and skin temperature (top) and comparison between galvanic skin response obtained at the finger (solid line) and at the wrist (dashed line).

As a result, wearable sensors measuring the SNS response are increasingly explored [10,11] as a means to assess personal stress levels in daily conditions such as work. Such techniques may objectify the amount of stress and at the same time provide a tool for its reduction. Our first-generation system (see Fig. 4) was used in a pilot experiment in which 30 people were subjected to work-related stress. The test consisted of a calculation task (the Norinder test), a logical puzzle task, and a memory task. All three tasks were conducted under time pressure while distracting news fragments were broadcasted through headphones. A perceived stress scale (PSS) questionnaire complemented the experiment. The overall accuracy in classifying mental stress was approximately 80%.

The inconvenience of the first set of sensors led to exclusion of 9 of the subjects. For that reason a second generation wireless sensor has been developed with a more convenient wrist-type device monitoring galvanic skin response, relative humidity, temperature, and having the ability to monitor activity (see Fig. 5, top). The correlation between monitoring galvanic skin response at the fingers (the gold standard) and at the wrist is very good (see Fig. 5, bottom). The validation of the entirely wrist-based stress sensor is currently under way.

Conclusions

This paper summarized the ongoing work on stress and fitness monitoring using wearable wireless sensors as a means to enable preventive medicine in the fields of stress management and weight management. While very promising results are being obtained, the practical form factor of these devices needs much attention to make these devices widely used.

Acknowledgment

The contribution of over 50 full-time researchers to the Body Area Networks research program is gratefully acknowledged.

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