AWARESHOE

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Abstract
Previous research aimed at developing procedures for preventing the formation of dangerous foot ulcers in diabetic patients has not been very effective, probably because they do not allow contacting patients often enough to persuade them to adapt their behavior before the damage has been done. The current research aims to develop a body area network (BAN) in an on-line monitoring application that does allow for timely feedback. To be able to interpret the real-time information about a patient's behavior, the signals from the BAN must be integrated with person-dependent (semi-)static information about the key risk factors.

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1. Problem Statement and Research Question

The incidence of diabetes in Western countries is already very high and it is rapidly increasing. One possible complication of diabetes is ulceration (pressure sore) under the foot sole. Between 2% and 8% of the diabetes patients develop foot ulcers during their life time. If not treated effectively, ulceration can lead to amputation of the lower limbs. Several factors known to be related to an increased risk of ulceration are described in the literature. The factors implicated most often are neuropathy (insensitive feet), vascular disease (restrict blood circulation), foot deformity, excessive callus, and increased plantar pressure [6]. Today, it is not possible to accurately predict whether a specific patient will develop foot ulcers, even if most or all of the risk factors are present. Most probably, this is due to the fact that the impact of the physiological risk factors depends to a large extent on the behavior of individual patients.

In the AwareShoe project we develop and test a computing system that is able to monitor the behavior of chronic patients continuously, but unobtrusively. The eventual goal is to persuade patients to adopt health-enhancing behavior and to warn them immediately if the do engage in potentially harmful behavior after all. For that goal patients will be equipped with a body area network (BAN) of wireless sensors, which can be used to monitor the patients behaviors over extended time intervals. The output of the sensors will be used to estimate behaviors, and the resulting information will be

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combined with static information about personal characteristics of the patient and with day-to-day physiological information that is known to increase the risk of developing ulcers. This should result in a decrease of the number of ulceration cases and prevention of the related decline in quality of life.

The monitoring and feedback system should be maximally non-intrusive and easy to use for the patient. Ease of use and unobtrusiveness are necessary requirements for creating an effective application which makes it possible and convenient to monitor patients for long periods of time. Wireless sensors in the monitoring application make considerations related to energy consumption extremely important as well.
Until now little is known about which behaviors increase the risk of developing foot ulcers in diabetes patients. This is due to the lack of procedures and monitoring systems that allow measuring behavior accurately and for a prolonged period of time. The system we are developing will make it possible to monitor patients over extended periods of time and to investigate the impact of behavior on the development of ulcers. Eventually, knowledge about the risks of specific behaviors should help to persuade patients to adapt their behaviors.

2. Approach and Methodology

We are implementing the architecture shown in Figure 1 for the use in the prevention of ulcers. The first layer (leftmost in the figure, called: measurement) obtains its input from the monitored patient. The input consists of three groups of measurements; the BAN is one of these three groups. The set of measurements must be chosen in such way that the behavior of the patient can be monitored on-line and for a long period of time. One group of the measurements will be obtained on a monthly basis

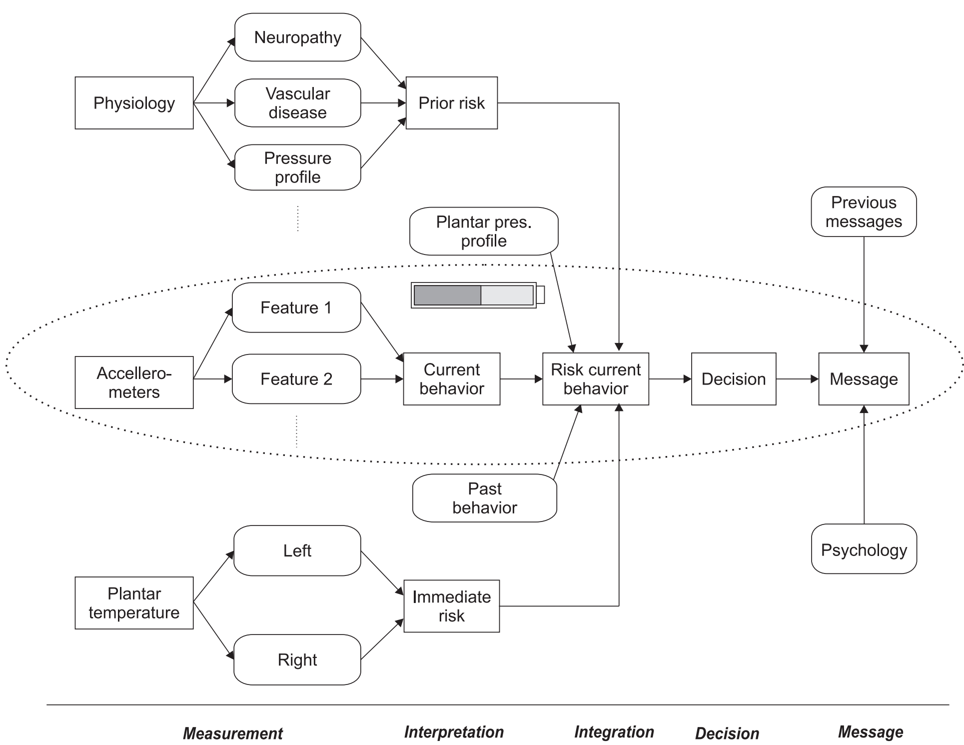

Figure 1. Body Area Network (BAN) architecture for preventing ulceration in diabetes patients. The architecture consists of five layers. The layers from left to right are called: measurement, interpretation, integration, decision, and messages. The architecture elements enclosed by the ellipsis are critical in terms of energy consumption.

(physical status, static), one on daily basis (plantar temperature, semi-static) and one continuously (acceleration of body segments, dynamic).

The temperature parameter is included in the measurements because research has shown that the skin temperature difference between spots on the feet indicates an inflammation. Therefore this parameter is identified as a good predictor of short-term development of ulcers [4].

In the fifth layer (rightmost in the figure, called: messages) messages are generated and sent to the patient. In between there are three more layers called: interpretation, integration and decision. The measurement layer is the input interface between the patient and the system.

In the interpretation layer the raw data is converted to information which can be interpreted more easily by the following layers. The data about the physical state are translated to a profile containing an indication of the level of risk a patient suffers, if a certain behavior is carried out by the patient. The temperature measurements are translated to an immediate level of risk for the patient. The accelerometer measurements are classified into five basic postures and behaviors which are related to foot ulceration.

The third layer implements the integration of the three groups of measurements described in the measurement section. A Bayesian network combines prior knowledge of the physical state profile, plantar pressure profile, current and past behavior of the patient and immediate risk.

The decision layer of the architecture synthesizes a decision based on the input of the current state of risk. This layer decides whether to intervene and in what way the patient should be stimulated to adapt his/her behavior. The decision must reflect the optimal trade-off between too many and too few messages. In a companion project we will investigate ways for adapting the contents and the form of the messages to the personal characteristics and preferences of the patients.

The classification of movements and postures relies on long-term on-line monitoring of accelerations of the patients' body parts. The BAN is formed by the accelerometers worn by the patients and a data logging PDA. Accelerometer-based BANs used in existing classifiers of movements and postures have some limitations that make long-term monitoring difficult.

First, most of the time wired sensors are used, which patients experience as obtrusive. Therefore, we intend use wireless sensors in the BAN. With the exception of the BAN, all components of the architecture could be implemented on server, desktop or laptop computers, for which energy efficiency is not a big issue. In our architecture most of the computation will be done on a PDA, but this will be integrated in a Wide Area Network (for example to allow (para)medics to intervene when necessary). For the BAN to be effective, it must be able to operate for extended periods of time on a single battery charge. It is well known that communication between nodes in a wireless network consumes much more energy than computation in the nodes. Therefore, we have to minimize communications within the BAN and between the BAN and the WAN.

Secondly, existing classifiers for patient behavior rely on accurately conditioned and controlled signals. The accelerometers must be tightened firmly to the body with correct placing and orientation. Consequently, current BANs used for classification of movements and postures need a lot of interaction of a specialist and are therefore patient unfriendly. We aim to make a BAN that is easy and comfortable to use for patients. For that goal, we implement a classifier that is robust against disturbances of poorly (or wrongly) attached sensors. These measures will results in simplified attachment and detachment, which can be executed by the patient him/herself. Finally, movement classification tends to rely on the combined inputs of multiple accelerometers attached to different body parts. We intend to develop classifiers that will allow for sufficiently accurate detection of relevant behaviors on the basis of no more than two sensors. This too will help to simplify the daily (dis)mounting of the network and the energy consumption.

The architecture will be implemented step-by-step, starting with the implementation of the measurement layer. As a part of the measurement layer we will develop a monitoring system with wireless sensors that operates for at least one day before recharching of the batteries is necessary. Moreover, it is required that this monitoring system is easy to operate by the subjects themselves. We are developing the measurement layer with healthy participants, and we will verify the performance with experiments conducted with patients from the target group. This approach has the advantage that we can minimize the burden for the patients in the target group. The interpretation, integration and decision modules will be realised by a Bayesian network model just as the classification of activities. The experiment data recorded from target-group patients are used for training and validating these models.

3. Related Work

There are three topics of related research most relevant for the current research: telemetric classification of behavior, pervasive systems and patient education. Interesting papers on these topics are discussed below. The first discussed paper is about telemetric classification, the second and third paper about pervasive systems and the fourth paper on the patient education subject.

Foerster and Fahrenberg (200) have published a usefull review on using accelerometry for the classification of activity behavior [3]. The choice of algorithm for detection of posture and motion patterns is still a crucial aspect of accelerometry. Several suggestions have been made how to differentiate between activities. Classifier systems such as statistical algorithms, (fuzzy) logic or artificial neural networks have been suggested, but we are not aware of experiments in which such systems have been tested under real-world conditions. Based on results of there own investigation, Foester and Fahrenberg recommend sensor configurations with a minimum of three sensors. They suggest a minimum of a two sensor configuration in the case of basic classification of sitting, standing, laying and moving will probably suffice.

In a recent research of Blanson Henkemans et al. (2008) evaluated an adaptive artificial assistant for supporting older diabetics' self-care [2]. The assistant supports limited and acute treatment scenarios and adapts its feedback according to the situation. The performance of the adaptive assistant was compared with a non-adaptive assistant. The authors concluded that an adaptive artificial assistant was more effective and time efficient in dealing with normal and health-critical situations. Moreover, working with the interface and receiving feedback form the assistant enhanced the participants' knowledge of diabetes. A relationship was found between the participant's personal characteristics and how oft the artificial assistent was used and the kind of feedback patients prefered. We will incorporate these findings in the design of our own system to maximize its use and effectiveness.

Anliker et al.(2004) described an advanced care and alert portable telemedical monitor (AMON), a wearable medical monitoring and alert system targeting high-risk cardiac/respiratory patients [1]. The system includes continuous collection and evaluation of multiple vital signs, intelligent multi-parameter medical emergency detection, and a wireless connection to a medical center. By integrating the whole system in an unobtrusive, wrist-worn enclosure and applying aggressive low-power design techniques, continuous long-term monitoring can be performed without interfering with the patients' everyday activities and without restricting their mobility. These suggestion of non-obtrusiveness are again necessary for effectiveness of the monitoring system.

Valk et al. (2002) conducted a systematic review on patient education [5]. The findings of this review suggests that patient education may have positive, but short-lived effects on foot care knowledge and behavior of patients. Still, it may reduce foot ulceration and amputations, especially in high-risk patients. These findings suggest that patient education can be effective, but only if feedback to the patient is sent with minimal delays to maximize the impact on behavior.

4. Preliminary Results

We have conducted an experiment to develop a reliable behavior classifier that is able to distinguish three different postures (sitting, standing, lying) and four different movements (walking at different speeds, bicycling at different speeds, walking up/down stairs). In addition, we investigated to what extent reliable classification can be obtained from accelerometers that are attached to the users' cloth, instead of to the body.

Five healthy subjects were equipped with six tri-axial accelerometers (Minimod, McRoberts). Three sensors were tightly fixed to three body segments (both upper legs and the torso). The other sensors were attached to the clothing of the subject on corresponding sites (a sensor was put in both pockets of the subjects' trouser and one was attached to the belt). The subjects performed a set of controlled movements and postures, viz. sitting, laying, standing, walking at four different speeds, walking up and down the stairs, and bicycling on a home trainer at four different speeds. In addition, a set of semi-natural activities were recorded, viz. sitting at a desk and working on a computer, reading in a chair without a table, playing a game of pictionary (while standing), bicycling outside, walking up stairs to fetch some item and a housekeeping task.

Matlab was used to process the signals and extract features from the signals. A first version of a (static) Bayesian network was created to classify the three postures of the body. A part of the data was used to train subject-dependent models and a part of the data was used to test the models. Both sensor sets (attached to body and cloth) were trained and tested independently.

The results of the validation of the static Bayesian model for both body and cloth attached sensor set were better than 90% for each subject. Moreover, the differences between the sensor sets were not significant. These results suggest that acceleration signals from sensor attached to the subjects' cloths will have enough stability to make a reliable classification of postures.

5. Conclusions and Future Steps

The research described in this paper intends to develop a telemetric monitoring application which aims to prevent the occurrence of ulcers in diabetic patents by give feedback on the activity behavior. The system has to be easy to use for a wide range of patients. All known risk factors are included as input parameters in the system. The interpretation of the measurements in terms of behaviors and the risk incurred by these behaviors in combination with personal information about the patients will be implemented in a Bayesian network model. The first experiments with behavior classifiers show that that acceleration signals from sensor attached to the subjects cloths will have enough stability to make a reliable classification. In future research we will evaluate an activity classifier on healthy subjects which is based on signals form a monitoring system with minimal obtrusiveness for the monitored subject. In later experiments we will use this monitoring tool to conduct large scale long-term measurements aimed at the evaluation of typical behavior patterns of target-group patients. Based on gained knowledge from these experiments we will develop an risk estimator and feedback system intended to influence the behavior of patients. The resulting system will be evaluated with experiments on target group patients.

I would like to discuss the architecture for continuous monitoring of diabetes patients proposed above. In addition, suggestions for the implementation of the architecture, especially of the measurement layer, would be most welcome. Also, I would appreciate comments on all issues related to patient friendliness. Suggestions for what I can do to stimulate patients to use the monitoring system every day and routinely are most welcome. The same holds for suggestions for how to make the messages that the system is going to send to the patients most effective. In general, I would appreciate suggestions for things I can do and things I should avoid in working with (elderly) diabetes patient to make sure that they are able to use the system and control the PDA application that is going to be the backbone of the monitoring system.

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