A System for Monitoring Physical Activity Data Among People with Type 2 Diabetes

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Abstract. Trends towards lower levels of physical activity have raised health concerns. Tools to capture, store and use information about physical activity might improve motivation to increase the level of such activity. This is especially important for Type 2 diabetes, since physical activity is one of the key components in achieving healthy blood glucose values. Over a period of four months, 15 people with Type 2 diabetes provided us with input on how a mobile system needs to be put together. Generally, they answered that such tools must be integrated as well as possible with their other daily tools and clothing. Based on their inputs, we built a sensor system for monitoring physical activity. The system automatically and wirelessly reports the accumulated number of steps taken, using a mobile phone as the patient terminal. We asked 1001 persons about their use of step counters/pedometers. About 6.5 % of them use such a device daily and about 20 % daily, weekly or monthly. Our concept differs from others of this nature in its simplicity, size and integration with other relevant patient data. It is fully manageable by patients themselves as a self-help tool.

Keywords. Patient monitoring, Data acquisition-data capture, Human interfaces.

Introduction

According to the World Health Organisation, physical inactivity and unhealthy diets are among the leading causes of the major noncommunicable diseases, including Type 2 diabetes, and contribute substantially to the global burden of disease, death and disability [1]. Studies have clearly indicated that increased physical activity both reduces the risk of developing Type 2 diabetes and is positive for those already diagnosed with the disease [2]. Growing awareness of the increase in obesity and Type 2 diabetes as well as a general concern with health and fitness have resulted in a strong focus on the use of step counters/pedometers as a tool for self-monitoring of physical activity. This article focuses on secondary prevention for people with Type 2 diabetes. The system presented may also hold potential for primary prevention, i.e. to be used by healthy people who want to reduce their chances of developing health problems.

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Aiming for Everyday Tools

Advances in biomedical engineering have brought us a number of new diagnostic tests and disease management tools. Information and communication technology have provided us with hardware and software which offer great benefits for health care applications. New wireless communication standards and the miniaturisation of electronic components have made it possible to make both wearable patient sensors and handy patient terminals. Mobile phones have grown into small computers in functionalities, often referred to as “Pocket PCs” or “Smartphones”, and are used as the patient terminal in our approach. By utilising and building on the three main components: sensor, wireless communication and patient terminal, we aim to design an application for automatic gathering of the user’s physical activity, and to provide a beneficial use of this data in an easy way. Depending on the patient’s needs and health challenges, it must be easy to adjust the system to automatically transfer the level of physical activity each hour, every two hours, twice a day, daily, or at other intervals. This calls for a sensor application with high usability, light in weight, small in size, and with a battery life of at least 6 months. When properly attached to the user it should be unnoticeable during daily activities. Vital factors therefore include miniaturisation of the electronics, minimal power consumption, as few buttons as possible and automatic and wireless data transfer. All the functionalities and user adjustments should be controlled from the patient terminal. The application presented is part of the wearable eHealth system [3], i.e. the “Easy Health Diary”, which gathers data on blood glucose values, nutrition habits, and the physical activities as described here.

State-of-the-Art for Non-Obtrusive Registration of Physical Activity

Step counters and pedometers are usually referred to as the same physical device, where the difference is only in functionality. Pedometers also calculate the distance walked, but this requires the user to enter the stride length. Today, step counters are mainly attached to the belt on the hip and have a built-in LCD to display the number of steps taken. One also finds MP3 players and mobile phones that include step counters as a fitness feature. Other ways of measuring physical activity include using heart rate monitors or global positioning system (GPS) devices. Heart rate monitors have the disadvantage that the user has to wear a transmitter chest belt, something most people find too obtrusive to wear on a daily basis. GPS is a good tool for measuring one’s movement, but is mainly useless indoors due to lack of signal strength from its satellites, and also needs frequent recharging due to high power consumption. It has not yet been possible to find a totally unobtrusive system for easily attaching physical activity measurement sensors to people. Examples of innovative systems are the SensVest [4], which requires the user to wear a specific vest with embedded sensors; the MPTTrain system [5], which uses music to improve exercise performance and is a combined heart-rate monitor and movement monitor device; the mobile-phone-sized NEAT-o-games application [6] using Bluetooth for transfer of the accelerometer data to a PDA; and the multi-modal sensor board and Bluetooth unit enclosed in a box worn on the waist for wireless monitoring [7]. Common to all of these is that they have a short battery life-length, are too large to be worn for long periods and/or require substantial user interaction for achieving the intended functionalities.
1. Methods

1.1. User-Centred Design Methods

As part of our design process, 15 people with Type 2 diabetes were engaged over a period of four months. The participants were recruited through letters sent to all members of the local diabetes association that were between the ages of 40 and 70 years. They gave feedback both on how they would like a comprehensive mobile-phone-based self-help system to be put together as a sustainable tool [8], and specifically on the physical activity parameter. The methods used were focus groups, paper prototyping and sketching, prototyping, questionnaires, and giving the informants small amounts of homework between the five focus group meetings. We gave the users an off-the-shelf step counter for use between the two first meetings and asked them to report their experiences. For reference on step counter use, we prepared four questions on use of health monitoring devices as part of the “eHealth Trends survey” in April 2007, with 1001 informants using telephone interviews (CATI).

1.2. Microcontroller Design Methods

The step-counter device was based on a microcontroller to provide the intelligence needed for performing logical operations. Requirements for the microcontroller included small size, low power consumption, flash memory, low cost, and I/O drivers with high flexibility. The Atmel ATmega164P 8-bit RISC microcontroller was found to fulfil these and became the sensor system’s main building block. To program the step-counter application features, special software and hardware programming tools were needed: the Integrated Development Environment (IDE) “AVR Studio” and the “AVR STK500” starter kit. The IDE provided an assembler, an editor, and a simulator, enabling possibilities for testing the functionalities during the development process. In addition, the emulator “Atmel AVR JTAGICE mkII” was used to test and edit the step-counter software on the actual microcontroller, in circuit. To set up communication to the wireless interface, the microcontroller’s asynchronous serial interface was used.

1.3. Data Transfer Methods and Electronics Design Methods

Bluetooth is at present the only short-range communication protocol which is fully implemented as a short-range communication protocol in mobile phones, and was therefore chosen for communicating the data to the patient terminal. The OEMSPA311i-04 Bluetooth adapter, 16 mm by 36 mm class 1, from connectBlue AB was used. An asynchronous serial databus without handshaking (RS-232-like protocol) was used for data transfer. The module was configured so that when powered up it attempts to connect to the patient terminal, informing the microcontroller when contact is achieved, and finally transmits the data received by its UART. At the patient terminal, an application was made to constantly listen for incoming data, storing it on the phone and sending it to the server and/or presenting it to the user on the mobile phone screen. The application is implemented in C# using .NET Compact Framework, and runs on the MS Windows Mobile 6.0 platform. To initiate transfer of step count data without requiring user interaction, we enabled automatic transfers at configurable intervals. The user can also transfer data on demand by pushing the only button on the step counter. This button was recessed level with the chassis to avoid accidental data transfer.
A mechanical sensor was chosen to minimise power consumption and microcontroller programming efforts, compared with a triaxial accelerometer that would have provided more flexibility. A mechanical sensor generates ripple and needs a low-pass filter for removing unwanted signals. Using passive components for the filter in addition to software routines made it possible to distinguish steps from noise in the signal. The sensor application’s power consumption ranges from 2μA to 40mA and requires a battery bigger than button-cell batteries: the Saft LS14250. The main current consumer, the Bluetooth adapter, has a built-in sleep mode, but even in this mode it consumes more than 1mA. This problem was solved using an external power control. The drawback is a longer start-up time for the Bluetooth module, but is acceptable since the result is an average power-up to power-down time of just 3 seconds.

Since the sensor and the mobile phone are paired, a link key valid only between these two Bluetooth units is created, providing security considered sufficient for this kind of data. The electronics are encapsulated in a plastic chassis, enabling an internal antenna and only a slight loss in signal strength. It was decided to have no LCD on the step counter, since we wanted all interaction to be controlled from the patient terminal.

2. Results

2.1. Users’ Feedback

In the 2007 survey on eHealth trends [9], we included a question about how often the informants in the Norwegian sample had used a step counter/pedometer during the last half year. A professional polling agency conducted 1001 interviews, in which 6.6 % of informants reported daily use, 7.4 % weekly use, 6.3 % monthly use, 12.2 % more seldom than monthly use, and 67.5 % no use during the last half year; see Figure 1. The cumulative percentage of daily, weekly or monthly use was 20.3 %. In comparison, a study by Eakin et al. [10] showed a pedometer use of between 5.1 % and 18.1 % during the last 18 months dependent on geographical location. In the eHealth survey, we also asked about the use of other self-monitoring devices such as pulse, blood pressure, and blood glucose monitors. Informants reported less frequent use of these devices, with cumulative monthly percentages of respectively 11.3 %, 7.7 % and 5.7 %. These results foster the belief that the parameter “step counts” is both easy to understand and motivating for people in general to monitor. Our Type 2 diabetes cohort confirms this belief, and the 15 participants expressed a positive attitude to the use of step counters. They wanted the functions of a step counter to be as automatic and easy to use as possible, and said that tools for self-help should be integrated with their daily tools and outfits. Further user needs are published elsewhere [8].

![Figure 1. Frequency of step counter/pedometer use by the 1001 Norwegian informants.](image-url)
2.2. The Final Prototype

The final prototype is dominated by a printed circuit board containing the Bluetooth module, the microcontroller, the movement sensor and the battery, see Figure 2. These four components are also the major contributors to the step counter’s physical size of 6 x 4 x 1 cm. To filter out random movements and noise, the application will not start counting before it has received six consecutive movements within a timeframe of 8 seconds. Then it counts normally until it has not been subject to any movements for 8 seconds. The power settings have been set to -4dBm (124), providing a communication range of 10 meters. In order to optimise power saving, the embedded microcontroller is set to go to sleep between each step the user takes. A new movement event will wake the microcontroller up for registering and storing the step. Although the step-counter application so far is equipped with a movement sensor only, it is designed for adding more sensors. By embedding a temperature sensor, a light sensor, and/or a noise sensor, the system may be programmed to be context sensitive. Potential cases may be to indicate whether the user is moving indoors or outdoors, is in a dark or light environment, is alone or accompanied, thus helping the patient terminal’s logic to choose the best moments for user interaction.

2.3. Test of the Step-Counter Application

At this stage the step-counter application has undergone a functional test only. During 2008, the prototype will be offered for a clinical test among 14 people with Type 2 diabetes. The functional test, performed both on a treadmill and in natural environments, showed that the step-counter application provides the user with sufficient accuracy compared with the “Omron Walking Style II HJ-113” step counter. Tests of walking at normal speed indoors and outdoors showed a difference of 2.5 % after 2 hours, 1.2 % after 7 hours and 0.9 % after 12 hours between the two step counters. The treadmill test was performed at five different walking speeds. At 1 km/h the Omron step counter had problems in registering steps at all, while our application registered all steps. At 2 km/h the difference was 4 %, at 3 km/h it was 3 %, at 5 km/h it was 7 %, and at 10 km/h there was no difference between the application and the Omron step counter.

It has also been demonstrated that the step-counter application sends data properly to the patient terminal, both automatically at preset intervals, and manually when the transfer button is pushed.

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**Figure 2.** The final prototype; the electronics (left), front view, side view, and the patient terminal.
3. Conclusion

This step-counter application differs from others in its simplicity and the graphical feedback automatically generated on the patient terminal. Historical and current data is presented, configured to the user’s own target. The system consists of two devices: the sensor to attach the belt or similar, and the patient terminal, which at the same time is the user's mobile phone.

A future goal is to reduce the sensor size to $3 \times 2 \times 1$ cm. This probably involves miniaturisation and change of the Bluetooth adapter, the battery and the movement sensor. The trade-off between using a passive mechanical sensor and using a triaxial accelerometer will be reconsidered based on our experiences from the clinical test. We are working towards embedding more sensors for designing a context-aware patient system. The choice of microcontroller enables a transition from assembler to C, which may be necessary when making the application more advanced.

The overall goal and the main work task is to finalise a patient management system that optimises the use of physical activity data as well as blood glucose data, nutrition habit data, and specific and general patient information. By applying context awareness and self-adaptability, we hope to further increase the usability and perceived usefulness so that the concepts described become useful and sustainable patient tools.

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References