Activity Recognition for Everyday Life on Mobile Phones

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Abstract. Mobile applications for activity monitoring are regarded as a high potential field for efficient improvement of health care solutions. The measurement of physical activity within every-day conditions should be as easy as using an automatic weighing machine. Up to now physical activity monitoring required special sensor devices and are not suitable for an every day usage. Movement pattern recognition based on acceleration data enables the usage of standard mobile phones for measurement of physical activity. Now, just by carrying a standard phone in a pocket, the device provides information about the type, intensity and duration of the performed activity. Within the project DiaTrace, we developed the method and algorithm to detect activities like walking, jumping, running, cycling or car driving. Based on activity measurement, this application also calculates the consumed calories over the day, shares activity progress with friends or family and might deliver details about different kinds of transportation during a business trip. The DiaTrace application can easily used today by standard phones which are already equipped with the required sensors.

Keywords: Physical Activity Monitoring, Sensor Location, Mobile Assistance, Acceleration Sensor, Pattern Recognition, feature extraction, DiaTrace.

1 Motivation

Mobile applications for activity monitoring are regarded as a high potential field for efficient improvement of health care solutions. The measurement of physical activity within everyday conditions should be as easy as using an automatic weighing machine. The determination of physical activities in everyday life suffers on suitable sensors and algorithms. Distributed multisensory systems provide a high accuracy for the recognition rate but they are very unhandy and inconvenient and can not be used in daily life. Single sensor systems achieve a sufficient recognition rate only in laboratory scenarios [8] and using a fixed sensor location and orientation which is in general at the hip, wrist or upper arm. The requirements on wearing position or hardware of these recognition systems do not support the real life scenario. The concern of everyday usage is not to have an additional sensing device but an integration of this functionality into a standard device such as a mobile phone, which should be easy to handle and accurate detect the every day activities.

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2 Related Work

In 2001, Richard W. DeVaul from the MIT started the scientific research of physical activity recognition by acceleration sensors. These research projects were carried out within the framework of the project MIThril (the name Mithril comes from a book by Tolkiens) with the aim to expedite context-aware wearable computing for daily life. From this research group important work is derived furthermore from e.g. S. Intille, Pentland et. al. who increased working on the comprehensive Context Awareness / Ambient Intelligence. The project MIThril was not continued in 2003 any further [5]. Furthermore the Finnish research institute VTT could speed up the research within the scope of a nationwide oriented project Palantir (the name Palantir likewise comes from a book by Tolkiens) together with the Finnish partners Nokia, Suunto, Clothing + and Tekes. The project [8] was discontinued in 2006. VTT itself continues currently the research in project Ramose, which is related to motion tracking. The research activities of Intel Research in cooperation with the University of Washington are focused on an activity logging system, which is called iMote. This platform provides support for the vision of Ambient Intelligence. The approaches of detection and classification of physical basic activities (e.g. walking, running etc.) can also be used for research on the quality of the execution of movements. Hereby the progress of e.g. Multiple Sclerosis can be examined, like Sylvia Lawry Centre MS Research Munich, Germany is doing. At present, in the field of algorithm development are especially active as follows: University of Technology Darmstadt, Georgia Tech (Group Abowd), Lancaster University (Group Gellersen), ETHZ (Group Mattern), Univ. Linz (Group Ferscha), University of Kagawa (Group Tarumi), VTT Finland and likewise University of Rostock (Group Kirste), Germany.

The current work shows that physical activity recognition just by one high performance acceleration sensor is possible in laboratory environments. The challenge of research is the development of a suitable method of preprocessing and the identification of relevant features for activity recognition in the every day life.

3 Mobile Phone as Sensor Device

In this paper we describe a novel concept of using a mobile phone without any additional devices for physical activity recognition. This enables a permanent, non-obtrusive activity monitoring for everyday usage.

The latest generation of mobile phones is using acceleration sensors for orientation detection while taking pictures of landscape or portrait objectives. The acceleration sensor, also often called g- or tilt sensor, are becoming popular also as a new input interface for games. Hereby the steering wheel or squash racquet will be simulated by moving the mobile phone. Some manufactures are using the sensor for new interaction like "shake control" by Sony Ericsson to control the sound player.

The quality criteria for acceleration sensors can be summarized in measurement range, sampling rate, sampling stability, quantization and noise. The acceleration sensor of mobile phones was designed for other purposes than activity recognition and so the sensor performance is quite low (e.g. 20Hz sampling, 3bit/g quantization). Usually, the sensor requirements for activity recognition are much higher than the acceleration sensor of mobile phones are able to provide. Sampling rates of over 100 Hz are usually used; a lower rate is regarded as unpractical because of sensor noise. The hardware of mobile phones requirements lead to the need of a better preprocessing and a suitable feature extraction.

3.1 Wearing Position

Current motion detection systems require a predefined location of the acceleration sensor. Various phones (e.g. Sony Ericsson 560) already provide very simple pedometer functionality. Hereby it is mandatory to fix the phone at the belt. This works for training or sport sessions but in general it is not very suitable for users to have predefined wearing position for their phone. Specific wearing position does not meet the wearing behavior of users in everyday life. In [4], a survey of about 1549 participants from 11 cities in 4 continents provide characteristics of how mobile phones are carried whilst users are out and about in public spaces, typical phone locations are described as follows:

- Trouser pockets,
- Shoulder bags,
- Belt enhancements,
- Backpacks,
- Upper body pockets and
- Purses.

To offer common pedometer functionality for everybody, easy and uncomplicated to use, it is very important to detect physical activity in every case of different wearing location.

Acceleration Sensing for physical activity need basic requirements on the sensor signal. In our laboratory we could estimate the acceleration forces at the simulation of sport equipment as follows:

– Bowling (hand)	~ 4g
– Jogging (hip)	~ 5g
– Basketball (hand)	~ 6g
– Jumping (hip)	~ 7-9g
– Playing, romp (hip)	~ 11g
– Tennis, Golf (hand)	> 16g
– Boxing without partner (hand)	> 16g

The acceleration of the body for the first steps of a run is about 0.4 g, a rollercoaster has up to 4g, a human survives a permanent acceleration of 10g and a tennis ball has up to 1000g during the start phase [10].

3.2 Sampling Rate

Muscles of the human body are controlled by information which is transferred by nerves. The response time of humans depends on the kind of the signal (acoustic signals cause a longer response time than optical). In addition, the temperature of the muscles, psychological and physical constitution as well as external parameters such as drugs, alcohol, nicotine, medicines influences the respond time. The average optical response time of a human is approx. 220msec [1]. The trill in the music for piano plays is indicated in the literature [7] as maximally 10 cycles per second and for stringed instruments as 13 cycles per second. A reflex however is a direct reaction without a procession in the brain which occurs within approx. t=0.06 seconds, which corresponds to t^{-1} = 16 Hertz. Because of Shannon theorem, a double sampling rate is necessary. The sampling rate should be a minimum of 32 cycles per second. Likewise to this view of sampling rate, researchers of similarly orientated projects [3] using similar frequency. This sampling rate is relevant for body movements. Artificial movements, e.g. engine vibration while driving a car provide additional frequency bands which are not covered. However, it is to be assumed that the selected sampling rate of 32 Hz is sufficient.

3.3 Relevant Activity Types

A mobile device which is carried by the user for the entire day might be influenced by the user's physical activity. The every day usage of the mobile device requires the consideration of the relevant user activities (activity types). The every day behavior of young people and children consists [6] of only a few activities types. Hereby the most performed activity are lying (ca. 9 hours), sitting (ca. 9 hours), staying (ca. 5 hours) and being active (ca. 1 hour)[2]. For the determination of the energy consumption, some activity types can be summarized such as sitting, staying or lying to "resting". The locomotion is typically performed by walking, jogging, cycling or car driving and should be represented each in a separate activity type. Fuzzy activities such as cleaning, gardening or household are classified as being active.

For an every day usage, this lead to the activity-list as follows:

- Device not present
- Resting (sleeping, sitting)
- Walking
- Running / Jogging
- Bicycle riding
- Car driving
- Being active (gardening, cleaning etc.)

This list can be extended and is not limited but the given list allows an estimation of the daily calorie consumption by the usage of the individual metabolic equivalent. DiaTrace is supporting to detect each of the given activity types plus jumping.

3.4 Mobile Phones Requirements

Mobile devices with Java J2ME development environment such as Sony Ericsson w910i or w760i provide a sensor api (JSR-256) for an easy access to the acceleration sensor. The integrated sensors of the devices provide a sampling rate of 20 Hz which is lower than a requested 32 Hz frequency. In addition, the samples are not constant in time. The following figure illustrates the sampling distribution and shows the strong abnormality.

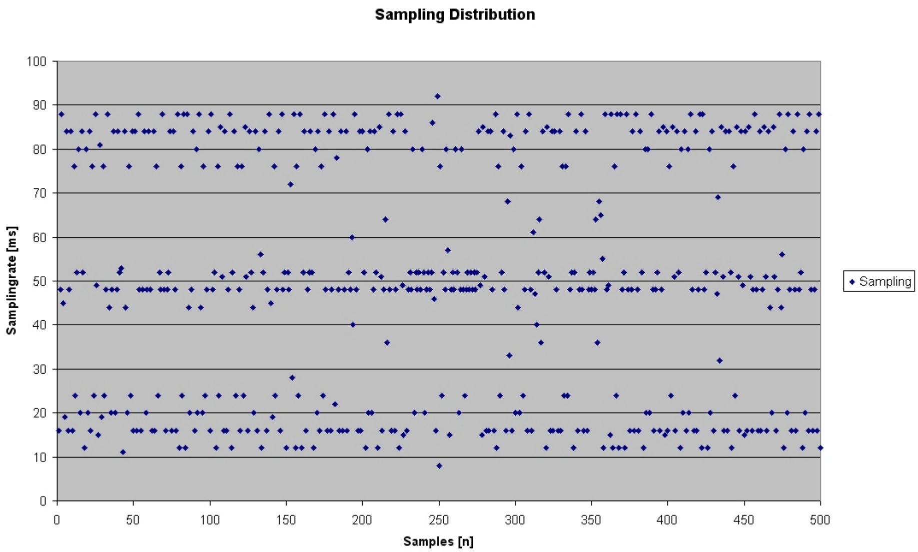

Fig. 1. Varying sampling rate of acceleration values

During normal phone usages (e.g. calling), the sampling rate varies even more, up to some 1/10sec. The device provides the acceleration data with the exact time-stamp. These strong constraints leads to the concept of a basic reconstruction of the input data.

3.5 Preprocessing and Data Conditioning

The very strong variability of the sampling rate of mobile phones requires a preprocessing and data conditioning of the acceleration values. Very acceleration value is delivered with an exact time-stamp. This enables the use of a data conditioning within the preprocessing module. We designed a preprocessing module which eliminates the effect of low sampling rate and varying scanning.

DiaTrace uses a reconstruction of the true course of acceleration by interpolation of the scanned acceleration value of each axis. This preprocessing compensates the varying sampling rate as well as the rough quantization. This leads to a new input signal for the pattern recognition. By using relevant features, a long term assessment of daily activities is possible by DiaTrace.

4 Sample Application

DiaTrace is a mobile application which provides assistive functionalities. DiaTrace measures the every day activities and reminds of additional activity if necessary, otherwise it congratulates the user. In a cooperative scenario – like long term support - the comfortable activity monitoring throughout everyday enables a new kind of social connectedness because group members can see what users are doing during the day.

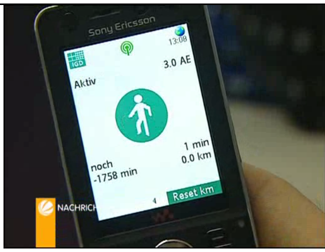

Fig. 2. Phone with integrated sensor showing actual activity

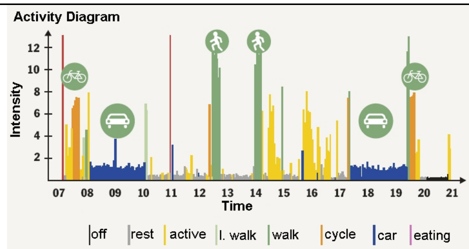

Fig. 3. Activity recognition by a mobile phone over an entire day

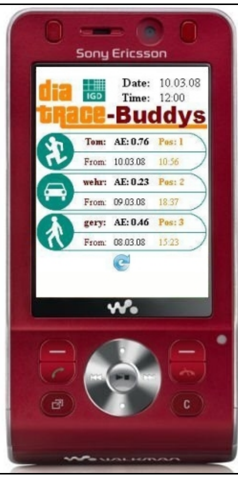

Fig. 4. Activity top ten of the buddies

Fig. 5. Electronic medals

The physical activity of a person can be shared to other friends. The mobile device with integrated acceleration sensor is able to send the activity level automatically to other buddies and so DiaTrace can be connected to a community platform. The mobile phone ranks the activity level and displays a top ten list with the current activity type. Other motivation instruments to support the performance of more physical activity are the achievement of electronic medals. In addition, the activities can be transferred to a personal web space. Here the activities are analyzed by intensities and daily energy consumption is calculated. The medical relevance of DiaTrace for overweight children is currently evaluated in a medical study. Hereby the eating is monitored by functionality of taking photos of the food with the mobile phone.

The application showed that physical activity monitoring by a standard mobile phone is possible. The evaluation showed that a recognition rate of the type of physical activities is higher than 95% by wearing the phone in the front pocket of a trouser. The correctness is lower at other wearing locations, some activity types (e.g. cycling) is false detected (e.g. as car driving) when the phone will be carried in a jacket or bag. The good recognition is possible by the preprocessing of data and suitable feature selection.

5 Conclusions

In this paper, we present the DiaTrace project which allows the identification of physical activity in everyday life on a standard mobile phone. A three-dimensional acceleration sensor, which is already integrated in standard phones, can be used to determine physical activity by domain specific feature extraction. By use of data mining techniques and a preprocessing of acceleration data, a suitable feature can be recognized which describe high quality and robust classification of physical activity. The proof-of concept prototype receives a recognition rate of >95% by the activity types of resting, walking, running, cycling and car driving, just by wearing the device in the front pocket of a trouser. The activity level can be shared to friends or buddies and might be helpful to appraise the sporting activity. The application can be used for monitoring the daily calorie consumption by inclusion of the metabolic equivalent for each activity type. This technique enables to support medical applications.

We envision the setup of a physical activity database for a homogeneous appraisal of results of activity recognition. Furthermore we are working on a combination of physical activity monitoring with emotion sensing devices like EREC [9], which would allow for an even better personalized, sensitive assistance.

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