Real time surveying and monitoring of Athletes Using Mobile Phones and GPS

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Abstract

We developed a system for real-time athlete surveying and monitoring with emphasis on outdoor and endurance sports. The goal of our work is to provide a lightweight, non-hindering and highly mobile application that is capable of getting real-time information from an athlete about the physiological state and the prevailing workout situation, also focusing on its subjective perception.

To provide this system, we implemented a software solution tailored to the task of online surveying and data recording on a standard mobile phone. In order to prove the usability of our design, it was used in a one hour running study with 84 participants. Self-rated information about the psychological state of the athletes as well as speed and GPS position information was collected specifically for this evaluation. We visualized the collected data in a combined way, integrating the speed and subjective state information in a joint representation together with terrain data and maps. The system proved to be highly reliable in practical use. Moreover, the majority of the study participants stated that the additional equipment was not hindering to their sports activity.

KEY WORDS: MOBILE PHONE, GPS INTEGRATION, SUBJECTIVE SURVEYING, JAVA MOBILE, DATA VISUALIZATION

Introduction

Information about the subjective feeling of athletes is very important for many domains. One example is sports product testing. Details such as appearance, functionality, handling and ergonomics are important points that have substantial influence on the choice of the customer. The subjective feeling of athletes concerning their equipment therefore is an important criterion for the success of a product. Another example is perception research, where information about the perceptive state of an athlete is collected over a longer period of time. Training and performance optimization can also benefit from this information.

The common problem is to access the desired information while the athlete is in a typical situation. Real-time surveying is of course possible in a lab environment, e.g. on a treadmill. This has already been done for example by Acevedo (1996) and O'Halloran (2004) in psychological studies. The obvious disadvantage is that the results are biased due to the nonnatural lab situation. The more normal situation of a long distance outdoor run, for example, is much harder to assess because direct contact to the athlete is complicated or not possible at all. In most cases, the desired subjective as well as objective information is collected after the respective sports activity. Abele and Brehm (1985) have done this in a study where they wanted to assess the change in the mental state of athletes caused by a set of different sport activities. The participants had to answer questions concerning their subjective actual feeling-states before and after a 60 to 90 minute course of physical activity. When following this procedure, part of the information is lost because it is not possible for the athlete to memorize all individual details of his perception. It is more desirable to access the desired information at certain time points or after reaching for example a certain waypoint on a predefined route in real-time.

To achieve this, we designed and implemented a system for the surveying of runners using mobile communication equipment, i.e. a standard mobile phone. For this specific project we decided to use the Java Platform, Micro Edition (Java ME, Sun, 2002b, 2007) as programming language because it is implemented on most mobile phones. The advantages of the cell phone hardware platform are manifold. It is lightweight, mobile and highly configurable. There is no extra cost associated with hardware development, only the software has to be adapted to the specific requirements at hand. Most mobile phones are highly suitable because of their advanced computational power. Communication and real-time data transmission could also be implemented easily if desired.

The system we implemented fulfills the following requirements:

- Predefined questions are handed over to the system as audio files, associated answers are recorded.
- The athlete is asked the questions at certain predefined time points.
- Alternatively we implemented the option to react to certain external events. This includes for example significant changes in running speed or altitude and the achievement of waypoints. External hardware like GPS receivers can be connected to the phone via Bluetooth to enable this.
- Headsets can be connected to the mobile phone via Bluetooth as well to assure maximum comfort for the athlete.
- If desired, arbitrary audio files (music) can be played between the question units for the purpose of motivating the sportsman.
- Configuration of the system is possible both directly on the cell phone or a personal computer.
- Once the configuration is completed, the software requires no further interaction. That way, it could be used at anytime that is convenient for the test person. Starting the predefined survey program requires only the press of a button.

We will give a short overview of previous work on the topic of athlete monitoring. In the following, the important building blocks of our system will be explained. We will also show an experimental evaluation of our mobile monitoring solution with 84 runners. This evaluation was done within the scope of a larger psychological study for which subjective information during a one hour outdoor run was needed. As a result and conclusion we will show that our system is highly reliable, providing very valuable information about the psychological and physiological state of an athlete.

Previous Work

The authors know of no previous work that aims at implementing a sports monitoring and surveying device by using the capabilities of a mobile phone. There are, however, several publications that deal with the same topic. An obvious example are telemonitoring devices that rely on radio transmission. Wang et al. (1992) showed the application of such a device in shell rowing. The disadvantage of such systems is that the athlete might get out of transmission range and information would be lost. An extensive review by Armstrong (2007) gives an overview about other applications of wireless connectivity for health and sports monitoring. None of the reviewed publications implements a method for getting real-time feedback about the subjective state of an athlete.

Hallberg et al. (2004) present a system that monitors heart rate and location of an athlete via GPS. The information is sent via GPRS to a media server that provides an enriched media experience to viewers of sports events. They also showed the practical usability in an example for cross country skiers. However, no direct audio feedback from the athlete concerning the subjective fitness and psychological state is featured.

Another application of GPS and physiological information was presented by Saupe et al. (2007). They also use Google Earth for the visualization of physiological parameters as well as information about endurance sport training activities on a large high resolution display. In contrast to our work, no direct subjective information is acquired for the analysis.

Methods and Materials

Java Platform, Micro Edition

One of our framework requirements was that our software should work with a broad range of mobile phones. The Java Platform, Micro Edition (Java ME) is preinstalled on most phones and therefore fulfills this requirement. We consequently chose this software platform for our implementation.

The capabilities of an environment for the Java Virtual Machine in the Micro Edition are defined by three important building blocks, see Figure 1. The most basic is the device configuration. Most common for mobile phones is the Connected Limited Device Configuration (CLDC) as specified by Sun (2007). It specifies the minimum hardware requirement. In the current version 1.1 these requirements include a 16-bit or 32-bit processor, 32 kByte RAM and at least 160 kByte non-volatile memory. The high level programming interfaces are defined by profiles. The Mobile Information Device Profile (MIDP) is built on the CLDC and offers basic APIs for programmers. The current version 2.0 (Sun 2002b) offers user interaction classes, security management and basic file connection capabilities. The third important building block for software development on mobile phones are the optional APIs. Phone manufacturers can decide which of these packages called Java Specification Requests (JSR) they want to implement on their devices. Factually, a lot of these additional packages are standard and can be used on most phones. Important optional APIs for our software are the:

- Mobile Media API (JSR 135, Sun 2006b) for playing and recording sound files and video processing.
- File Connection API (JSR 75, Sun 2004) for file handling.

- Bluetooth API (JSR 82, Sun 2002a) for Bluetooth connectivity.
- Location API (JSR 179, Sun 2006a) for position determination.

Applications that build on the MIDP and any of the optional blocks are commonly referred to as MIDlets.

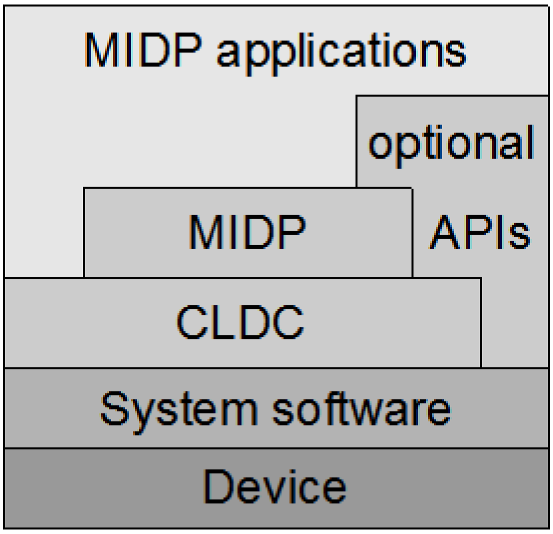

Figure 1. High level Java ME architecture view.

Mobile Phone Hardware

For the development of our MIDlet software we had to restrict ourselves to mobile phones that offer a CLDC 1.1 compatible hardware and MIDP 2.0 with the optional APIs as stated above. Most of the current cellular phones fulfill this requirement. We wanted to show with our reference implementation that our software is working on different types of mobile phones. The companies Nokia and Sony Ericsson offered the best online support for developers, we therefore chose a Sony Ericsson W850i, a Nokia N70, a Nokia E50 and a Nokia 6110 Navigator, see Figure 2. Each of the selected devices offers a slot for memory cards and thus enough capacity to store information even for very long studies. The phones are all lightweight and have high battery capacities for more than 4 hours of active use.

Figure 2. Selected phone models. From left to right the Sony Ericsson W850i (116g), the Nokia N70 (126g), the Nokia E50 (104g) and the Nokia 6110 Navigator (125g) are shown (Nokia, 2007 & Sony Ericsson, 2006).

Development Environment

Both selected phone manufacturers offer developer tools that provide device emulators and advanced debugging capabilities. This is very important for MIDlet development because error identification on the mobile platform can be very tedious. The software development itself was done with NetBeans 5.5 with mobility pack. The manufacturer SDKs can easily be integrated in this development environment, additional tasks like code obfuscating and optimization are thereby provided.

Implementation Details

Software Structure

The evaluation system had to be easily configurable and very flexible in order to support a lot of different devices and study options. Questions and position data had to be recorded as well as predefined sound files played to the athletes. The software had to work with minimum preparation time and no user interaction at all once the tests were running. The building blocks of our software that are shown in Figure 3 will be explained in the following.

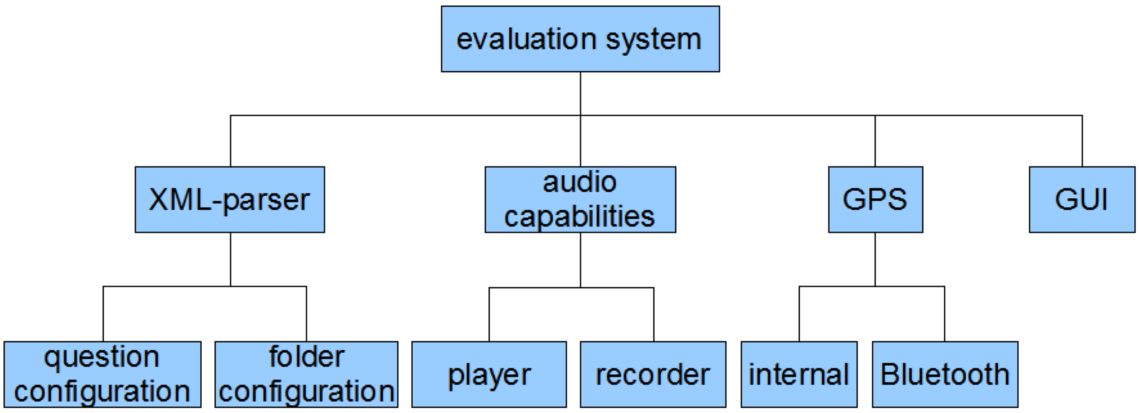

Figure 3. Structural diagram of the software for the evaluation system.

XML-Parser

The configuration of question units and storage location for the recorded sound files and position information was done with a XML file. Additionally, we stored information like start time, recorded files, identification number of the mobile phone and other information in a XML info file after the survey was completed. Because XML parsing is only supported by JSR 172, which is seldom implemented, we had to come up with our own parser.

The system can be configured to play sound files at certain time points or in reaction to external events, e.g. when a predefined distance has been covered. Subsequent to the questions, answers can be recorded, in this case a short sound is played at the beginning and the end of the recorded time span. The system can also be configured not to record after playing a sound file in case the athlete should be briefed, e.g. to decrease the pace. Another option is silent recording, i.e. recording without playing any sound at all. We used this option to capture the breathing noise of the runner in order to be able to determine the respiratory frequency.

Audio capabilities

The audio part supports threaded playing and recording in order to allow for example seamless position information storing even during question units. The configuration is done in one single XML file. In case there is an overlap of sound files, i.e. in the event that the combined playback and recording duration is longer than the span to the desired start of the next unit, this overlap is automatically resolved. Figure 4 illustrates this further. The order of the question units in the configuration file defines the precedence for the overlap resolution.

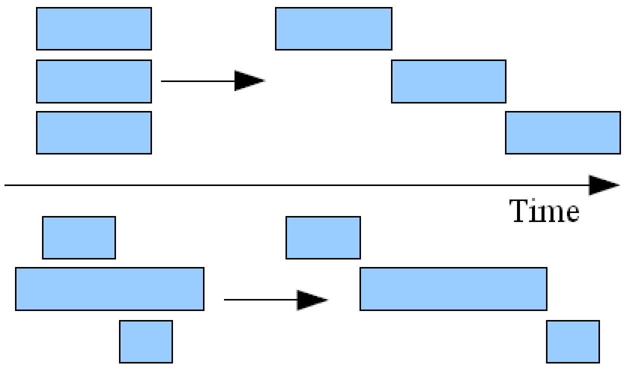

Figure 4. Overlap resolution. Audio files are played in the order that is defined in the configuration file.

The audio codec is automatically selected dependent on the sound files to play. For recording, we used a codec suited for speech. We found that a bit rate of 128 kbit per second with a sample rate of 8 kHz was sufficient for our purposes.

GPS Integration

GPS integration was an integral part of the software development in order to have access to speed, altitude and position information. The software works for phone models with integrated GPS like the Nokia 6110 Navigator as well as with an external GPS receiver (e.g. a Nokia LD-3W) connected via Bluetooth. The GPS data is sent in an interval of approximately one second, which is sufficiently precise for the purpose of recording running position information. Each sample consists of longitudinal and latitudinal position information, speed of movement, altitude, time information and various precision and validity parameters.

The data is stored in the original NMEA (National Marine Electronics Association) format (Langley, 1995), as well as directly converted to the KML (Keyhole Markup Language) format used by Google Earth. This conversion allows for a quick and easy method of visualizing the run. Run parameters like speed and psychological state can be represented as height above ground (see Figure 5 in the results section) or color coded.

Graphical User Interface

The GUI that we developed extends the limited window manager provided by Java ME. It allows changing several configuration options, to connect to the internal or external

GPS device and view the current position information. Once the surveying process is started, no further user interaction is required in order to minimize interference with the athlete.

Experiments

Experimental evaluation of the system was performed in the context of a psychological study with 84 runners in Portland, Oregon (USA). While the details of the study itself are beyond the scope of this paper, the relevant points for the evaluation of our mobile surveying system will be given.

The objective of the study was to appraise the subjective feelings of the runners during a recreational run. Each athlete participating in the study was asked to run outdoors for one hour. They could freely choose their preferred route and speed as we could record these parameters with the GPS signal. We chose to use the Nokia 6110 Navigator cell phones for the purpose of this study as they have an inbuilt GPS receiver. This prevented that the runners had to carry an external GPS receiver as extra equipment. The phones were placed in a belt that was attached to the upper arm of the participants. The runners also wore a Bluetooth headset to ensure maximum comprehensibleness.

Before starting the run, an audio file with instructions was played to the participants, followed by a first set of 8 questions. After each question, a short sound was played to indicate the start of the recording interval. The end of the three second recordings was marked by another sound. The athletes were instructed to answer each question about their subjective state with a self-rated grade as given in Table 1. An example question is "Do you feel motivated?".

Table 1. Grades for the athlete self-rating.

Spoken answer	Meaning
0	not at all
1	very little
2	little
3	somewhat
4	rather
5	very
6	extremely

Directly following this first question unit the runners were asked to start their one hour run. During this run, question units identical to the first one were posed with an interval of 5 minutes between the start of each unit. A total of 13 question units with 8 answers per unit were thus recorded for each athlete.

Results

The mobile surveying system worked without technical difficulties for all 84 runners. A total of 8736 sound files with self-rated subjective state information were recorded. We transcribed the audio files by listening to them and then manually entering the spoken answers in a data matrix. We found that 355 sound files (4.1%) were unusable, i.e. containing no meaningful answers. The main reason for this was that at the beginning of the study, we did not clearly enough emphasize the fact that the answers should be spoken in between the two sounds indicating the recording time. Consequently, a lot of runners spoke their answers right after the questions were asked when we started the evaluation. We therefore changed the set of instructions after the 19^{th} participant so that the record interval was clearly explained. After this change, only 62 entries could not be acquired, mostly because the runners were exhausted at the end of their runs and did not answer in time. In summary it can be said that as long as the athletes gave their answers during the recording time, the information was audible and could be transliterated. No audio sample was lost due to malfunctioning of the mobile phone.

We also collected a questionnaire after completion of each run. Among other details, we wanted to know how much impeded the athletes felt by the additional equipment. The results can be seen in Table 2. It can be seen that most runners perceived the cell phone and headset as very little or little impeding. Only 4 out of 84 athletes found the equipment to be hindering.

Table 2. Impediment by the additional equipment as perceived by the 84 study participants.

Perceived Impediment	Number of runners
very little	51
little	29
some	2
much	2
very much	0

It was also very important that the GPS signal recording worked in order to get reliable position and running speed information for our study. After analysis of the recorded data, we found that only 0.07% (173 out of 260214) of the position samples were unusable. Because of the fact that in no case two consecutive samples were missing, it was straightforwardly possible to interpolate the unavailable position information with a linear estimation strategy.

Figure 5 illustrates the GPS information for one example runner. The chosen running track and speed can easily be analyzed. We can also show the subjective states, in the example of Figure 5 the state of perceived fatigue is displayed. It can clearly be seen that the perceived tiredness is increasing during the run. This visualization allows for a straightforward and convenient analysis of the interplay between various parameters like elapsed time, speed, elevation circumstances and subjective state. Additional data, e.g. heart rate, can easily be integrated into the visualization if present.

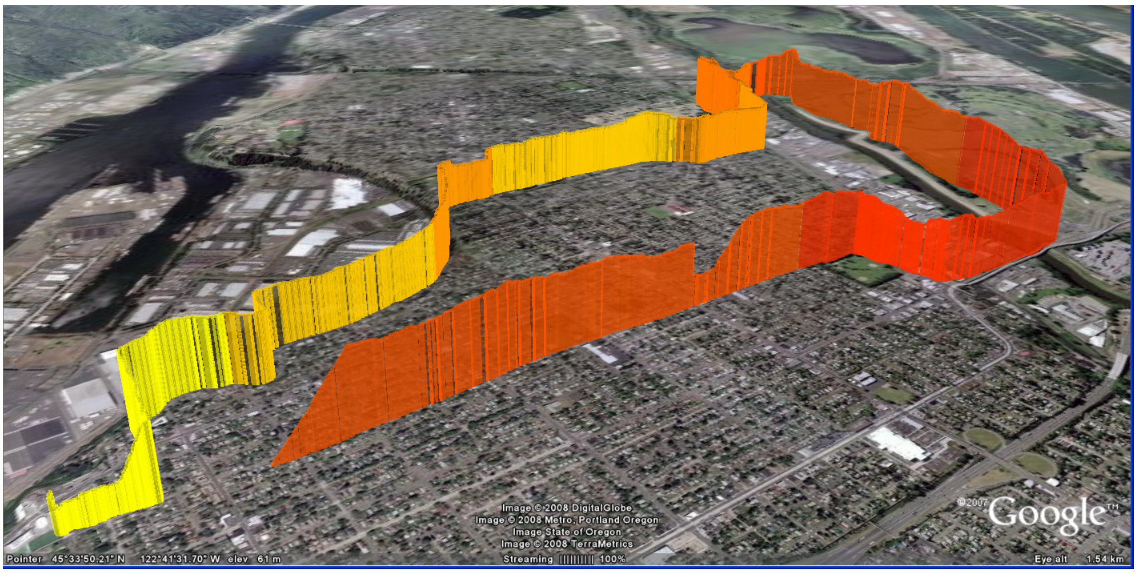

Figure 5. Visualization of running speed for a 1 hour example run in Portland, Oregon, USA. The image is based on Google Earth. The speed is displayed as the height of the colored band along the running track. The self-rated fatigue state is color coded. Yellow means little or no perceived fatigue. The redder the band becomes, the higher is the perceived fatigue state of the athlete.

Conclusion and further work

We designed and realized a system for collecting real-time subjective, physiological and other information about a sports session. For the implementation we made use of the advanced computational power and the multimedia capabilities of mobile phones, which offer a high adaptability through software packages tailored to the problem at hand. Our system is capable of asking questions about the subjective state of an athlete as defined in a configuration file or as a reaction to external events. Other information like speed and position can be collected via an internal or external GPS receiver. It is also possible to connect other sensors like heart rate monitors using Bluetooth connection.

The system has already proven its usability in practice. The system has been found to be not hindering to the sports activity of running by a majority of 84 athletes. Run information has been collected for an hour for each of the athletes with 100% reliability for the audio information and 99.93% reliability for the position information. The position and other information can very conveniently be visualized using Google Earth. The data of this ongoing study is currently analyzed, the results will be the topic of another presentation.

Our system could also be used for evaluation of other outdoor and endurance sports like rowing, cross-country skiing and biking. It is highly mobile, lightweight and applicable even for long studies due to extendable memory and high battery capacities. To our knowledge, it is the first time that a surveying system has been implemented on a mobile phone.

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