Monitoring Subjective Perception and Physiological State of Athletes or Patients in Real-Time using a Mobile Phone

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Abstract

We present a lightweight, non-hindering and highly mobile real-time monitoring system for surveying patients or athletes while performing outdoor activities, e.g. sports. Monitoring athletes or patients while performing outdoor activities is of interest in biomechanics, sport research and rehabilitation. We implemented the surveying application with Java ME on a standard cell phone with GPS and a Bluetooth headset. The system is capable of recording real-time information about the physiological state of the user, his GPS position and speed. At the same time it can query the subjective perception of the user by asking questions via the headset.
Feedback about the usability of the system was collected in three psychological studies, showing the high user acceptance and reliability of the system. The collected data was visualized with GERVIT using Google Earth, incorporating the subjective user state into the visualization.

Keywords:
Smartphone, GPS, Subjective Surveying, Java Mobile, Visualization, Digital Sports, Embedded Healthcare, Monitoring, Embedded Pattern Recognition, Pervasive Health, Rehabilitation

1. Introduction

The subjective feeling of patients during rehabilitation or of athletes performing sports is an important feedback to the physician or trainer [1]. Using this information the rehabilitation or training performance can be analyzed and optimized. The subjective feeling of users is also of great importance in product testing and perception research, where it can be used to improve the appearance, functionality, handling and ergonomics of the training devices.

The monitoring of the physiological state and the subjective perception is a relatively easy task when it is performed in a controlled hospital or lab environment [2]. The physiological state is monitored and the physician or trainer can interview the subject about his feelings or perception in regular intervals. However, this is very hard to achieve while performing outdoor activities.

The goal of this work was to develop a universally usable embedded mobile system capable of recording the physiological state and additionally interviewing the subject in regular intervals and recording the answer. As the device had to be used during outdoor activities like running, the main focus was to provide a lightweight and non-hindering system. To provide this system, we implemented a software solution tailored to the task of online surveying and data recording [4]. In this paper we give further implementation details on the system and evaluate usability results from additional studies that employed the system. Moreover, we provide further visualization results by using GERVIT [5] and Google Earth.

Previous work mainly focuses on wireless transmission of health and sports data [3]. These systems have been applied to monitor the heart rate of athletes during shell rowing [11] or to transmit the heart rate and location of athletes via GPRS to a media server for enriching the TV experience when viewing sports events [5]. Compared to our approach these systems suffer from a limited transmission range or rely on the mobile phone network. Information is lost when the devices looses connection, which is not the case with our work. Other approaches employ data loggers to record data about athletes or patients. The system presented in [9] was designed to log GPS and physiological information of bikers. It uses a similar approach of visualizing the results in Google Earth. However in contrast to our system, it does not provide any information about the subjective perception of the athlete. It is also not implemented on a smartphone with specifically tailored software as in our case.

2. Methods

We used a standard mobile phone with Java capabilities (J2ME), an inbuilt GPS receiver and Bluetooth™ connectivity to collect perception feedback and physiological data. The system guided the subject during outdoor activity and was capable of giving instructions. The perceived state of the subject was acquired using an automated interview system during the run. The system was capable of asking predefined questions, like "Do you feel good?". The answer of the subject was then recorded on the mobile phone for offline evaluation or forwarding to a remote examiner.

To provide a solution for the tasks stated in the previous section we decided to build a software application running on a broad variety of mobile phones. The Java Platform, Micro Edition (Java ME, [10]) was chosen as the development environment for this task, as it is pre-installed on many current phone models. Additionally Java ME provided a great variety of APIs to interface with the phone hardware (e.g. GPS and headset) as well as file-system routines to record the data on a memory card. Software development was done using NetBeans 5.5 with mobility pack.

The following sections include a description of the hardware used for development and implementation details of the software. This includes the XML configuration options, the GPS recording format, the audio system for playback and recording, as well as the graphical user interface.

2.1 Mobile Phone Hardware

As Java ME was chosen as the programming platform, the software is only able to run on mobile phones supporting this platform. The minimum hardware requirements for Java ME are specified in the Connected Limited Device Configuration (CLDC) by Sun [5]. Additionally the devices may support a variety of profiles, which are specified in Java Specification Requests (JSR). Every phone must at least support the Mobile Information Device Profile (MIDP), which provides basic APIs for user interaction, security management and file access. Besides the MIDP the software presented in this paper also uses the following additional profiles, which are required to run the software: Mobile Media API (JSR 135) for playing and recording sound files, File Connection API (JSR 75) for file handling,

Bluetooth API (JSR 82) for Bluetooth connectivity and Location API (JSR 179) for position determination.

The minimum requirements to run the software are that the phone supports the Java Platform, Micro Edition with a CLDC 1.1 compatible hardware, MIDP Version 2.0 and the stated APIs (JSR 135, 75, 82 and 179). This includes most current phone models. For development and testing we selected a small sub-set of phones from different manufacturers. Additional constraints included that the devices weigh less than 130 grams, have a decent battery capacity of over 4 hours of active use and a memory card slot to store the recorded data. For development and debugging it was also necessary that the manufacturer provided the necessary SDKs and device emulators. Selected models included the Sony Ericsson W850i, Nokia N70, Nokia E50 and Nokia 6110 Navigator (see Figure 1). Additionally a standard Bluetooth headset and an external GPS receiver for phones without an internal receiver were used.

Figure 1: The four mobile phones used for development and testing. From left to right: Sony Ericsson W850i, Nokia N70, Nokia E50 and Nokia 6110 Navigator.

2.2 Software Architecture

The main goal when designing the mobile phone software was to provide a flexible system that can be easily extended when necessary. It was therefore decided to split the application into building blocks according to the main tasks:

- Acquisition and recording of the current GPS position and speed
- Playback of questions and recording of the answers via headset
- Providing a graphical user interface (GUI) to start and stop the recording
- Providing a flexible configuration of questions and recording times

The architecture of the software can be seen in Figure 2. As the architecture was chosen in this way it can be easily extended by additional building blocks, which might include additional sensors or actors. The implementation of the four parts is explained in the sections below.
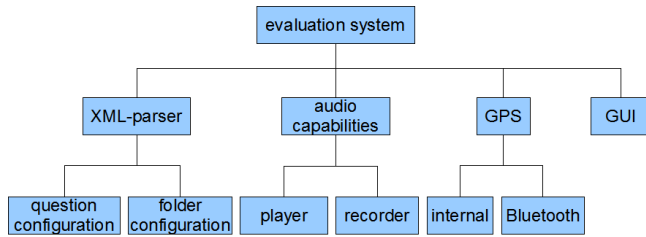

Figure 2: The architecture of the mobile phone software is divided into 4 parts: XML Configuration, Audio System, GPS Recording and Graphical User Interface (GUI)

2.3 XML Configuration

To be able to use the system in a variety of scenarios and studies, it was necessary to provide an easy way to specify the questions and when they are asked. This configuration was done using an XML configuration file on the mobile phone, which specified the location of the question WAV or MP3 files, the time points to ask the questions, the length of the recordings and information about the storage location. Figure 3 shows an example configuration, which plays an announcement without recording at the beginning and two blocks of two questions each.

```
<config>
  <questions backuppath="file:///E:/Sounds/"/>
</config>

<questioner>
  <question name="intro.mp3" rectime="0" starttime="0"/>

  <question name="q_01.mp3" rectime="3" starttime="100"/>
  <question name="q_02.mp3" rectime="3" starttime="100"/>

  <question name="q_02.mp3" rectime="3" starttime="400"/>
  <question name="q_01.mp3" rectime="3" starttime="400"/>

  <question name="end.mp3" rectime="0" starttime="700"/>
</questioner>
```

Figure 3: An example XML configuration file specifying an introduction without recording and two blocks with two questions each.

As the JSR for XML parsing (JSR 172) is not supported directly by most current phones, a small XML-parser had to be developed for this task. The implemented parser supports reading basic XML documents like the configuration file. Data fields are not supported by the parser implementation, as they were not used in the configuration file.

2.4 GPS Recording

The recording of the GPS information is an integral part of the software. If enabled in the GUI, the software acquires the GPS data from the receiver using either the Location API (for mobile phones with internal receiver) or the Bluetooth API (for external receivers). The data is received and stored in the NMEA (National Marine Electronics Association) GPS format [7], which contains the position, altitude and various parameters on the precision (see Figure 4).
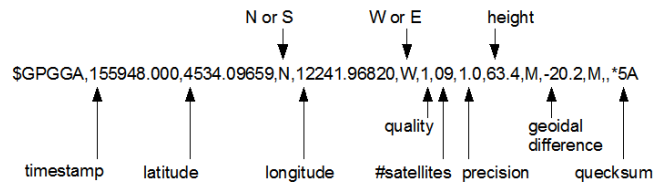

Figure 4: The NMEA GPS format

The data is recorded with a frequency of 1 Hz, which is precise enough to record the position and speed of runners. Additionally the data stream is converted on the fly to the KML (Keyhole Markup Language) format used by Google Earth.

2.5 Audio System

The main task of the software is to ask the user questions and record the given answers. We employed the Java Mobile Media API for this task. The system automatically determined weather a headset was present and used it for playback and recording. The questions itself have to be provided as WAV or MP3 files and entered into the configuration file, together with the time when they should be played. After starting the system, the files are then read from the file system and played at the specified time points. Overlapping questions are automatically resolved by playing them in sequence (see Figure 5).
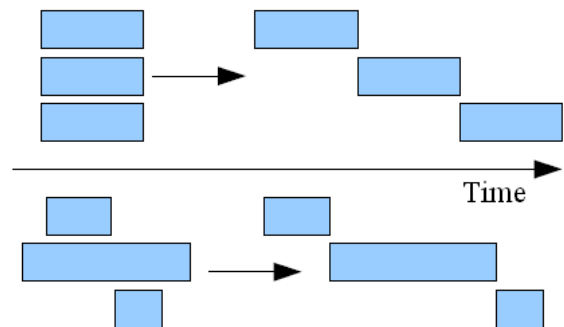

Figure 5: Overlapping questions are played consecutively in the order of specification.

3

After playback the user is given some time and the answer is stored on the file system as a WAV file. When the questions overlapped the system automatically ensures there is enough time for an answer. Recording is performed with a bit rate of 128 kbps with 8 kHz sampling rate, which was sufficient for the purpose. The recording can also be turned off in the configuration file, e.g. for the purpose of announcements, to give instructions or simply to play music.

2.6 Graphical User Interface

The graphical user interface or GUI is usually crucial for the acceptance of a mobile application. In this case however it was one of the goals that the system did not require any interaction with the user. We therefore did not employ a complicated GUI but focused on displaying only the most basic information as text.

The GUI that was implemented uses the Java ME window manager and is able to display simple text messages as well as menu items. It allows to change various options (e.g. select the internal or external GPS receiver) and to display status information (like the current GPS position). Such status information is very important in the field to check whether the system is ready or not. Once the recording has been started, no further user interaction is required.

3. Experiments

The system we presented in this paper has been successfully used in a series of psychological studies performed in different countries around the world. While details of these studies are beyond the scope of this paper, the main objectives were to acquire information about the subjective feeling of athletes while performing a recreational run.

The studies included three locations with a different number of runners participating: Portland, Oregon, USA (84 runners), Los Angeles, California, USA (61 runners) and near Heilbronn, Germany (286 runners). The participating athletes were all frequent recreational runners and had to perform a one-hour run while being asked questions by the system. The running speed and route during the run were completely left to the participants, as the GPS allowed for a reconstruction of those parameters. For data collection we chose a

Bluetooth headset and the Nokia 6110 Navigator cell phone, as now additional GPS receiver was required using this phone. The phone was fixed to the upper arm of the participant for optimal GPS reception. The system was configured to play a short introduction explaining the questions to the participants. Then questions were asked in sets of eight questions each. The questions included were designed to assess the subjective psychological state of the runner, including questions like "Do you feel motivated?". After each question the participants had time to give an answer on a scale from 0 (not at all) to 6 (extremely). After the first question unit the runners were asked to start their run. During the run the same eight questions were repeated in intervals of 5 minutes. The order of the questions was changed in each unit. In total 13 question units with eight answers were recorded for each participant.

4. Results and Discussion

We used the data collected in the psychological studies to evaluate the usability and reliability of the system. Data collection could be performed on all three locations without any technical problems. The system was easy to use and did not pose any usability problems to the people conducting the studies. After data collection the answers were transcribed manually and checked for missing answers or GPS problems. Table 1 gives an overview over the collected data and how much of the data could be used for each study.

Location	Subjects	Audio samples usable	GPS samples usable
Heilbronn	286	96.6 %	98.5 %
Los Angeles	81	93.7 %	98.4 %
Portland	84	94.3 %	98.4 %
	431	95.7 %	98.4 %

Table 1: The subjects and the usable audio and GPS samples for each data collection location.

The mobile surveying system proved to be highly reliable in practical use. From the 431 total participants only 9 people (2.1%) had to be excluded due to problems with the speech recording, while only 4 subjects (0.9%) had gaps in the GPS data. From the remaining 44824 audio samples only 1080 samples (2.4%) contained no answer or too much noise.

Missing GPS data was mostly due to a lost signal during the run and only occurred seldom. The main reason for unusable audio files was usually not noise as one might speculate, but most often that the recording did not contain any answer from the subject. This was mainly due to the fact that the runners had answered before the recording had started, where they should have waited for the signal. The situation was improved later in the study by reducing the time between question and answer recording. If the runner did answer the question properly the signal was almost always understandable.

The acceptance of the system by the athletes participating in the studies was also very high. The majority of participants stated that the equipment was not hindering for their activity.

Less then 5% of the subjects found the device distracting or uncomfortable.

As the GPS data was collected during the run, it was possible to calculate the running speed and to visualize the path using Google Earth. As one goal of the studies was to develop a better understanding of the changes in motivation during the run we additionally employed GERVIT [5], a tool for visualization of other variables together with GPS data. With this tool it was possible to visualize the changing motivation of the participants during the run (see Figure 6 and 7). In the figures the changing color represents the perceived fatigue of the subject. Additional data, e.g. heart-rate can be easily integrated into the visualization.
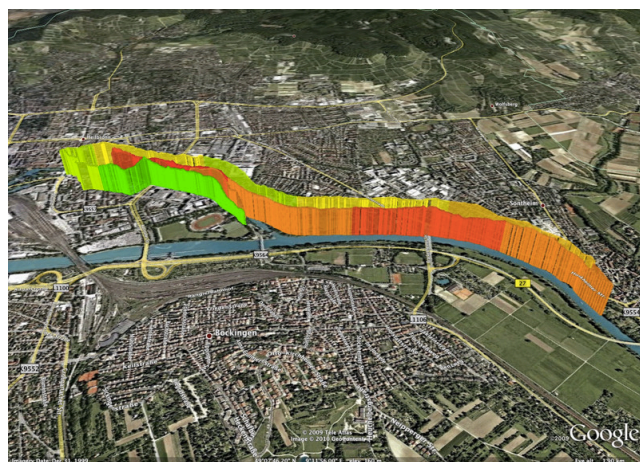

Figure 6: Visualization of a one-hour long example run in Portland, Oregon, USA (left) and Heilbronn, Germany (right) using GERVIT and Google Earth. Height represents speed, while color indicates the perceived fatigue ranging from yellow (not at all) to red (very).

Figure 7: Visualization of a two different example runs in Los Angeles, California, USA using GERVIT and Google Earth. Height represents speed, while color indicates the perceived fatigue ranging from yellow (not at all) to red (very).

5. Summary and Conclusion

We presented an embedded solution for real-time remote monitoring of physiological state and subjective perception for use in outdoor activities. The evaluation of the system in a major psychological study showed a high user acceptance and the practical usability of the system. The system showed an overall reliability of 96% for the audio and 98% for the GPS information. In addition to the data collection system we presented an easy visualization of the collected data together with terrain data and maps, which can be used to observe the changes in motivation during the run.

Future work will focus on an extension of the system and further applications. As the system is highly modular it will be straightforward to integrate further sensor like heart-rate sensors or accelerometers. As the system is easy to configure with different questions, an adaption of the system to other applications or studies is possible without difficulty. Such applications might include the surveying during training, rehabilitation or mobile healthcare scenarios. Because of the implementation on a Smartphone, the system can also be extended to react to changes in the user state and to give instantaneous feedback to the user.

6. Acknowledgements

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