Mobile Recording System for Sport Applications

Patrick F. Kugler [1 +], Dominik Schuldhaus [1], Ulf Jensen [1] and Bjoern M. Eskofier [1]

[1] Digital Sports Group, Pattern Recognition Lab, University of Erlangen-Nuremberg, Germany

Abstract The recording of kinematic or physiological signals is an important part of any biomechanical study. Systems for the recording of such signals are widely available. However, they are often expensive, complicated to setup and can only be used in a lab environment. Therefore they cannot be used for outdoor recording or long-term monitoring of athletes performing outdoor sports. This is especially a problem for the assessment of habitual outdoor runners, where recording in a more natural environment would be preferred.
To overcome these limitations, we have developed a lightweight mobile recording system for sport applications using off-the-shelf hardware. The system consists of SHIMMER™ sensor nodes and a standard Android™ smartphone running a mobile recording app. It enables simultaneous recording of physiological and kinematic data, as well as location information during outdoor sports. We give an overview of the recording framework and additionally present an automatic labeling algorithm based on the location of the athlet. We evaluate the usability and packet loss of the system in a pilot study, recording data from different sensors. Additionally a longer outdoor run was recorded to demonstrate the practical use for future studies. Finally, we outline how collected data could be used for data mining and real-time feedback applications.

Keywords: kinematic data recording, inertial sensors, wireless body area network, SHIMMER sensor platform, Android smartphone, embedded signal processing, classification, feedback training

1. Introduction

During sports related studies it is often desired to record certain parameters while the subjects are performing. Usually this includes kinematic and kinetic data, as well as electrophysiological signals like the electrocardiogram (ECG) or electromyogram (EMG). Standard systems for this task already exist, e.g. marker based motion tracking systems, force plates or physiological recorders. However, these systems are often expensive, complicated to setup and limited to lab use. Hence they cannot be used during outdoor sports or for long-term monitoring to assess the effects of fatigue. This is especially a problem for casual running, which is typically performed outdoors and for longer periods of time. The only solution for in the lab is a treadmill, however this has a considerable influence on the running style [1]. Recording in the lab would introduce a bias as the artificial conditions interfere with the natural movement. Instead it would be preferred to capture the performance of the athlete in a more natural outdoor environment.

Recently wireless body area networks have become available [2,3]. They consist of small wireless sensor nodes which integrate inertial or physiological sensors. Example projects are CodeBlue, Mercury, MobiHealth and MIThril [2,3]. However, they either use custom hardware or only describe a general framework and not a ready-to-use recording application. In similarity to our study, the authors of [4] describe a mobile recording application for mobile phones using wireless sensor nodes. Though, their system requires a modification of the phone software and will not run on standard devices. Currently, there is no solution available that is easy to use and suitable for recording during outdoor sports.

To address this problem, we have developed a lightweight mobile recording system for outdoor sport applications using off-the-shelf hardware. The system consists of three main components: commercial SHIMMER [5] sensor nodes, a custom mobile recording application for Android smartphones and post processing algorithms for an automatic position based labeling. We provide a framework for simultaneous recording of physiological signals, kinematic data from inertial sensors and location data using the global positioning system (GPS). The system is very flexible and can be easily extended using other SHIMMER sensor modules (e.g. EMG) or custom sensor hardware. In contrast to previous work the mobile recording app presented in this paper is instantly available for practical use and was specifically developed with sport applications in mind. It supports a large variety of sensors using off-the-shelf sensor hardware and will run on any phone supporting Bluetooth® and running Android version 2.0 or higher without modification.

+ Corresponding author. Tel.: + 49 9131 85 27890.
E-mail address: patrick.kugler@cs.fau.de

The purpose of the paper was to present the current status of the mobile recording system and to outline future applications. We present the wireless sensor nodes, the mobile recording app and the post processing algorithms. We provide a pilot evaluation of the usability of the system, the package loss and demonstrate the practical usability for future studies. Finally, we outline how the system could provide training data for classification problems and give preliminary results on street/grass condition classification.

2. Mobile Recording Framework

Figure 1 gives an overview of the mobile recording framework. It consists of three major components: The wireless sensor nodes, an Android smartphone running the mobile recording application and a desktop computer for post processing. The main part of this system is the mobile recording app, which is used to setup the sensors and to start the recording procedure. The app receives sensor data from various sensors and stores the data together with the location of the subject. Recorded data can be transferred to a computer for post processing, automatic labeling and further analysis. Together, these components form an easy to use mobile data collection system.

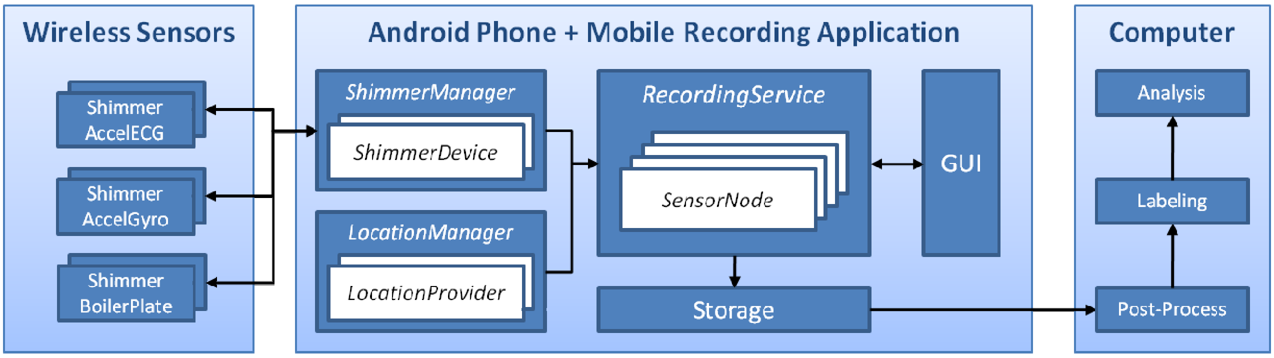

Fig. 1: An overview of the mobile recording framework and its components.

2.1. Wireless Sensor Nodes

To provide a usable and practical recording environment for sport applications, we chose hardware from an off-the-shelf mobile sensor platform called SHIMMER [4]. The nodes are small and lightweight and can be placed on various positions around the body (Fig. 2 left). They employ a low-power TI MSP430F1611 microcontroller with 8-channel 12-bit ADC, a lithium-ion battery and a wireless module supporting either Bluetooth or IEEE 802.15.4. Each node integrates a 3D accelerometer and supports a large variety of plug-in modules for physiological (EMG, ECG, GSR), kinematic (gyroscope, magnetometer) or other sensors.

The mobile recording framework is flexible enough to support different kinds of sensors and firmware images. Currently three standard open-source SHIMMER firmware types are widely used [4]: *AccelECG*, *AccelGyro* and *BoilerPlate*. All are compatible with our framework. The images *AccelECG* and *AccelGyro* only support a fixed sensor configuration and sampling rate. In contrast, the image *BoilerPlate* allows a flexible configuration of sensor channels and sampling rate without reprogramming the sensor node.

2.2. Mobile Recording Application

The mobile recording application is the main part of the recording system. We chose to use the Android operating system, as it is an open and widely supported platform and provides direct access to GPS and Bluetooth capabilities. The middle part of Fig. 1 gives an overview of the architecture. The necessary recording tasks are realized by a *RecordingService*. This service provides an interface to setup or control the recording. The main advantage of a service is that the recording is performed independently from the user interface, e.g. recording continues even if the user receives a phone call. The *RecordingService* can handle multiple sensors via the common *SensorNode* interface. Sensors inside the phone (e.g. GPS) as well as external sensors (e.g. SHIMMER) have to implement this interface. As GPS support is directly provided by the operating system using *LocationManager* and *LocationProvider* objects, only an adapter class implementing the *SensorNode* interface was needed. Support for SHIMMER was added by creating a custom *ShimmerManager* with multiple *ShimmerDevice* classes, one for each supported firmware.

The actual recording app was realized as a graphical user interface, which communicates with the *RecordingService* and allows the user to perform different tasks. The user can connect the sensor nodes, setup a recording task (setting sensors, sampling rate, etc.) and start, pause and stop the recording. Additional information about recording time and sensor status is provided. During recording the service receives data from the connected sensors and stores it on the SD card or the internal memory of the smartphone. The data is stored in a time-coded folder and contains one file for each sensor in CSV format. The files include the raw sensor data, a sensor based timestamp t_{sensor} and a local timestamp t_{phone} for each sample.

2.3. Post Processing

Data collected from multiple sensors during a longer outdoor run is sometimes not suitable for a direct analysis. Often the precise location of the athlete at each point in time is required. As the sampling rate of the GPS sensor is typically much lower compared to the other sensors, a post processing step is required. Additionally, the track might consist of multiple rounds or different sections. This is often obligatory when performing a study where the athletes have to run a predefined route, which includes different conditions (e.g. grass, trail, street). In this case the current round and section numbers for each point in time are needed.

In a first step, the different sensors are roughly synchronized using the shared timestamp t_{phone}. Secondly, each sample is assigned a valid athlete location by linear interpolation of the GPS data. To assign round or section labels, the location of the different round or section boundaries has to be additionally provided (e.g. from a map). An algorithm using the Euclidian Distance Transform [9] is then used to find the points where the athlete passes these boundary locations. Finally the track is partitioned in rounds and sections and corresponding labels are added to each sample.

3. Evaluation

To demonstrate the practical use of the presented mobile recording system, we evaluated the system during outdoor running. The mobile recording software was installed on a Samsung Galaxy S2 smartphone running Android version 2.3. A SHIMMER node was mounted firmly on the right heel counter of a running shoe (adidas adiZERO™ Boston, Fig. 2 left). We recorded accelerometer and gyroscope data at 200 Hz from the shoe node and ECG data at 500 Hz from a node on the chest.

Different sampling rates and sensor configurations were tested in multiple short outdoor runs of about 10 minutes each. Fig. 2 (middle) shows some recorded example data. We evaluated the usability of the user interface, the reliability of the sensors and the applicability of the different firmware images. The recording app was easy to use and always responsive. The data was evaluated for possible packet loss by inspecting consecutive timestamps t_{sensor} for each sensor. No packets were lost using the presented setup.

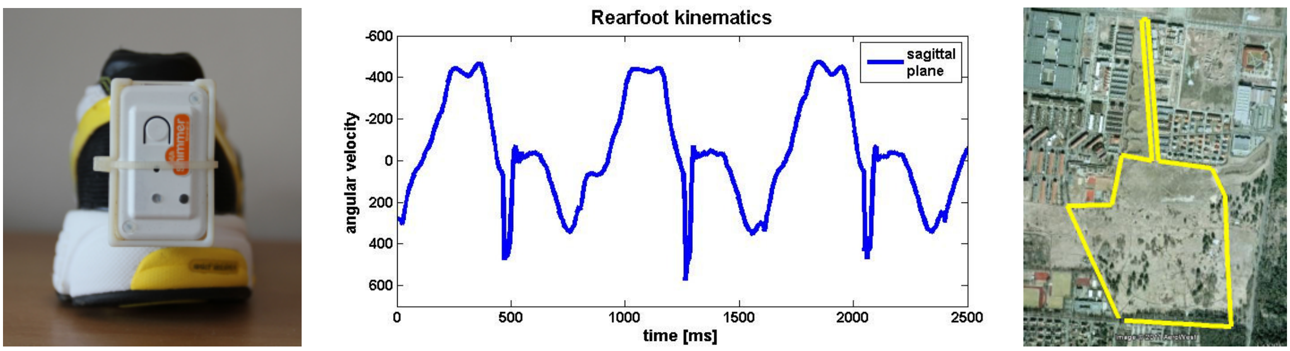

Fig. 2: Wireless SHIMMER sensor node mounted firmly on the heel cap of a adidas adizero boston running shoe (left), example sensor data from the shoe node during running (middle) and a map of the outdoor running track (right).

In addition to the short running tests, one male runner performed a longer outdoor run on a predefined running route (Fig. 2 right) of about 4 km length, containing sections with different surfaces (street, trail, grass). The recorded data was automatically labelled into rounds and sections using the presented algorithm. Manual inspection of the section labels using Google Earth™ showed that the labels were assigned correctly. Some inaccuracies in the absolute position of the runner on the map were visible (e.g. path did not follow the street). However, this did not affect the correctness of the section labels.

4. Discussion

The practical evaluation of the mobile recording system showed that the system is capable of long-term recording of GPS location and sensor data from multiple nodes. It handles different sampling intervals and records without any package loss. The use of Bluetooth currently limits the system to 7 nodes and a total bandwidth of 768 kbit/s. However, this is sufficient for most recording applications and can only be improved by changing the wireless modules. Visual evaluation also showed that the automatically assigned labels were correct. The small offset in position was most probably due to GPS or map inaccuracies. As it did not influence the relative positions, it represented no problem for this application.

The labelled data from the outdoor run can be used as input for data mining algorithms and the training of classifiers [10]. First tests using a Support Vector Machine classifier [11] indicated that running on street and grass can be automatically distinguished. These are preliminary results and an extended study with more subjects is required for confirmation. However, it demonstrates that the mobile recording system is an excellent tool to provide the necessary data for these kinds of studies.

Future studies might include running on different surfaces or inclinations and long-term monitoring, e.g. to quantify the effects of fatigue. The collected data can then be used to build assistance systems, which give direct feedback while the athlete is performing. Such online-classifiers and feedback applications can be easily integrated into the presented framework. This was already realized in [12], where the framework was used for a coaching app for golf puts. Future work will focus on similar apps for a variety of sports and also clinical applications, e.g. to assess gait impairments in Parkinson's disease or falling risk of elderly people.

We also plan to extend the recording app by integrating a live sensor view and a playback of the recorded data to enable a direct inspection of the data quality. Additionally, the automatic labeling will be integrated directly into the app. Future work will also focus on the development of a custom SHIMMER firmware image, which will allow smooth integration of new sensors. Additionally the buffering of sensor data on the node, data compression and algorithms for a precise time synchronization will be future topics.

5. Summary

We have presented a lightweight mobile recording system for sport applications that consists of off-the-shelf hardware, a mobile recording application for Android phones and an automatic labeling algorithm. The system enables simultaneous recording of various sensors and GPS information during outdoor sport. In future studies the presented recording system will provide a valuable tool for long-term monitoring of outdoor sport activities and will provide data for classification systems and real-time feedback applications.

6. Acknowledgments

This work was created in collaboration with the Embedded Systems Institute (ESI) Erlangen, supported in part by the Bavarian Ministry for Economic Affairs, Infrastructure, Transport and Technology and the European fund for regional development. All trademarks are the property of their respective owners. Technical support was provided by the adidas AG, Herzogenaurach. We wish to thank all participants.

7. References

[1] B. M. Nigg et al., A kinematic comparison of overground and treadmill running. *Med. Sci. Sports Exerc.* 1995, **27** (1): 98-105.

[2] M. Chen et al., Body area networks: a survey. *Mobile Netw. Appl.* 2010, doi:10.1007/s11036-010-0260-8.

[3] H. Alemdar et al., Wireless sensor networks for healthcare: a survey. *Comp. Netw.* 2010, **54** (15): 2688–2710.

[4] O. Pereira et al., Body Sensor Network Mobile Solutions for Biofeedback Monitoring. *Mobile Netw. Appl.* 2010, doi:10.1007/s11036-010-0278-y.

[5] A. Burns et al., SHIMMER™ – A Wireless Sensor Platform for Noninvasive Biomedical Research. *IEEE Sensors Journal* 2010, **10** (9): 1527-1534.

[6] P. Danielsson, Euclidean Distance Mapping. *Computer Graphics and Image Processing* 1980, **14**: 227-248.

[7] R.O. Duda et al., *Pattern Classification.* 2nd ed., Wiley-Interscience 2000.

[8] V.N. Vapnik, *Statistical learning theory*. 1st ed., Wiley & Sons 1998.

[9] U. Jensen et al., Sensor-based Instant Golf Putt Feedback, In: *Proc. of the International Symposium on Computer Science in Sport (IACSS 2011)*, accepted for publication.