ANALYSIS AND VISUALIZATION OF SPACE-TIME VARIANT PARAMETERS IN ENDURANCE SPORT TRAINING

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Abstract

We develop methods for data acquisition, analysis, and visualization of performance parameters in endurance sports with emphasis on competitive cycling. The goal of our work is to provide methods to improve the performance of athletes in training and in competition. Measurements from a palette of devices, including common bike computers, GPS-recorders, power meters, and spiroergometric devices are combined requiring data fusion and synchronization. In addition, we consider integration of maps with elevation information and areal photographs together with recorded video footage of training courses. We also apply biofeedback methods that require complex data processing. Appropriate ways to jointly present such diverse data need to be developed for their analysis and visualization. A particular challenge is the information visualization of complex multi-dimensional signals of traveling sensors. For the simultaneous visualization of large information quantities we use the “Powerwall” at the University of Konstanz, i.e., a large high resolution display (dimensions 5.20 m x 2.15 m, pixel resolution 4640 x 1920) which offers the display of high resolution terrain data and maps together with static and dynamic parameter sequences from measured training rides or a running biofeedback simulation. The following topics are addressed among others: (1) adaptation of training course profile for laboratory biofeedback simulation, (2) learning of tactic approaches for a given training course profile, (3) evaluation of efficiency of different feedback parameters. The paper surveys some of the initial approaches, in cooperation with the Heart Institute Lahr/Baden, Germany.

Keywords: performance parameters, endurance sports, visualization, data processing, data fusion, biofeedback training

Introduction

In professional training for competitive cycling measurements are taken that capture physical parameters of the athlete and mechanical parameters of the bike in the field or of an ergometer in a laboratory environment. Such data series are usually transferred to a computer for display and analysis by special purpose software. Such systems focus on monitoring and analysing those performance parameters that are characteristic for the specific motions in biking. The goal is an improvement of cycling performance in training and eventually in competition. There is a rapidly growing palette of commercial measuring devices, ranging from common "bike computers" capturing speed, cadence, heart rate, temperature, and barometric pressure to more complex ones for GPS localization. Moreover, there are (expensive) power meters and spiroergometric devices that measure ventilation and gas exchange. For scientific research it is desirable to combine several such devices, thus, creating the need for methods for data fusion and synchronization. Commercial metering devices come with specific software that does not readily support the desired joint representation and analysis. In our work we strive to combine all types of data with high-resolution maps of training regions and corresponding video recordings synchronized by software to individual training rides. The amount of data collected can get very large requiring methods for appropriate analysis and visualization. For the simultaneous visualization of large information quantities we apply the Powerwall at the University of Konstanz, i.e., a large high resolution display (dimensions 5.20 m x 2.15 m, pixel resolution 4640 x 1920) which offers static or dynamic display of high resolution terrain data and maps together with parameter sequences from measured training rides. From the computer science side the challenge is

- to custom tailor tools for the acquisition, synchronization, fusion, and management of large numbers of time series, and
- to devise solution strategies for the combination of terrain data, video, simultaneous time sequences of many parameters on the Powerwall and on regular size computer screens
- to organize the visualization of past training sessions and online biofeedback training sessions suitable for the domain experts, i.e., for training science, resp. the athlete.

The research project is ongoing and we describe in this paper our approach and some implementation details.

Previous Work

Large display devices
(Ni et al, 2006) provide a detailed survey of current large display technologies. The authors consider hardware setups (caves, multi-monitor desktop systems, tiled LCD panels, projector arrays (like our powerwall), stereoscopic and volumetric displays), rendering techniques, network setups, streaming techniques, software toolkits. A number of software toolkits for display streaming and distributed rendering is briefly introduced. The paper then considers applications for large displays, including vehicle design, geospatial imagery and video, scientific visualization, collaboration and tele-immersion, education and training. The paper closes with considerations on user interface design and interaction techniques and gives a top ten hitlist of research challenges with large displays.

Time series visualization and synchronization
(Müller & Schumann, 2003) gives a broad overview of existing visualization techniques for time-dependent data. (Aris et al, 2005) discusses the challenges of visualizing unevenly spaced time series and proposes four representation methods. The methods are evaluated with respect to their advantages and disadvantages for different applications. (Marwan, Thiel, & Nowaczyk, 2002) presents a method for synchronizing two time series. The method exploits a recurrence plot, from which it isolates a so called line of synchronization (LOS). The LOS yields a non-parametric rescaling function with which one can synchronize the time series. (Liu, 2004) presents a method to measure the degree of synchronization of two time series.

Studies on data acquisition in biking and applications
(Balmaer et al, 2000) assessed the validity of power output recorded using an air-braked cycle ergometer (Kingcycle™) when compared with a power measuring crankset (SRM™). (Belli & Hintsy, 2002) evaluates a study with 22 male subjects on the question of optimal pedalling rate selection for cycling in field conditions. (Stapelfeldt & Mornieux, 2007) study and evaluate biofeedback methods for training of the continuous power exertion on the pedals over the entire turn of the crank. Satellite GPS navigation has already been successfully used in sports training, e.g., for rowing and skiing (Blumenbach & Henke, 2005).

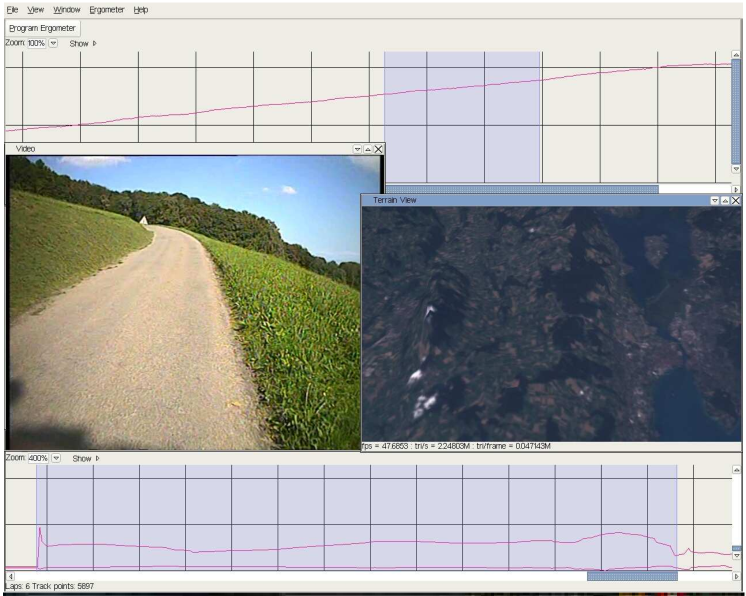
Methods

Visualization on the University Konstanz Powerwall
Konstanz Powerwall is a large back projection screen lit by eight self-aligned beamers each of which controlled by one computer over which a master machine resides, see (Keim et al, 2006). The machines are connected by Gigabit Ethernet. In order to display interactive visualizations, in contrast to static images, we employ a distributed rendering system that uses the processing power of all machines. A review of common software toolkits for distributed rendering on PC clusters is given in (Raffin & Soares, 2006). Because of its flexibility, we chose the Chromium stream processing framework (Humphreys et al, 2002), a framework for processing streams of OpenGL commands. Chromium can be considered as a kind of OpenGL proxy in our environment. To a software application that runs on the master machine, Chromium presents just one large OpenGL display. To the individual machines that drive the beamers, Chromium acts as a normal software application, displaying their respective part of the screen. However, while Chromium gives us the benefit of flexible distributed rendering with OpenGL, it also presents some challenges to the development of our visualization software. Many OpenGL applications use OpenGL only for displaying 3D models or scenes, but not for the user interface. The user interface is usually shown in a windowing environment, such as Microsoft Windows or the X-Window-System, because OpenGL has only very limited support for user interface design. As Chromium can only process and distribute OpenGL commands, we need to do everything in OpenGL, including the user interface. Another challenge is the limited network bandwidth between the machines that drive the Powerwall. A bandwidth of one gigabit per second may seem a lot, but given the display dimensions of 4640 x 1920 pixels, it would only allow to transfer 4.6 frames per second, assuming 24 bits per pixel. Fortunately, Chromium does not transfer raw pixel data, but encoded OpenGL commands to be executed by the machines driving the beamers. As an OpenGL command can affect many pixels, the OpenGL description of an image to be rendered is usually much smaller than the raw pixel data. Nevertheless we must design our application carefully in order to minimize the amount of data to be transmitted for a frame. A third challenge is presented by Chromium itself. In its current version, it is not capable of multicasting. That means that OpenGL commands that must be sent to more than one machine, such as texture definitions for polygons that span multiple tiles of the display, must be sent multiple times, wasting network bandwidth. Multicasting would allow several machines to receive such data simultaneously, improving network efficiency.

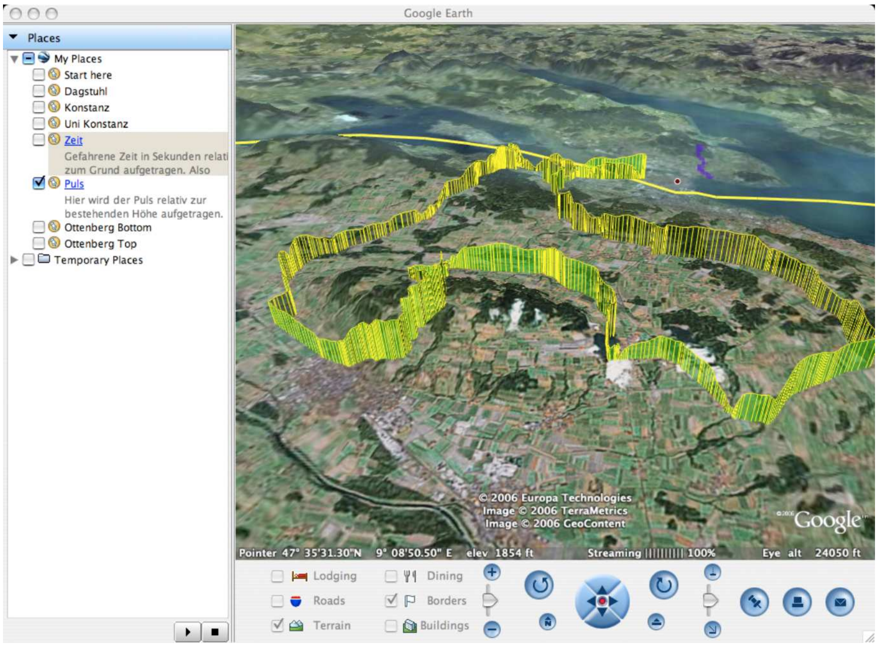
The following screenshot on the right shows a first example of simultaneous display of a video sequence together with 2.5D terrain data and a couple of time series.

Time series synchronization

One example requiring time series synchronization in our application is the alignment of a video sequence with recorded GPS trip parameters. The video sequence was captured using a helmet camera on a selected training course of 2.5km. Simultaneously, a GPS device (Garmin Edge 305, see picture, left) recorded longitude, latitude and elevation with a resolution of one sample per second. The output of heart rate, cadence, time stamp, longitude, latitude, and altitude per sample is given in the form of an XML file. The video sequence has 25 frames per second. For the synchronization it suffices in this case to manually identify the time origins in both sequences and then to interpolate positions assuming a constant frame rate for the video. Beforehand the GPS positions were transformed into appropriate Cartesian coordinates. This way, Cartesian coordinates can be computed for each video frame and a (fractional) video frame number can be obtained for each GPS measurement or for an additional interpolated point.



In our application this time series synchronization allows replay of any given training session on the same training course, given a corresponding sequence of recorded GPS parameters. Moreover, for biofeedback experiments in the laboratory, video display and computer controlled traction of an ergometer station can be accurately rendered matching the given course track including its incline at an ascent. This setup could open a number of new possibilities for athletes and training scientists. It could enable an athlete to condition himself to the strain conditions of an unknown course without actually visiting that course. This setup also allows us to measure variables that can be measured in a laboratory environment, but are not easily measurable in the field, in a realistic laboratory simulation of a specific training course. An example of one such measurement is motion capturing, which allows to precisely measure movements of specific body parts with a high resolution in space and time, and can help to detect and eliminate inefficiencies in the motions of an athlete.



Visualization of heart rate of 2.5D terrain data for a 50km training ride South of Konstanz in Thurgau, Switzerland, based on Google Earth. The heart rate is displayed as the height of the yellowish band along the cycling track. The height must be taken above the ground, not above sea level, since the terrain varies in height.

Procedures

This ongoing research is divided in three steps:

Step 1: Data acquisition of terrain data of a specific training course combined with data acquisition of the physiological workload of the athlete.
Step 2: Evaluation of the visualized data (Powerwall) in a laboratory situation for each athlete.
Step 3: Evaluation of feedback training in the field.

Objectives regarding training science

In our studies we address the following issues regarding training science

1. Biofeedback training – adaptation of traction control and visualization to actual course, i.e., the traction is related to the incline of the road and the video sequence displays the current location.
2. Conditioning of the athlete´s performance with respect to a given unfamiliar training course.
3. Evaluation of feedback parameters (what is possible? – what is necessary? – what can be perceived?).
4. Design of training sequences on ergometer for specific courses independently of weather conditions and season.
5. Analysis and evaluation of specific bike ergometric parameters with the help of visual feedback (for example, seating position)
6. Can feedback training lead to stable results? (reliability of the conditioning).

Conclusions

Our project setup combines training science for competitive and amateur cycling with state-of-the-art visualization and biofeedback leading to practical application in a laboratory setting with an ergometer as well as for training and competition in the field. Currently, our project still is in Step 1 listed above, i.e., in the development of appropriate data acquisition methods and tools.The focus of our current work is on road biking, but we plan to extend the work to other endurance sports such as running and rowing.

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