The Therapy Top Measurement and Visualization System - An Example for the Advancements in Existing Sports Equipments

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Abstract

In this paper we report on ongoing work where sensor technology and wireless networks are integrated with sports equipment to improve the utility and usability of such equipment. Our focus is on the iterative design process for a multi-disciplinary team. We show how mutual learning became a central issue for the success of the design and development.

KEYWORDS: UBIQUITOUS COMPUTING, SPORTS, SENSOR NETWORKS, USER INTERFACE

Introduction

Health is one of the most important issues in well-being of individuals as well as for a society. Sports, physical recreation and sportive games have many positive effects and can improve overall health and personal happiness. Sports have many facets ranging form fun and entertainment to physiotherapy and rehabilitation. Equipment plays an important role for sports; in many areas the equipment and technologies available shape the way we do and perceive sport. Our motivation in this project is to assess how ubiquitous computing technology can improve users' experience in sports. In particular in this paper we describe the developed system in detail.

In this paper, we report on a successfully deployed novel system in the field of sports and healthcare. It consists of several pieces of sports equipment augmented with sensors, communication and processing. By recording and monitoring exercises and by providing audio-visual feedback a new experience can be created. The technology enables users to see how they do their exercises and helps to correct and optimize their training. Monitoring and visualization of advances helps and motivates the users. Additionally the automated continuous feedback eases the task of physiotherapists and coaches as it reduces the need for human intervention. This makes it possible that the training devices can be used with less supervision and hence at lower cost.

Therapy Top – Medical Background

The therapy top is a widely used piece of equipment in the sports school that we investigated. Technically it is disk with a diameter of about 40 cm that has a rounded bottom and a flat top to stand on. There are more than 30 regular exercises that can be done with the therapy top, see the case study for details. This includes exercises for beginners and advanced users,

involving one ore more feet on one ore more therapy tops. The therapy top is used in sports schools, physiotherapist practices and at home for several reasons: (1) improving the equilibrium sense, (2) improving muscle disequilibrium in legs and ankles (3) convalescence of patients after accidents and (4) muscle training in knees, backside and waist;
The difficulty in using the therapy top is to accomplish complex movements while checking that the movements are correct (e.g. the tilt angle is correct). Currently, these checks are done by a instructor at the beginning of the training who checks when the angles are correct an when not. Having continuous feedback and long-term monitoring of improvement appeared as one area where introduction of technology could help to improve the users' experience.
After injuries of the ankle, a training to improve the proprioceptive functions and to strengthen the muscles acting around the ankle is highly recommended. Due to the range of motion an ankle allows, we have certain muscles that have to be trained. These muscles are: m. tibialis anterior, m. extensor hallucis longus and m. extensor digitorum longus. These three muscles belong to a group of muscles which are used to move the toes upward (dorsal flexion). The muscles to move the toes and the foot downward (plantar flexion) are: m. gastrocnemius, m. soleus, m. plantaris, m. popliteus, m. tibialis posterior, m. flexor digitorum longus and m. flexor hallicus longus. Knowing about the anatomical structure of the ankle, we distinguish two axes of rotation. Subject to the point of application of the muscles, it provides us with the function of the muscles crossing the ankle joint. According to this they are not only responsible for dorsal and plantar flexion, but also allow for pronation of the ankle. After an injury of the ankle joint complex, the joint is normally fixed by a strong bandage or by a cast. This external stabilization leads to inactivity of the muscles surrounding the ankle. Thus it is necessary that an appropriate training program improves the function of these muscles. The right training process can show adaptive hypertrophy for these muscles.
While moving on and with the Therapy top, the effect is not only an adaptive hypertrophy but also an improvement of the control for the muscles. We call this a proprioceptive training. Proprioception is a process that helps us to control the muscle contraction. That is done while interpreting incoming information that responds to external forces. This information is given by stretch receptors in the muscles and in the ligaments. They help us to control the position of body parts, united by a joint. To stabilize the interpretation of the proprioceptive information, it is good to give another hint about the position of the body parts. This information can be given by a physiotherapist or by a computer controlled system that gives a visual or acoustical signal, going along with the real position of the body parts in an area.

System Description

The platform used for acquiring sensor data and transmitting them into the local subnet is the Particle Computer platform. Particle Computers are small wireless sensor nodes. The node's hardware comprises a communication board integrating a microcontroller, a radio transceiver (125 kbit/s, with a range of up to 50 meters), a real-time clock, additional Flash memory and LEDs a speaker for basic notification functionality. Particles especially address scenarios of high node mobility and issues of small size. The Particle communication board together with one of the sensor boards measures 15x48 mm. This is equal to the size of an AAA battery and allows unobtrusive embedding of wireless sensor technology. Particles can run of a single 1.2V battery which consumes on average 50mA. The particle computer can be extended by additional boards. With sensor and RF usage, the power consumption raises (peaks) to 80 to 100 mA. As sensor, a three-axis acceleration sensor is used.

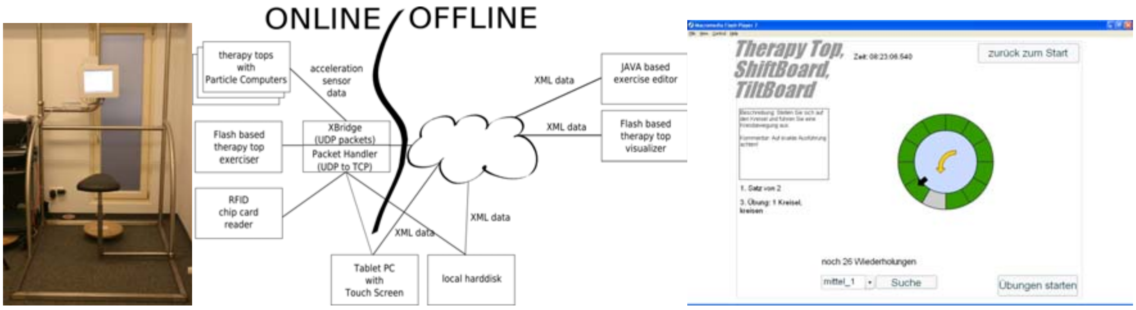

Figure 1: (a) The chair can be swung in for patients recovering from an operation and who cannot stand on a therapy top. All other users can exercise with one or two therapy tops within the steel frame. The surrounding round steel tubes provide safety in case of a stumbling or falling. For normal trainings, two therapy tops can be used at the same time, one for each foot. (b) Architecture overview. Sensor input from augmented sports devices is transmitted via RF to the infrastructure (Particle XBridge), collected and preprocessed by a UDP-to-TCP Java-based application and finally made available to the visualizing Flash application. (c) Screenshot of the GUI of the training component. The current exercise along with a minimum but training-related additional information is displayed in a clear screen layout.

The Particle is powered by two mono accumulators (2.4V, 16.000 mAH) providing a runtime of about a week at maximum power consumption. Using the microcontrollers sleep functionality when no system usage (no change in the acceleration values over a defined period of time) is detected, we derived a run-time of over a month without any maintenance. This low maintenance is especially important for the user study and the deployment. Space is not a critical requirement as in the wooden therapy top there is enough space for a cubic hole of 8x8x8 cm for batteries, sensor and measurement platform.

The pre-processed sensor data is available in the local subnet. As our development environment, Macromedia Flash, cannot directly handle UDP sockets, we developed an intermediate application. The three functionalities of it are: (1) pass the data via a TCP Socket, (2) provide a time stamped raw data storage and (3) chip card authentication.

The Flash exerciser application loads the user profiles and starts the training process. The users can review pre-recorded videos of their exercises before each exercise. The training itself is visualized in near-real time on a Tablet PC. This Tablet PC is mounted into a steal frame and positioned directly before the user at a view angle that supports good readability of the display contents. The user-system interaction is limited to RFID card authentication and touch-based interaction as input modalities. Audio-visual feedback of the exercises forms the output channel. The setup of the installed system, the system architecture and a screen shot of the Flash exerciser are depicted in Figure 1.

A graphical and simple-to-use editor allows the physiotherapist or coach to specify new exercises along with restrictions, e.g., that two therapy tops must be used and that they are to rotate contrariwise. The editor allows adding new exercises, new users and manages user-exercise program relations. This editor has been developed in JAVA and uses XML as data storage format.

The exercises are stored as XML, as is the raw sensor data from the device. This enables the trainer or physiotherapist to later review the training done by the user or patient and discover potential problems, e.g., that the patient cannot reach a certain angle with his ankle. The processed training data as well the raw sensor data are both stored on the local hard disk for later usage. The visualizing application allows coaches and trainers to review all training within a minimum time. An intuitive graphical user interface helps identifying potential deficits in the users' trainings. The RFID card reader used for authentication and access control is connected via serial line to the touch screen pc.

Conclusion and Results

In this paper we presented a successful development process for augmented sports equipment. Using an iterative design process that focuses on users' needs we augmented sports equipment with sensor technology. To create a useful system it became apparent that integration with processes and infrastructure is essential. To explore the usefulness of a system with users in a natural environment the integration as standalone prototype is not sufficient. The effort required to integrate the system with existing infrastructure and to common safety standards was much greater than the effort for building a first functional prototype. Our experience showed that having functional prototypes from the very beginning of the development is of great importance. Paper prototypes and non-functional mock-ups were used successfully but were not sufficient to get the idea of the system across to users. Especially with regard to real time functionality (e.g. visualization of the movement with the device) having a working prototype is essential to give other people on a multi-disciplinary team and users a good understanding of the design space. Having this shared understanding of the design space helps to jointly develop new ideas and finally useful systems. The therapy top system is still in use in the sports school and used during normal trainings. The system also serves as basis for several research projects in medicine. One project focuses on the effects of audio-visual training support especially for improving the fitness of children. Another project, as part of a Ph.D. study, evaluates the system during rehabilitation. We will continue our development on this system to contribute to these projects.

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