Designing Ubiquitous Computing Systems for Sports Equipment

Abstract

In this paper, we report on a user-centered, iterative design process for augmenting sports equipment with ubiquitous computing technology. In several design iterations, a fully working system for training and physiotherapy, comprising hard- and software components of ubiquitous computing technology, has been developed. The prime focus of the project is on user needs in this domain. In a multi-disciplinary effort we first investigated what shortcomings current practices have and how novel technologies can help to improve the experience and value for users and instructors alike. The system is deployed, in use and has been evaluated with a large user study. Based on our experience we outline general principles and design guidelines for ubiquitous computing applications in the field of sports.

1. Introduction

Integrating computing and communication technology into sports equipment offers new opportunities for creating novel devices and equipment with enhanced functionality. Our research indicates that using technology probes [8] and an extended user centered design process allows the design of ubiquitous computing sports systems that have an immediate and lasting impact. By having a focus on users' needs throughout the development and deployment phase and by involving all stakeholders during the whole project, could a valuable and easy to use system be developed. By supporting common usage patterns and integrating the new technology with existing infrastructure, the various technological components deployed sum up to more than the mere parts to form a successful end-user system. The key to successful development and deployment is to respect and acknowledge the social and technological context of the application domain and the resulting specific requirements. This, though being taught in requirements engineering for many years now, is often neglected in ubiquitous computing projects. Additionally, in ubiquitous computing, various specific aspects to software engineering arise. Those specific patterns that we took into account in our work, are discussed by Landay et. al. [11].

In competitive sports and professional training facilities very elaborate technical systems are in use. However, these systems are very complex to operate and difficult to be used by amateurs and hobbyists. Additionally, high-end sensor systems are, due to the high costs, only available for atheletes in competetive sports. Our focus was on developing a low-priced system which is usable by a broad range of people. Consequently, sports, personal fitness and healthcare are interesting domains for ubiquitous computing research which we want to lay the focus of our work on.

Over recent years, interesting and useful systems have been developed showing the benefit that can be achieved from using ubiquitous computing technologies in these fields [4, 9]. Especially small-scale embedded devices equipped with sensor input enabled the augmentation and creation of devices that allow totally new applications. 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, new experiences can be created. The technology enables users to see how well they perform their exercises and helps to correct and optimize their training. Monitoring and visualizing advances inform and motivate 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.

The goal of our research was to assess how a transfer of pervasive computing technology into a real-world scenario can be made possible. The challenge here lies in making technology work when used with and by real people and not only in a restricted laboratory scenario. Most current pervasive computing systems do work perfectly in a laboratory situation but fail when taken out into the real world. We therefore show how such a process has to incorporate the stakeholders during the development process. We explicitly chose a scenario where a relatively simple technology like a wireless sensor node with acceleration sensors can be used to create a meaningful end user system that can be deployed and maintained by ordinary people and users.

The contributions of the paper are as follows. First, we report on the positive experiences with technology probes and an extended user-centered design process. We show how a requirement analysis was done and report on the iterations to actually build the final system. We demonstrate that knowledge transfer within the interdisciplinary project team is highly necessary and can be achieved.

Second, we describe technological aspects of the deployed system, report on how the system was integrated into the existing infrastructure and explain the lessons we learned in this process.

Third, we report on a two-weeks continuous user study with 47 participants doing 100 training sessions in a large sports school. The study confirmed that novel technologies, if they focus on the users' needs, can achieve great acceptance with users and operators and that new technology needs to reach a high level of functionality, beyond the prototyping stage, to be meaningfully assessed.

Fourth, we summarize the lessons learned in this project and generalize them into design guidelines for the field of ubiquitous computing in sports and healthcare.

2. Development Process

In the *anonymized* project [14], we explored options for the development of ubiquitous computing systems for sports. The overall philosophy was to focus on stakeholders' needs while developing the best possible technical solution. To achieve this we consequently followed a user centered design process that was extended by the use of technology previews and technology probes. The development was done in several iterations, creating prototypes of different fidelity. These have all been deployed and tested with users in the real use environment. During the process a multi-disciplinary team of physiotherapists, sport coaches and computer scientists were involved.

It has been a basic principle of our approach that during the whole process the interests of user and stakeholders drive the development. We identified all potential stakeholders before any development to make sure the system can be evaluated according to the special needs of ubiquitous computing systems, as discussed by Scholtz et. al [15]. The objective was to build a system that was suited and customized perfectly to their respective needs and based on the latest technology available. The advances with regard to the technology were rather on the system architecture side with the basic technology components used as vehicle to achieve the goal – a working and widely deployable ubiquitous computing prototype. The overhead necessary for our extended design process is significant but results justify its employment.

2.1 Central Elements of the Design Process

We used different methods and tools during the iterative design process. In particular, the following elements are of interest and proved to be important for the success:

2.1.1 Technology Developers Learn About the Domain in Depth

Even though the development took place in a multidisciplinary team, it was invaluable that members from each discipline had an in-depth understanding of the other fields. To understand the application domain one of the computer scientists regularly attended a sports school as 'customer' and 'user'. This was done before the start of any development in the project for a period of more than three months doing regular sessions. This gave the computing researchers insight in how people are taught to do the exercises, how reporting and error-correction is done. After that, unstructured interviews with both trainers and trainees were conducted looking for problem domains where improvement would be welcome. During this time, informal interviews with different stakeholders were performed. This input was essential for the technology developers to gain an understanding of the application domain and the work processes. Gaining knowledge in the domain helped to shape technology solutions, as the experience gathered influenced many (small but crucial) decisions that had to be taken in the course of a project.

2.1.2 Technology Preview and Technology Probes

To communicate the potential of available technology, several demonstration systems were used. These technology previews – either quick 'hacks' or systems developed in previous projects – outlined basic functionality, such as real-time data capture with sensors, wireless data transmission, and real-time visualization. Placing the technology in the context of the application domain inspired the non-technical members of the team and showed them restrictions (data sensing and communication, etc.) at the same time.

Giving some technology parts, even if not handled perfectly, to a domain expert proved to be very valuable, as in further discussions they referred to what they knew was possible. We did not include end users in this process because to understand a specific system after only seeing a crude technology preview requires an in-depth and rather abstract understanding of the processes and goals. Our experience showed that many users at the school lack such knowledge.

2.1.3 Paper Prototypes and Mock-Ups

Paper prototypes and mock-ups were used as communication tools in early phases of the development. Using paper prototypes proved to be an efficient way for informal system specification and to document requirements. As all participants could equally influence the appearance and 'functionality' of the prototypes, this methods allowed a truly multi-disciplinary development. Non surprisingly, this worked especially well for issues related to visualization (hardware and software) and documentation. It was interesting to see, however, that these methods have limits when it comes to integration and real time functionality. Here a great level of abstraction is required to see how such prototypes work. It seems that this is easier for technologists than for the other people involved.

2.1.4 Functional Prototypes

Throughout the project we developed functional prototypes with different fidelity. Depending on the investigated question and the target audience, these prototypes ranged from simple demonstrators highlighting a single issue to the final fully functional prototypical system that is integrated into the existing infrastructure. Nevertheless, we learned that providing real functionality is essential to assess experience, especially if it is novel. For demonstrators and simple prototypes we used Flash. In Flash the graphical elements can be defined and changed very quickly which allowed the rapid prototyping of the user interface and the exploration of different options for the visualization.

Low level functionality (e.g. acquisition of sensor data) was developed early in the project and remained basically the same throughout the whole development process. It was very valuable to have developed these components early in the project and to provide an easy to access interface to have the data available for prototyping. We used a wireless sensor network platform for data acquisition and sockets for communication.

By having functional prototypes, the experience and usage becomes very realistic and people using the system come across more issues than when just thinking or discussing about it. Issues like privacy surfaced only when people used the system, not when they just reflected on the potential use of a system.

2.1.5 Iterative Development

Having quick development cycles was important as in ubiquitous computing systems many components have an impact on the experiences created with the overall system. Packet-loss and communication delay in the wireless sensor network used to acquire sensor data can be tackled in multiple ways. In our example, designing a visualization that is robust against a certain amount of data loss was one solution which came naturally in the iterative design process as the iterations in the visualization were quicker than in the development of network protocols.

Each step in the iterative development was usually comprised of the following parts: creation of an idea for a design or improvement of a design, specification of the requirements and assessment of the technical feasibility, feedback from the whole project team on the specification, prototype or implementation, demonstration or deployment in the real use environment, and evaluation. This approach can be compared to agile software development in standard software engineering.

At the early iterations the system was built on standard hardware, hardly integrated with the target environment and very limited in scope and functionality, but functional. In later stages specific hardware was developed, integrated with the existing infrastructure, and with an extended functionality. Even though functionality was limited at the beginning, having a functional system from the first step on was important. One very positive effect was the high motivation achieved within the team by always having a functional system.

Ease of use, for all the people dealing with the system, was a central issue during all iterations. Some user features, that increased the usability significantly, required the integration with the infrastructure. Therefore there was often a question of priorities what features to include at what effort. Here, our target was to choose the parts that allowed the best improvement with regard to the user experience from step to step.

2.2 Augmenting Sports Equipment

As the initial goal was to assess how ubiquitous computing technologies can enhance the users experience we did not know beforehand how the project would be implemented. There basically were two options to use technologies: either augment the human or augment the equipment. After the observations and interviews in the early project phase it became apparent that following the second approach, augmenting sports equipment, is the more promising way to address users needs. Augmenting the user immediately raises issues related to safety, privacy and comfort; additionally, there are already various devices available in the mass marked (e.g. pulse monitoring).

To decide which equipment to augment with highest priority, a set of interviews was conducted. It was of particular interest which devices where used most often in training by a wide variety of people. Additionally, it was investigated where users had difficulties during training, especially with the devices used so far. The following four devices fitted these criteria: Therapy Top (see Fig. 1), Tilt Board, Shift Board, and Synchronous Training Machine. We augemented all of these training devices but will only present the process for the therapy top in this paper.

(a) Therapy Tops

Figure 1. (a) Two therapy tops are shown. (b) The Synchronous Training Machine is used to bend and straighten the legs. The length of the foot bar and the weight determine the difficulty of the exercise.

2.2.1 Therapy Top

The therapy top is a widely used piece of equipment in the sports school that we investigated. 70% of all people use it for training or rehabilitation purposes. Technically it is a disk with a diameter of about 40 cm that has a rounded bottom and a flat top to stand on, see Fig. 1. 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 or more feet on one or more therapy tops. The therapy top is used in sports schools, physiotherapist practices and at home for several reasons, some of them are:

- improve the equilibrium sense
- improve muscle disequilibriums in legs and ankles
- convalescence of patients after accidents
- 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 an instructor at the beginning of the training giving advise when the angles are correct and 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.

We also investigated the other training devices shown in Fig. 1 which are all used during regular training. We opted for the Therapy Top as it was the mostly used piece of sports equipment and can be used for more purposes than the other investigated training devices.

2.2.2 Training with Equipment

Our observations revealed that for most of the equipment used in the sports school a typical process can be observed. The user is instructed by a trainer how to use a certain piece of equipment. This usually fits into a larger set of exercises designed for a particular person for a certain goal (e.g. regaining full flexibility of the ankle). The description of the exercise changes over time depending on the advances of the user.

At the beginning, the instructor provides a lot of feedback, but over time the user is expected to understand the exercises and training process and less feedback is provided. Depending on the equipment, training is also done at home (e.g. with the therapy top). In these cases the user gets no feedback at all.

2.2.3 Prototyping Augmented Sports Equipment

In the course of the project augmented versions have been created for several of the devices described above. These have been deployed and evaluated. In the next section we show how the therapy top was augmented in detail.

3 Case Study: Therapy Top

After an initial study on potential candidates for a novel augmented piece of sports equipment, the therapy top was chosen. In an extended user centered design process we created an augmented version of a therapy top. As introduced before, there are many different exercises that can be done with the therapy top of which some are described in the table in Sec. 3. More exercises along with short video demonstrations can be viewed at the project page at *anonymized*[14].

Beginner’s Exercises

- simple balancing (standing) on the therapy top
- standing on one leg on the therapy top
- knee-bends with both feet on one therapy top
- go from normal stand to tiptoe stand
- tilting (seesaw) backward and forward with both feet on on therapy top

Advanced Exercises

- circling with one foot while tilting with the other
- tilting forward/backward with both feet placed behind each other
- tilting left/right with both feet placed behind each other
- tilting left/right (counter-clockwise) with both feet placed behind each other

3.1 Medical Background on Therapy Top

After injuries of the ankle, a training to improve the proprioceptive functions and to strengthen the muscles acting around the ankle is highly recommended. The therapy top is a typical device for performing this training. Due to the range of motion an ankle makes possible, we have certain muscles that have to be trained. These three muscles belong to a group of muscles which are used to move the toes upward (dorsal flexion). 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 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 stabilisation 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.

3.2 Overall Development Process and Goals

The overall development process consisted of several iterations of visits to the sports school, interviews with coaches and users, discussions on the current prototypes, problem identifications and an update of the requirements analysis. This enabled us to quickly identify problems during the development, to correct the approaches and to keep the goal of a usable end-user system in mind during the whole project. We derived a basic set of development goals. These included:

3.2.1 Data Acquisition and Visualization

The orientation and tilt of the therapy top should be captured by a wireless sensor platform as any cable connected to the therapy top would be hindering, if the cable would wind up around the top while circling.

The delay between sensor acquisition and visualization should be minimal to allow for a direct feedback for the user. Any noticeable delay would have made the user wait for the visualization to update before he could have continued his exercise. This would have rendered the system useless. The visualization should be able to also visualize any boundary violations like insufficient tilt angle or tilting over one side during the forward/backward tilt exercise.

3.2.2 Exercise Definition and System Integration

As with the normal exercises, users get their training plan and tend to carry them with them all the time during their training. Information like exercise type, number of iterations and sets are associated with this plan. For this printed training plan, there exist exercise definitions in the support system of the sports school. This system currently lacks the ability to define the extended exercise parameters. Therefore a special editor was developed. The data storage format for the exercises is XML which can later be easily integrated within the existing training plan software. Training data, raw and preprocessed for the training visualization, are stored as XML so they can be used by this proprietary system, too.

3.2.3 Functional Requirements

The minimum functional requirements to a meaningful deployed system were defined together by domain experts in medicine, rehabilitation, coaches, users and technologists. Only by several joint sessions of all the involved stakeholders, we were able to derive this list.

- data sampling rate of about 50 Hz
- long-term data storage
- tilt angle calculation
- angular data accuracy of at least 3 degrees

- audio-visual training support using pre-recorded videos
- near-realtime training visualization
- authentication support and per-user profiles

3.3 Technology Preview, Mock-Ups and Paper Prototypes

Before any technical implementation, the physiotherapists and coaches were shown a sensor data capturing device. We used the sensor technology already developed for the *anonymized* Project[14] and the race game application developed for it. A small program visualized the orientation and state of a physical object. The simultaneous demonstration of sensor device and visualizing application helped to create a deeper technological understanding.

Along with this hardware, several paper prototypes of potential applications related to the therapy top were discussed. These mock-ups included drawings of a virtual therapy top and angular and tilt values and a game which could be controlled by a microcontroller. It was explained that if this was included in the therapy top, children could playfully do their exercises while actually performing their training.

Presenting the people involved in the design team with a technology preview was essential to make them understand what is technologically feasible. Combining an understanding of technology and domain-specific background in sports and rehabilitation, we could determine the key parameters, presented in Sec. 3.2.3 that would be necessary for a meaningful system.

3.4 First functional Prototype

We used Flash for visualizing the orientation of the therapy top during our initial meetings as it allowed us to quickly prototype user interfaces.

The C program for sensor data acquisition remained basically the same throughout the whole development process. It simply gathers acceleration sensor data and transmits it via radio-frequency (RF). The iterations were concentrated on a better bandwidth utilization of the available RF slots.

The first version of the graphical user interface required manual input of the users name and exercise parameters (e.g. number of repetitions, start direction (forward/backward or left/right) and minimum and maximum tilt angles). This version used a standard laptop (no touch screen) as well as mouse and keyboard for data entry. The initial visualization (see Fig. 2) used one circle for each circle or tilt made with the therapy top, displaying small points at each angle where sensor data were captured, independent of the exercise done at that moment. An even distribution of the data points showed that the exercise was smoothly done in the case of the circling exercise.

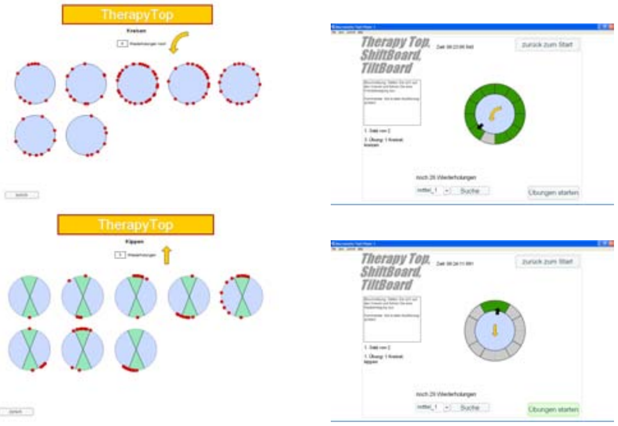

Figure 2. Discontinued (left images) and final visualizations (right images) for circling (upper two images) and tilting exercises (lower two images). Feedback from the development process resulted in major improvements to the inital version.

3.5 Development Cycles

This visualization was discussed in a scheduled meeting of the stakeholders. It was found that displaying a large number of circles and data points would be distracting for the user. Therefore the visualization was changed to display only the last circle. Initial and final visualization are depicted in Fig. 2. In the last iteration, the circle was partitioned into sectors of 30 degrees. These were colored if any data was received in this sector. It is possible that no data at all is received if e.g. the user simply does not enter this area or if RF packet loss is too high. The color of the sector is either red, yellow, green or grey. The whole data for a segment is analyzed before coloring takes place. Green here means that the user a) entered this sector and b) kept within the defined parameters for the exercise such as the maximum and minimum tilt angle. Yellow means that the user kept most of the time within the defined boundaries. Red finally means a substandard performance in this sector. The initially grey sector stays grey if no data is received at all. This variant allows for easy judgement of the current exercise quality with a minimum of cognitive load and attention required by the user. For this reason we did not represent the current tilt angle as length of the arrow (a longer arrow representing a larger angle) either. The current circle is updated in near-real time to allow for a fast feedback. Thus, the trainee is able to determine what was right or wrong with the last iterations of the exercise and can more easily adopt his training.

At the beginning, we only visualized the incoming data as described above. We soon added a judgment of the exercise quality per circle, but this was rated confusing by the users. Following completion of the training set an overall performance statement was given, providing motivation and overall feedback such as 30 % of your exercises were correct. This proved to be sufficient for the users. The coaches and physiotherapists get a per-circle judgement along with a per-circle visualization in their visualizing application. This different visualization for users and physiotherapist became possible after the inclusion of long-term data storage. This lead to a development of a specialized tool where the per-patient and per-exercise information of previously stored exercises is visualized. By using this tool, the physiotherapists and coaches are able to completely review all training sets within a minimum time and no direct supervision and annoyance for the trainee. By using their domain-knowledge together with the sensor data, they can detect potential problems of the user, e.g. if he is not able to smoothly circle around due to reduced sinews in the legs or other potential problems. We found that their trained view at the visualization is also superior to any low-level interpretation logic. Therefore, no automated problem-recognition logic was added. But this could be a potential improvement for future system development. The initial versions were developed on a standard personal computer and demonstrated on a laptop. For real world deployment, we chose a touchscreen as this is easier to use while doing the exercises.

An easy-to-use graphical profile editor was developed allowing the physiotherapist to select users, define exercises for them and also to define new exercises. Along with the exercise parameters, a video can be added. This allows the user to review his next exercise. The exercises were conducted by an expert coach and videotaped. Users of the sports school already possess a RFID card which is used to authenticate them at the entrance of the sports school. To allow users to simply start their training, we added an RFID reader to our system. Now all necessary user data are retrieved at system logon. No further input is required. The user is also greeted by his name and given an overview of his current exercises. Currently, most people in the sports school carry their printed training plan with them as it is hard to remember the exercise parameters (weight, number of repetitions, etc.) for a large number of different machines. This is now included in our system. To allow data capture unrelated to specific exercises, which is important for the future research (see Sec. **??**), we added a test mode where up to two therapy tops (at maximum one per foot) can be used for arbitrary exercises. The time from data capture to visualization is about 50 to 100 ms. This small amount of delay is nearly unnoticeable, especially when really standing on a therapy top and performing the exercises. This allows for easy adaption and improvement in the exercise quality.

3.6 System Description

The knowledge gathered in the many joint discussions and prototyping iterations resulted in the final system which we now describe in this section.

3.6.1 Hardware

The platform used for sensor data acquisition is the Particle Computer platform [5, 7, 2]. With sensor and RF usage, the power consumption is about 80 to 100 mA (peaks). For sensing, a three-axis acceleration sensor is used. The microcontroller is powered by two batteries (2.4V, 16.000 mAh) providing a runtime of about a week at maximum power consumption. By using the microcontroller's sleep functionality when no system usage is detected, we obtained 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 (see Fig. 1 (a)) for a cubic hole of 8x8x8 cm for batteries, sensor and microcontroller.

The complete hardware setup for training and rehabilitation is shown in Fig. 3. Mouse and keyboard are only used for starting the computer.

3.6.2 System and Software

The sensor data is transferred from RF to the local subnet by the XBridge. A Java-based packet handler provides the data to the Flash application for visualization. It also stores all data in raw format. Additionally, it notifies the visualization component when a user authenticates himself to the system. The Flash application then loads the stored training plan for the users. Before any training, the user reviews his current training plan, as he would have done with his printed plan in his normal training. He then can view a pre-recorded video of the current exercise which was performed by a trainer. He now can

(a) System setup for rehabilitation

(b) System setup for normal training

Figure 3. (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 round bars at the side provide safety in case of a stumbling or falling. (b) For normal training, two therapy tops can be used at the same time, one for each foot. The training equipment is surrounded by the steel construction providing safety for the person doing the training. The RF receiver is located at the right side of the black cupboard. The RFID card reader is mounted on top of the touch screen.

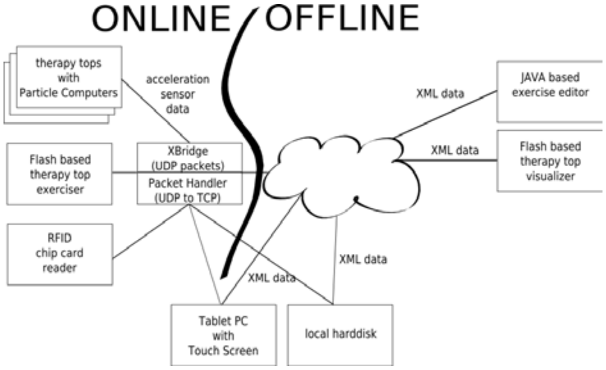

Figure 4. Architecture overview. Sensory input from augmented sports devices is transmitted via RF to the infrastructure, collected and preprocessed by a UDP-to-TCP Java-based application and finally made available to the visualizing Flash application.

start his training. After each exercise, he can wait an arbitrary time to recover. The two images on the right side of Fig. 2 show screen shots of the final visualizing component. After training completion, the application briefly gives feedback on the training. It then waits for the next user.

With the visualizing component, the coaches can quickly review all training units done with the system. By its easy and straightforward visualization of complete exercises and sets, problems can quickly be discovered.

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

3.6.3 Visualization

The system's graphical user interface for exercising is depicted in Fig. 2. Circle and tilt exercises using one therapy top are shown in the two rightmost images. For exercises with two therapy tops, they are visualized similarily but taking into account the relative position of the tops to each other. If in the profile editor the placement is defined e.g. as 'left one before the right one' this is reflected by the visualization.

The position of the touch screen can be adjusted in height and tilt. This allows users to view their training at a comfortable angle within the supporting structure depicted in 3. This is especially important for rehabilitation patients that are required to sit down for their exercises.

3.6.4 Integration

The data storage format for raw sensor data, preprocessed sensor data as it is used in the visualizing component as well as the exercise definitions, is XML. By using this format, a quick integration of the developed components in the existing system of the sports school is possible. The application that now generates the printed training plan can easily be extended to produce the XML for the respective exercise. This allows to continue the usage of the developed system in practice.

4 Study and Evaluation

We evaluated our system in a sports school with 47 participants over a two-weeks time frame. The participants completed 100 training sessions with our system. We had in total 21 female and 26 male participants, the youngest was 18 years old, the oldest 64. The training sessions took part in a separate, private room within the sports school to prevent interruptions by other people. In the following, we concentrate on the results of the evaluation of the therapy top.

The participants performed one to four training sessions with our system. 42 participants were regular customers training at the sports school. Five were trainers who will be using the system later in their regular work. As part of their training plans, all participants had a number of exercises with one or two therapy tops. From their training plans we derived four sets of the most common exercise combinations. Those exercises were stored and associated to four RFID cards. Participants were already familiar with those cards as they are used for access control to the sports school.

The 100 sessions took from 10 to 15 minutes each, depending on the training program and the rate at which the participants did the exercises. The training units with our system were done during the participants' regular training avtivity to ensure real training conditions. All raw sensor data gathered during the sessions was stored. We additionally videotaped a random selection of participants, resulting in 10 hours of video documentation. 32 of 47 participants returned the distributed questionnaires on time. We did not force an on-site return as participants stated that they wished to finish their regular training or did not have their glasses on in the sports school.

4.1 Pre-Study Interviews

For the evaluation, we interviewed the participants with a structured questionnaire to get background information, especially on their reasons for doing exercises with the therapy top and what problems they had with it. We were also interested in how many different exercises the participants were doing regularly and for what time period. We also asked them how they judged the correctness of the exercises they did and if they inquired for help if they were unsure or if they would like to be supervised at all or at certain intervals to improve their exercise quality.

The reasons for doing exercises with the therapy top were muscle build-up, improvement of the equilibrium sense, rehabilitation, injury prevention, improvement of the coordination capabilities and the motoric apparatus.

Common problems the participants stated to have were waggling over one side when tilting instead of tilting exactly over the middle, not completing whole circles during the circling exercises or not doing the exercises constantly. These issues can be addressed by our system. Problems we cannot address are skidding from the therapy top or moving the therapy tops apart while doing two therapy tops exercises. These problems are due to the nature of the exercises and the training equipment.

36% of the participants stated that they already asked the trainers for a re-demonstration. They stated that this seemed necessary for them only when doing new exercises. Also, the problem to them was not understanding what to do, but to do it themselves. The minority (27%) of the participants judged the correctness of their training as good or very good. This illustrates the difficulty of selfjudgment of the exercise quality. Nearly all of the participants stated, that they have already been corrected by a trainer more than 2 times. 92% of the participants stated that they always did **not** ask for support if they were unsure whether they were performing the exercises correctly. Also, most people would not like to have a trainer present when they were exercising. To them it was enough that trainers were available and making their rounds through the sports school. On these regular checks the trainers revise incorrect execution of exercises. Issues for not having a trainer present were 'I do not like to be watched.' or 'I know in principle how I should do it, but I do not get it right'.

After we explained the system to them, the participants were doing one of the four defined exercise sets. Each set of exercises comprised 3 different exercises each which had to be done twice with 30 repetitions of each time.

4.2 User Study Accomplishment

Participants were first demonstrated and taught the usage of the system:

- Authentication using an RFID card
- Reviewing the training plan (exercises, repetitions for each, amount of sets to complete) on screen
- Pressing the start button. For each exercise, a description of what to do and potentially a comment on how to achieve good performance was displayed. Before each exercise, there exists the possibility to view a movie of about 5 to 10 seconds where a trainer performs the current exercise. When people were ready, they placed the therapy top(s) in a convenient distance to the screen, potentially adjusting tilt and height of it. Then they mounted the therapy top and started exercising.
- While they were exercising, the user interface displayed a representation of the circle (see Fig. 2) on the screen.
- After finishing the repetitions for the exercises and completing the set of exercises twice, the application was returning to the authentication screen.

- Now participants were shown the visualization of their training, using a second application. Potential problems, e.g. waggling always over the left side in the tilt forward/backward exercise, were discussed with them. This could for example indicate a muscle disequilibrium in the legs. From the informal talk with them we were surprised that people stated that trainers previously discussed the very same issues with them when they were handed their training plans.

4.3 Results

We evaluated the system with the following key criteria in mind:

- Does the system give enough feedback?
- Can the users improve themselves with the system?
- Is the training more satisfactory to the user?
- Can training be done without any supervision?
- Is the user interface intuitive and usable?
- Do people become more aware of the errors they make?

The results we derived for these questions from our questionnaire are depicted in Fig. 5 and Fig. 6. We used a Likert scale with five options to assess these criteria. Depicted numbers above bars are the absolute number of people with respective opinion. Results show that all important issues were addressed properly. The system fulfils the users' expectations towards a computer-augmented therapy top system.

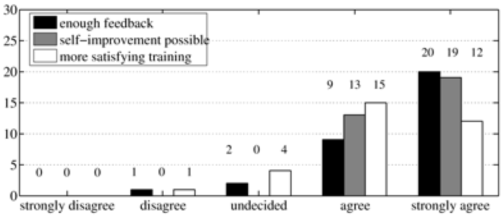

Figure 5. User study results for the following questions: system feedback, user's self-improvement and more satisfying training with audio-visual feedback.

Participants stated that training with the audio-visual feedback of our system was increasing their motivation for doing therapy top exercises. This surprised us as people also stated that they in general disliked the therapy top exercises.

The electronics and system components were rated as unobtrusive by all of the people. The electronics in the therapy top themselves is completely invisible and just signals operation by a blue LED underneath a cover.

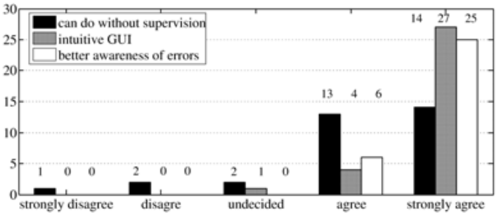

Figure 6. User study results for the following questions: training without supervision, usability of the GUI, error awareness.

We asked people if they would find a cable as appropriate. Most of them judged a cable as hindering and obtrusive. A cable would limit the possible placement of the therapy tops. Also, a cable would wind itself up during the circling exercises which would limit the usability in large parts.

The possibility of watching a pre-recorded video of a trainer doing the exercise was rated as only partially meaningful. The most often named reason by the participants was: 'I know what I am supposed to do and how but I simply do not get it right'. This was especially mentioned in conjunction with the first exercises for the people on the therapy tops and also with more advanced exercises.

We got interesting feedback from the trainers. They said that the possibility to define the tilt angles was a very good thing. Most people tend to just tilt back and forward very fast and not in a controlled manner. Defining tilt angles that are reasonable below the maximum tilt that can be accomplished with a certain therapy top could make people more aware of correct exercising if it forced them to stop the tilt movement at this angle.

We built the steel frame around our system to provide safety to our participants. In their normal training, they look for a free place nearby a training machine where they could get hold if something goes wrong, e.g. if they topple over. The dimension of the floor frame of 1.5 m x 2 m was chosen as appropriately large. People stated that by visualizing the boundaries of the exercise place, they were more aware of incorrect exercising if they recognized that they needed more space.

4.4 Improvements for the Therapy Top System

Although the system was fairly well advanced and had no break down while in use, some issues still have to be addressed for further development. Some participants positioned two therapy tops mirrored compared to the visualization and did not notice it for a complete exercise. Also, going in wrong direction with the circling exercises was not always recognized by the participants, despite of the arrow in the visualized circle. This needs to be addressed, ideally the next version of the system would detect this and automatically give audio-visual feedback to the user.

Especially for the circling exercises, people tend to lift the heel as this makes circling at the back half of the exercise easier. A pressure sensor could help make people more aware of this problem.

Also, a gyrosensor instead of the accelerometer could supersede the correct placement of the therapy tops before the exercises, namely in a way facing towards the screen, as especially tilt exercises would otherwise be visualized in a wrong way with current system. Though, we did not mention the fact that the placement is critical, people did it correct nearly all the time. This is owed to the fact that people placed the therapy tops in a way they could read the number on the plate and an arrow on this plate was directing at the screen.

For a home scenario and to facilitate the data transmission as well as to pass the bandwidth limit, we are currently exploring switching to WiFi or Bluetooth data transmission. This will reduce the need for a specialized reception component, too.

5 Related Work

Sensor support for competitive athletes is nowadays very common, for example in football or in skiing [12] or Taekwondo [3] and used for independent judgment of the athlete's performance.

The technology used has to be accepted by all participants and should work in the background, which we also found to be a crucial issue. Issues related to social acceptance factors are important and have to be taken into account as early as possible in the design process, otherwise the system will always be problematic, as discussed for several deployed systems in [12].However, it needs to be mentioned that in professional sports practice the acceptance for technology (even if not very usable) is high when it offers a completive advantage. The benefits of a personal fitness and health monitoring device, the Personal Wellness Coach, have been discussed in [1].

The positive effects of electronically augmented sports equipment, which we also experienced in our project, have been shown in the Thera-Network in [10]. How computer-augmented sports devices increase the motivation of especially young children to do sportive exercises is subject to the Fizzees project [13]. The sensor system here too is used only as vehicle to achieve the overall goal of improved fitness.

The electronics used and the architecture for communication sensor data to Flash developed in the *anonymized* Project [14] helped us during system development.

Technology probes [6, 8], as used by us during the development cycles, are an effecive method for assessing the needs and wishes of end-users in real-world settings and to develop a common understanding on the potentials of the technology. They also are able to foster the users' creativity to come up with new ideas.

6 Lessons learned, Recommendations and Guidelines

The following 3 issues summarize central findings of our project. For the introduction of pervasive technologies into new domains, and especially in sports, we recommend to take them into account.

In particular we recommend: Gain a deep and comprehensive understanding of the application domain Follow a user centred and technology driven approach Work with short prototyping cycles an deploy functional prototypes

6.1 Understanding the Domain

The changes to systems and overall processes that are induced by pervasive computing can be massive. For successfully applying pervasive technologies in new domains it is essential to gather a full understanding of these domains and the potential of the technologies. The process we outlined before aims at understanding 4 different areas: The current process and use of technologies Processes that are established and technologies currently in use provide significant insight for domains. Here in particular it is essential to understand why processes are done in a particular way and why certain technologies are used. Understanding this will also allow to foresee problems in the design of a new system. The design space and available technologies Understanding what can be changes and what can not be changed is a first important step in sketching the design space. An in-depth knowledge of potential technologies, especially sensors, user interface components, and networking, is essential to see where technologies fit in. The impact of the introduction of technologies on use and process It is hard to fully understand how new technologies will impact processes and use; however it is vital to assess this in advance. Especially to make the informed decision an estimation of the impact off the proposed changed is required. In situation where different options for new designs are available looking at the potential impact can be a significant help to make the decision.

6.2 User centred and technology driven

At first this may appear as two opposite approaches, but our results show that these approaches go well together. Combining user centred engineering with a technology driven approach can push boundaries. As we outlined before showing users potential technologies and presenting different technologies options and getting extensive feedback is a powerful approach. Without a technology push many solution are incremental and focus on the users needs that are tied to the old approach. Showing new opportunities given by novel technologies offers means to assess the users needs but less bound to current technologies.

6.3 Short prototyping cycles and functional prototypes

To establish new technologies and novel forms of use prototypes are a central means. Prototypes help to express the ideas of the designer and developer and communicate in a well suited way these ideas to the user. In return critiquing the prototypes by users is a very detailed form of feedback that helps well to understand the users point of view, ideas and concerns. Especially in sports we realised that functional prototypes are of great value. In many cases only functional prototypes can provide the experience or a preview of the expected experience that allows the user to sensible judge and evaluate the new developments. We have experienced that functional prototypes, even if simple, have many advantages over static (e.g. paper prototypes), even in very early stages of a project.

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