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A Server-Based Mobile Coaching System Integrating Ubiquitous Data Acquisition Technologies and Intelligent Real-Time Analysis

DISSERTATION

zur Erlangung des akademischen Grades

Doktor der technischen Wissenschaften

eingereicht von

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an der Fakultät für Informatik
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by

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to the Faculty of Informatics
at the Vienna University of Technology

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Erklärung zur Verfassung der Arbeit

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Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

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Abstract

The emerging area of "computer science in sport" and particularly the upcoming field of "ubiquitous computing in sport" are highly influenced by the progress of Information Technology (IT). In general, the current tendency of ubiquitous or also called pervasive computing describes the movement of information processing towards miniaturized, interconnected and intelligent computer devices as integral parts of everyday life. Given the continuous advances and recent boom in the mobile technology sector, in particular, nowadays also sports frameworks integrating pervasive equipment are in ongoing development. Especially mobile feedback systems are getting continuously widespread and important for the monitoring of sports performances. Sensor devices are becoming smaller, increasingly cable-free and, at the same time, smarter, enabling efficient methods for the acquisition of sports-related parameters. The diversity, capacity, networking ability and handy design of today's mobile devices, on the other hand, allow the implementation of effective supervision and instant intervention routines. The present thesis demonstrates the design and practical realization of an easy adaptable sports framework integrating innovative online analysis and real-time feedback techniques.

A first goal of this work is to point out the implication of pervasive computing for sport and sport science and to demonstrate some of the most important developments. For such purposes, an overview of typical implementations and fields of application regarding the use of ubiquitous computing equipment is given and illustrated in detail by the realization of the developed mobile coaching framework, aiming at the instant support of athletes and coaches during the training process.

The overall concept of the implemented system includes a server component for the bidirectional communication between sportsmen and coaches. Thereby, athletes are equipped with wireless sensors and an up-to-date handheld Personal Computer (PC) for data acquisition purposes, while coaches can access the measured information online and return appropriate feedback via the host computer to the athletes' devices. First implementations of the approach concentrate on the application in running and moreover for the use of pupils and teachers in school sport.

The reception of the sensor data is based on ubiquitous technologies such as ANT™ (a wireless sensor protocol commonly applied in the field of sport)-enabled smartphones, facilitated either via an ANT Universal Serial Bus (USB) stick, a (mini/micro) Secure Digital (SD) card, an individually designed Bluetooth®-to-ANT adapter or a built-in ANT module. The collected data is immediately forwarded from the Internet-connected mobile device to the server, where it is permanently stored. In this way, coaches and other experts can access the acquired real-time characteristics via developed web applications, providing not only instant analysis but also prompt feedback routines. Thus, specialists can assist athletes and intervene in their training by looking at the performance outcomes, thereby optimizing the achievements and also avoiding fatigue or injuries.

At the same time, with the increasing measurement possibilities and hence the growing data amount, also the computer-based analysis of the collected information and the immediate return of feedback become more significant. Consequently, intelligent methods are needed in order to extract significant patterns out of the measured items and send automated real-time notifications to the performing athletes.

Therefore, another major aim of the thesis is to propose sophisticated routines for the computerized analysis of the gathered parameter values. Regarding the server-based mobile coaching framework, Artificial Intelligence (AI) techniques running on the host component appear to be an efficient approach for data evaluation purposes. Accordingly, a particular adaptation of the system aims at the use in fitness and the automatic assessment of the executed exercises on weight training machines on the basis of machine learning techniques including classification algorithms like Artificial Neural Networks (ANNs) or fuzzy logic concepts. In running, on the other hand, the focus is set on the integration of an antagonistic meta-model for the analysis of physiological adaptation processes called Performance Potential (PerPot) for the optimization and enhancement of long-distance runs like marathons. The main goal thereby is to detect a possibly occurring fatigue in real-time and, in this way, to avoid exhaustion at an early stage. But also related application scenarios such as monitoring routines for medical purposes gain in importance and are therefore addressed throughout the thesis.

Keywords: Sports Applications, Feedback Systems, ANT, Wireless Technologies, Sensor Networks, Mobile Computing, Ubiquitous Computing, Real-Time Analysis, Artificial Intelligence, Machine Learning, Pattern Recognition, Performance, Simulation, Running, Cycling, Weight Training, Medicine, Adolescents

Kurzfassung

Der aufstrebende Bereich der "Sportinformatik" und insbesondere das aufkommende Gebiet des "Ubiquitous Computing im Sport" sind stark von den Fortschritten der Informationstechnik (IT) beeinflusst. Im Allgemeinen folgt der aktuelle Trend des Ubiquitous oder Pervasive Computing der Entwicklung der Informationsverarbeitung in Richtung miniaturisierten, vernetzten und intelligenten Computergeräten als integrierter Bestandteil des täglichen Lebens. Vor allem angesichts der kontinuierlichen Fortschritte und des jüngsten Aufschwungs des mobilen Technologiesektors sind heutzutage auch Sportlösungen mit ubiquitären eingebetteten Systemen in ständiger Entwicklung. Besonders mobile Feedbacksysteme sind immer mehr verbreitet und wichtig für die Überwachung der sportlichen Leistungen. Die heutigen Sensorgeräte werden immer kleiner, zunehmend drahtlos und gleichzeitig auch intelligenter, so dass effizientere Methoden für die Erfassung von Sportparametern vorhanden sind. Auf der anderen Seite ermöglichen die Vielfalt, Leistungs- und Netzwerkfähigkeit sowie das handliche Design der heutigen Mobilgeräte die Umsetzung von wirksamen Überwachungs- und sofortigen Eingriffsmethoden. Die vorliegende Arbeit zeigt zunächst die Implementierung und praktische Umsetzung eines leicht anpassbaren Sportsystems, welches innovative Analyse- und Echtzeit-Feedback-Interventionen über das Internet einbindet.

Ein erstes Ziel dieser Arbeit ist es, die Bedeutung des Pervasive Computing für den Sport- bzw. Sportwissenschaftsbereich und einige der wichtigsten Entwicklungen zu demonstrieren. Deswegen wird eine Übersicht über typische Implementierungen und Einsatzgebiete unter Verwendung von ubiquitärem Equipment gegeben und anhand der Realisierung des entwickelten Mobile Coaching Systems, welches als Ziel die unmittelbare Unterstützung von Athleten und Trainern während der Sportausübung hat, tiefgründig dargestellt.

Das Grundkonzept des implementierten Systems schließt eine Serverkomponente für die bidirektionale Kommunikation zwischen Sportlern und Trainern ein. Dabei werden Athleten mit drahtlosen Sensoren und einem modernen Handheld Personal Computer (PC) zwecks Datenerfassung ausgestattet, während Trainer auf die gemessenen Daten online zugreifen und entsprechendes Feedback über den Server an die Geräte der Athleten rücksenden können. Erste Implementierungen des Ansatzes konzentrieren sich auf die Anwendung im Laufsport und darüber

hinaus auf den Einsatz durch Schüler und Lehrer im Schulsport.

Der Empfang der Sensordaten beruht auf ubiquitäre Technologien wie ANT™(ein drahtloses Sensornetzwerk-Protokoll, das im Sportbereich weit verbreitet ist)-fähige Smartphones, realisiert entweder über einen ANT Universal Serial Bus (USB) Stick, einer (mini/micro) Secure Digital (SD)-Karte, einem eigens entworfenen Bluetooth®-to-ANT Adapter oder einem integrierten ANT Modul. Die gesammelten Daten werden umgehend über das Internet-fähige Mobilgerät an den Server weitergeleitet, wo diese dauerhaft gespeichert werden. Auf diese Weise können Trainer und andere Experten über Webanwendungen auf die erfassten Echtzeitdaten zugreifen, welche nicht nur sofortige Analyse- sondern auch zeitnahe Feedbackroutinen zur Verfügung stellen. Somit können Spezialisten Athleten direkt unterstützen, in dem sie in das Training eingreifen und dieses durch Kontrolle der Leistungsergebnisse optimieren, um dabei auch Ermüdungen bzw. Verletzungen zu vermeiden.

Mit den zunehmenden Möglichkeiten der Datenerfassung und den dadurch wachsenden Datenmengen bekommen gleichzeitig auch die rechnergestützte Analyse der gesammelten Informationen sowie die unmittelbare Rückmeldung eine immer größere Bedeutung. Folglich sind intelligente Verfahren erforderlich, um aus den gemessenen Kenngrößen signifikante Muster extrahieren und automatisierte Echtzeitmeldungen an die trainierenden Athleten senden zu können.

Daher ist ein weiteres wichtiges Ziel der Arbeit, fortschrittliche Routinen für die computergestützte Analyse der erfassten Parameterwerte vorzuschlagen bzw. zu entwickeln. In Bezug auf das Server-basierte Mobile Coaching System scheinen Verfahren aus der Künstlichen Intelligenz (KI/AI), welche auf dem Host-Computer laufen, ein effizienter Ansatz zur Datenauswertung zu sein. Dementsprechend richtet sich eine besondere Anpassung des Systems auf den Einsatz im Krafttrainingsbereich und insbesondere auf die automatische Bewertung der ausgeführten Übungen an Fitnessgeräten unter Anwendung von Methoden des maschinellen Lernens einschließlich Klassifikationsalgorithmen wie Künstliche Neuronale Netze (KNN/ANN) oder Konzepte der Fuzzy-Logik. Im Laufsport liegt andererseits der Fokus auf der Integration eines antagonistischen Metamodells für die Analyse von physiologischen Adaptionsprozessen namens Performance Potential (PerPot), welches die unmittelbare Optimierung und Verbesserung von Langstreckenläufen, wie zum Beispiel Marathonläufen, ermöglichen soll. Das Hauptziel dabei ist es, eine eventuell auftretende Müdigkeit in Echtzeit zu erkennen und auf diese Weise eine Erschöpfung frühzeitig zu vermeiden. Aber auch andere relevante Anwendungsszenarien wie die Überwachung für medizinische Zwecke gewinnen an Bedeutung und werden daher in der Arbeit behandelt.

Schlüsselwörter: Sportanwendungen, Feedbacksysteme, ANT, Drahtlostechnologien, Sensornetzwerke, Mobile Computing, Ubiquitous Computing, Echtzeitanalyse, Künstliche Intelligenz, Maschinelles Lernen, Mustererkennung, Leistung, Simulation, Laufsport, Radsport, Krafttraining, Medizin, Jugendliche

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CHAPTER **1**

Introduction

The computer industry has made a huge progress in terms of hardware and its enhanced capabilities throughout the last decades. A main factor for this development is connected with the progress of electronics and the invention of the first microprocessors in the early 1970s (Malone, 1995). However, already in April 1965 the Intel® co-founder Gordon E. Moore has foreseen and published a paper regarding the future of integrated circuits stating that "The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. Certainly over the short term this rate can be expected to continue, if not to increase." (Moore, 1965). This prognosis has been named after the author and is widely known as Moore's law, which is surprisingly still valid these days (as shown in Figure 1.1). In addition, the author predicted that the diffusion of electronics is going to push science and establish many new areas and developments including home and central computers, automatic controlling units and portable communication equipment. These statements can be also seen as the first vague forecasts for the up-to-date ubiquitous and cloud computing society.

1.1 The Impact of Moore's Law on Modern Technologies (in Sport)

Based on Moore's law, today's highly evolved Information and Communication Technologies (ICTs) are in fact important integration components of various research fields including applied sport science. In particular, the continuous advances of wireless (sensor) and mobile technologies enable new opportunities in the development of sports applications. Recently, ubiquitous sensor equipment is widely used for the measurement of sport-relevant data such as biomechanical and physiological parameters during the workout, training as well as competition processes. Modern handheld Personal Computers (PCs), at the same time, allow mobile and instant tools for the acquisition and initial processing of the measured values.

Due to the progresses and convenient integration possibilities of up-to-date ICTs, together with the wireless characteristics of recent sensor technologies as well as the mobile features and advanced web connectivity of common handheld PCs, such equipment may be applied for the real-

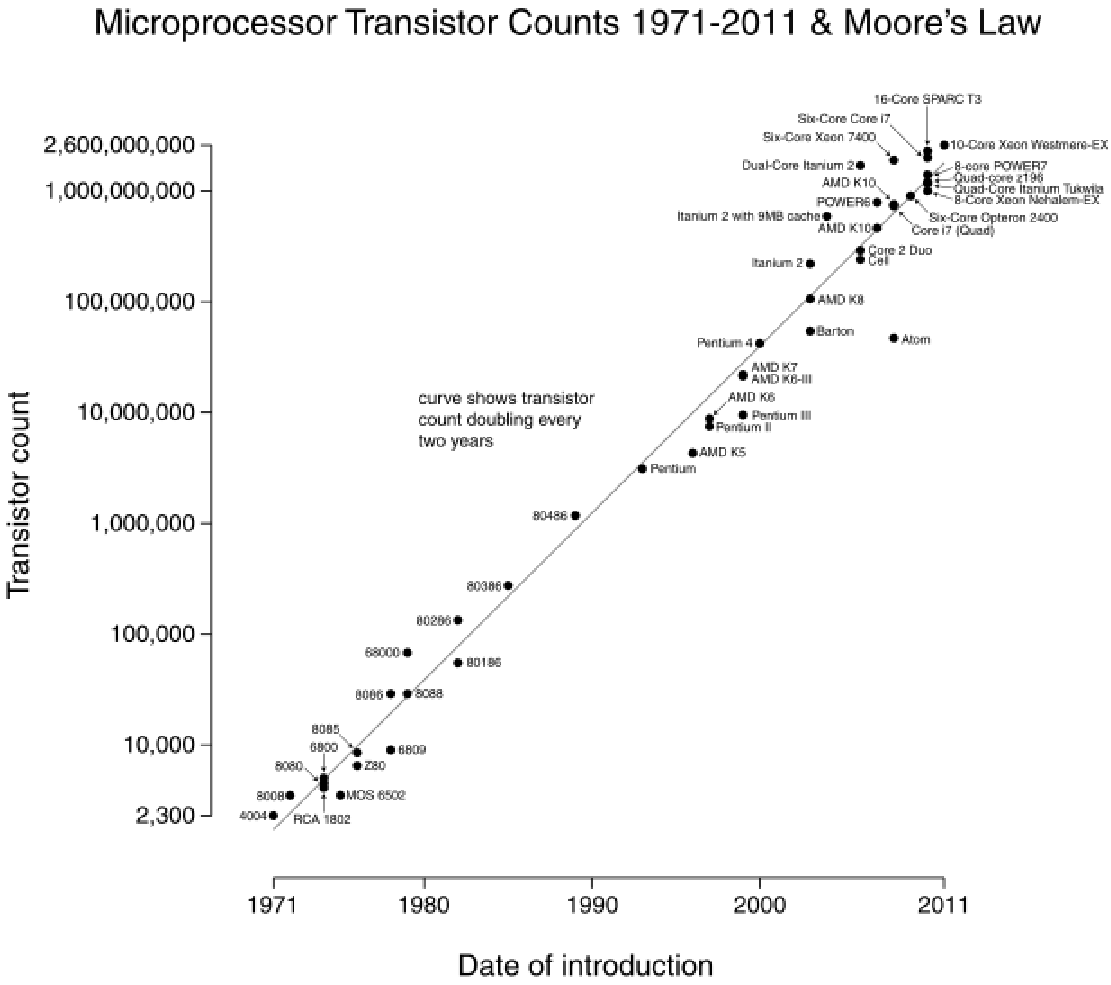


Figure 1.1: Moore's law (from Wikipedia, 2013b).

time accumulation and analysis of sport-specific data. Moreover, mobile devices may thereby serve as a "virtual coach", providing information on the current performance or even advising athletes with instant feedback. A server component may be integrated into the process for the administration of the measured parameter values as well as sensors and users, on the one hand, and instant data access and analysis opportunities, on the other hand. In this way, notifications may be sent from (remotely located) experts such as coaches, who can monitor current and past data measurements in real-time and intervene in the performances appropriately.

The centralized host computer can be moreover applied for the automatic analysis of the measured data. In this way, also the feedback routines can be computerized by the development, adaptation and embedding of intelligent modeling techniques, based on which the intervention of the sports performances can be accomplished in an automated manner.

The present thesis demonstrates the practically tested implementation of a mobile and multi-functionally applicable workout system on the basis of ubiquitous data acquisition technologies and server-based real-time analysis. Based on that, sophisticated developments for the realization of computer-assisted evaluation routines are proposed and demonstrated in practice.

1.2 Structure of the Dissertation

First of all, the exact research objectives together with the precise idea, specifications and conditions as well as challenging tasks and practical application fields are depicted. In addition, general information on the actual scope of use is given, which is however discussed deeply in the according chapters.

The related fundamental backgrounds are addressed thereafter in Chapter 3. This includes, on the one hand, an introduction into the area of "computer science in sport", thereby describing in more detail the history and research development of this area. Moreover, the upcoming field of "ubiquitous computing in sport" and its influence on recent implementations in sport is highlighted by various relevant examples. Thereby, information on recent developments in the ICT sectors such as mobile devices and sensor technologies is given.

Chapter 4 is entirely devoted to the methodology of the developed application – more precisely to its server-based architecture and the bidirectional communication details between the clients of the approach.

The development work done such as hardware and software as well as additional implementation activities are presented in Chapter 5. Thereby, the impressive progress of ubiquitous technologies (in sport) throughout the time is illustrated.

The subsequent chapters (6-8) concentrate on the practical application of the framework in the fields of endurance sport (such as running) and weight training but also other areas like medicine or school sport.

The thesis continues with a discussion including a final outlook and closes with a conclusion, recapitulating the presented mobile coaching system.

1.3 Contributions of the Author

Parts of this thesis are based on several author's contributions, which were submitted and/or accepted in peer-reviewed journals as well as conference proceedings. Table 1.1 illustrates these manuscripts and the location of their content in the according chapters. The most important passages including significant investigations, methodologies and outcomes are cited throughout the text. The entire reference list can be found in Appendix B, which includes also the author's presentations of the relevant work at several conferences.

Contribution	**Chapter(s)**	**Status**
Novatchkov and Baca (2013a)	2, 4, 7	published
Novatchkov and Baca (2013b)	4, 7	published
Novatchkov and Baca (2013c)	3, 9	accepted
Novatchkov and Baca (2013d)	7	published
Novatchkov and Baca (2012a)	4, 7	published
Novatchkov and Baca (2012b)	3, 9	submitted
Tampier, Baca, and Novatchkov (2012a)	2, 6	published
Tampier, Endler, Novatchkov, Baca, and Perl (2012b)	2, 6	published
Novatchkov, Bichler, Tampier, and Kornfeind (2011a)	2, 3, 4, 5, 9	published
Novatchkov, Bichler, Tampier, Kornfeind, and Baca (2011b)	5	published
Baca, Kornfeind, Preuschl, Bichler, Tampier, and Novatchkov (2010)	3, 4, 5	published
Novatchkov, Bichler, Böcskör, Kornfeind, and Baca (2010)	2, 3, 4, 5	published
Preuschl, Baca, Novatchkov, Kornfeind, Bichler, and Böcskör (2010)	2, 3, 4, 8	published
Novatchkov, Kornfeind, Bichler, and Baca (2009)	3, 5	published

Table 1.1: Author's related contributions in peer-reviewed journals and conference proceedings, their location in the text and their status.

CHAPTER **2**

Research Objectives

Before discussing the relevant fundamentals, literature and theoretical concepts, at first, the most important objectives of the research and the thesis are described in this chapter. In particular, this includes the principal idea and conception of the approach and furthermore its intended aims, essential requirements, ambitious challenges as well as practical usage and application scenarios.

2.1 Overall Goals

In general, the overall research attention is directed towards the establishment of a mobile coaching system that is capable of integrating modern ICTs and makes use of their advantages for the purpose of providing intelligent "live-online-feedback" (Novatchkov et al., 2010). Based on the intention of involving ubiquitous equipment such as wireless sensors and mobile devices in the sport training process, the central idea of the thesis includes the implementation of the framework design with the focus on its application for the computer-aided (remote) analysis of performance data and generation of personal and particularly also automated feedback notifications. Consequently, a major aim is to investigate and suggest intelligent evaluation routines for the computerized assessment of gathered sport-specific parameters in respect to the intended mobile coaching procedure.

2.2 Mobile Coaching Concept

The basic concept of the thesis is closely related to the mobile coaching project being carried out at the Department of Biomechanics, Kinesiology and Applied Computer Science at the Institute of Sport Science in Vienna. First ideas regarding the system architecture are presented in (Baca and Kornfeind, 2007). Figure 2.1 illustrates the overall structure of the mobile coaching framework (Novatchkov et al., 2011a). As shown, the main intention involves the bidirectional communication between performing athletes and (remotely located) experts. Due to the centralized approach, a particular aim is to represent the specialists' knowledge and expertise by the

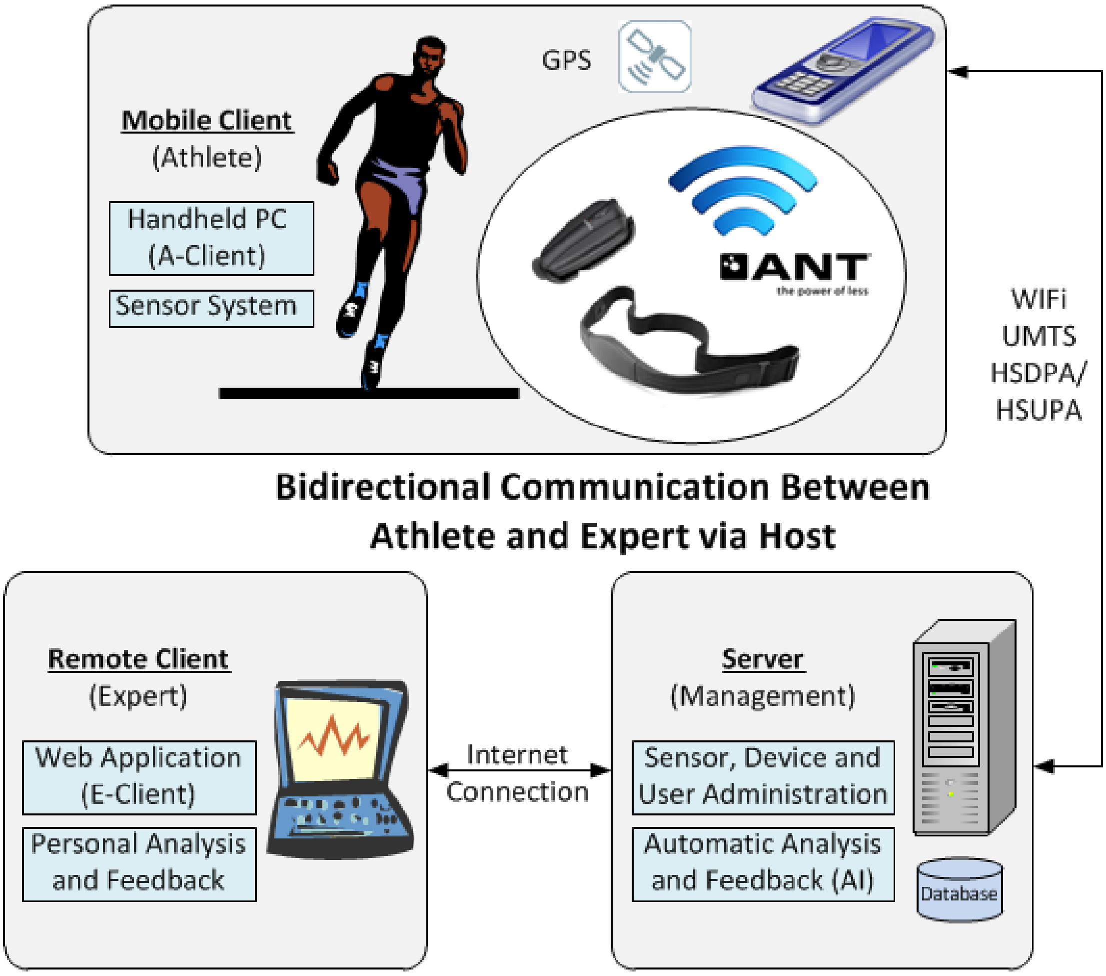


Figure 2.1: Overall concept of the system (bidirectional approach).

computer-based implementation of automated evaluation routines. A more precise description of the server-based concept can be found in Chapter 4.

2.3 System Requirements

In the first instance, the general idea of the approach requires the design of prompt and suitable sensor data acquisition solutions as well as analysis and feedback methodologies for the detection of relevant information during training (Novatchkov et al., 2010). Thereby, it is of high importance not only to monitor the athletes' trainings by acquiring sport-specific parameters but also to apply the measured signals for the determination of crucial characteristics, based on which an effective and systematic workout can be achieved.

Regarding the usability of the feedback application and furthermore for the purpose of its acceptance, the system should have the following basic requirements (Novatchkov et al., 2011a):

- Mobility
- Low power consumption
- Minimal interference with the athlete's training
- Convenient integration facilities
- User-friendly design and easy usage
- Clear presentation tool

In terms of the technical realization, the main focus is set on the implementation of efficient methods for the measurement, collection and bidirectional transmission of relevant performance data to the remotely located experts as well as crucial feedback information to the athlete, including the following hardware and software features (Novatchkov et al., 2011a):

- Mobile sensor data acquisition based on wireless sensors and handheld PCs
- Accumulation, buffering and (if possible/reasonable) data reduction techniques on the mobile device
- Synchronization and immediate data transfer to a server component
- Transfer, storage and management of big amount of data
- Remote analysis and feedback routines for coaches and other experts
- Data cleaning and filtering, feature extraction, pattern recognition and modeling mechanisms
- Integration of efficient algorithms for the automated analysis and generation of prompt feedback information
- Return of notifications to the athletes in real-time

2.4 Challenges

Based on the depicted goals and requirements, the design of the framework implicates a number of implementation challenges, which are described next.

2.4.1 Data Transfer

A first major challenge of the development is connected with data streaming, representing the process of sending and collecting big data sets across networks like the Internet but also sensor protocols (Novatchkov et al., 2010). This requires the establishment of prompt and reliable network solutions based on effective (sensor) technologies. A major task thereby is to find efficient methods for the collection and transfer of large amount of data as it occurs during different sport activities and motion sequences, including transmissions from sensor equipment to mobile devices as well as from handheld PCs to more powerful components (e.g. server).

One possibility is to design effective routines for the convergence of mobile devices and sensor networks in terms of data reduction as well as data mining (Fitzek and Rein, 2007). Thereby, the target goal consists of developing convergent implementations based on service-oriented methods for a first fraction, transformation and simplification of the measures and extraction of relevant characteristics by applying information retrieval routines before actually sending the gathered values to the server component.

Consequently, a specific requirement regarding the connection between the sensor equipment and mobile devices involves not only the design of homogeneous or heterogeneous sensor networks but also the processing of sensor values without unneeded power or energy consumption, sensor identification, message overload and data traffic (Novatchkov et al., 2011a). The basis therefore is set up by the underlying sensor network protocol, which has to be adapted and parameterized with regard to the required implementation scopes. Thus, a relevant challenge requires also the realization of a stable client-server communication, for example, by the development of appropriate program routines with well-defined message formats for the correct transfer, reception, storage and display of the data packets.

2.4.2 Intelligent Data Analysis Tools

Another complex task is to implement and adapt intelligent data mining algorithms (Novatchkov et al., 2010), either integrating specific training and potential data into knowledge-based and expert systems or, alternatively, machine learning or modeling techniques for the automatic analysis, interpretation and extraction of useful information out of the large data sets and generation of feedback (described, for instance, in Mester and Perl, 2000).

As a particular example, common pattern recognition methods typically involve the preprocessing of the data by cleaning and filtering it, followed by the segmentation, feature extraction and modeling stages (Novatchkov and Baca, 2012a). The main purpose thereby is to create and learn reasonable models such as methods integrating classification algorithms with the goal of subsequent decision making on the basis of predictive classes. Such automatic routines are particularly important for assisting athletes in their trainings by generating appropriate feedback.

2.4.3 Generalization

The generalization of the concept is also a crucial point (Novatchkov et al., 2010). One specific aim concerns the diversity as well as easy embedding facilities of the used technologies – for instance by supporting a variety of sensor equipment for a number of disciplines. In particular, it is important that the system is preferably generic for diverse application areas. Here it should be noticed that one beneficial goal concentrates on the development of a system that is suitable for the needs of professional and amateur athletes coming from various sport sectors and hence easily adaptable for different purposes. The main focus, though, is set on popular sports like running, cycling and fitness (for details see next section).

Another common idea regarding the generalization of the approach refers to the integration of common sensor technologies and handheld PCs. In particular, the objective involves the embedding of standardized protocols, which are used by the majority of the population and may be easily applied in widespread fields.

2.5 Usage and Application Scenarios

Based on the generic idea of the approach, another main intention of the thesis is to illustrate the feasibility and applicability of the framework for a variety of domains. For such purposes, a general overview is given below, while detailed information on each field is addressed in the according chapters (6-8).

2.5.1 Endurance Sport

As mentioned above, possible applications include the training and coaching processes in professional and hobby endurance sports like running, cycling and rowing (see Figure 2.2 for a typical scenario). Here it is particularly important to develop effective tools for the monitoring and improvement of the athletes' results by the insertion of instantaneous analysis and notification routines. One particular example might involve the optimization of the training in such endurance sports by involving load and performance characteristics with the overall goal to adapt and predict the workout in terms of fatigue and recovery (Tampier et al., 2012a,b).

2.5.2 Weight Training

In addition, feedback systems are getting more and more popular in fitness and recreation centers as well. Cardio machines like treadmills, stationary bike monitors or cross trainer machines already return information about the athlete's heart rate, pace, distance, calories etc. However, regarding the fitness area, one implementation goal in conjunction with the present thesis is to build intelligent weight training machines that are capable of sensing crucial parameters like the applied force and the instantaneous displacement of the weight (Novatchkov and Baca, 2013a). The measured determinants can be applied for the modeling and assessment of the gathered data and, subsequently, the generation of appropriate feedback.

More precisely, the high sensitivity of cable force sensors built into training machines seems to facilitate the investigation of the interrelation between cable force and exercising technique. Moreover, monitoring cable force and weight displacement might allow a more specific resistance training in terms of muscle contraction velocity. Appropriate feedback based on these

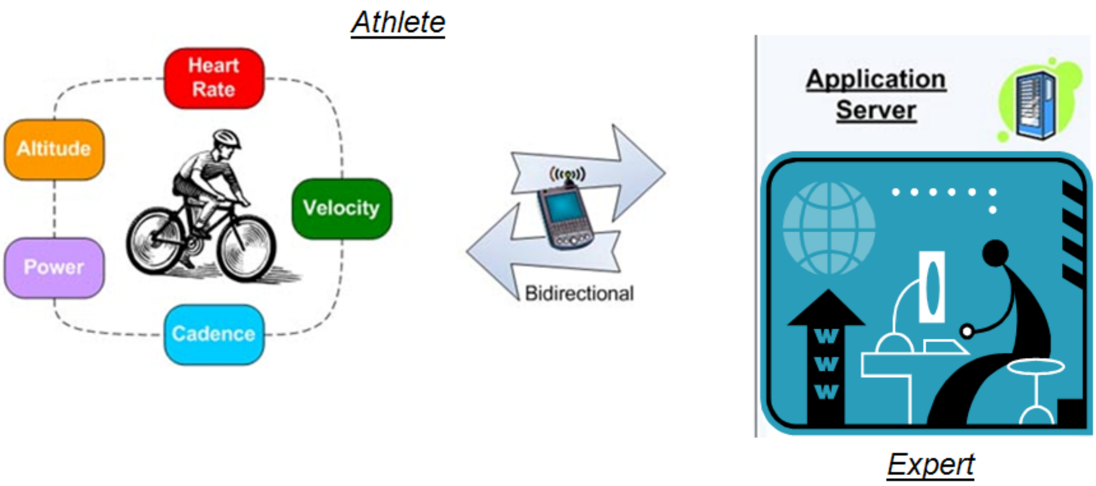


Figure 2.2: Typical usage scenario in cycling.

parameters may assist sportsmen and also their weight trainers to achieve their personal goals more efficiently. Consequently, such realizations could result in better support for beginners, inexperienced athletes but also fitness coaches.

2.5.3 School Sport

As another instance, in school sport pupils (in this case representing the "athletes") are often demotivated in doing physical exercises (Weiss, 2004). But exactly sport at young age is believed to have a positive effect in preventing diseases like obesity or diabetes. The insertion of new technology might not only increase the motivation factor but also lead to an ideal workout for the pupils. A computer-aided supervision system can help in optimizing their individual fitness by giving customized instructions and thereby also prevent often occurring frustration, underload, overstrain or incorrect strain (Preuschl et al., 2010).

2.5.4 Medicine

In addition, similar approaches gain popularity in other fields such as medicine, aiming at the telemonitoring of patients. Therefore, another relevant field concentrates on the design of effective supervision systems with possible real-time notifications – for example in case of occurring medical abnormalities of persons at risk like cardiacs.

2.5.5 Online Training Groups and Communities

Since the framework should preferably include web-based analysis and feedback tools for coaches and experts as well as athletes, other beneficial application fields of the system might be seen not only in the instant access facilities but also conceivable establishment of training groups by feasible comparison opportunities of performance data between registered users. Sportsmen might be able to view and evaluate their own achievements as well as the ones from their "combatants", possibly resulting in a competitive behavior among them. Such an online competition could boost the athletes' outcomes and lead to the formation of training communities for different sports fields (Novatchkov et al., 2011a).

CHAPTER 3

Fundamentals

Before going over to the description of the mobile coaching concept and its application in practice, a couple of fundamentals should be taken into account in order to discuss the basic knowledge and understanding of the background theory. First of all, a brief introduction into the field of computer science in sport is given, which includes theoretical, historical, scientific but also practical information on this discipline. Furthermore, details are presented on the upcoming area of ubiquitous computing in sport, which is directly related to the mobile coaching idea. Therefore, a closer look is taken at the pervasive computing influence on sport and at the design of a variety of modern sports frameworks for leisure, analysis or decision making scopes. For these purposes, the reader is provided beforehand with the most significant characteristics on common communication technologies such as sensor equipment and mobile devices.

3.1 Computer Science in Sport

Today's development of science and research is more and more influenced by the constant progress of computer science. In particular, the paradigm of Information Technology (IT) is nowadays an important integral part of various fields of activities. ITs as well as applied informatics have been introduced in many research areas, in which they are by now well-established. One such area is sport, where the integration of informatics plays a crucial factor for various purposes like, for instance, the analysis and enhancement of the sports performances and competition results (Novatchkov and Baca, 2013c).

The emphasis of this section of the thesis is to indicate and highlight the goals, activities, developments but also challenges of the rather newly established area of computer science in sport. This requires, at first, knowledge about the historical background, the existing research communities and the most significant fields of interest. In addition, common benefits, controversies and issues as well as up-to-date solutions and recommendations regarding the discipline are presented.

Moreover, the intention of this chapter is also to illustrate and discuss the already observable and predictable fact that the current trends and future perspectives of computer science in sport are going to be highly influenced by present IT techniques and realizations. Some of the most influencing developments are related to the recently evolving pervasive, mobile and cloud computing routines including the implementation of sports-related sensor and Internet technologies, miniaturized and intelligent equipment, social and virtual environments as well as real-time analysis and effective feedback routines.

3.1.1 Background

In general, the emerging and ambitious domain of computer science in sport focuses on the conjunction of theoretical background and practical aspects as well as methodologies of IT and sport science (Baca, 2006; Wikipedia, 2013a). The interdisciplinary discipline is getting more and more important for the support and advancement of the sport research by adapting and deploying computer-based but also mathematical concepts in sport. The application of computer science is particularly crucial for the acquisition, collection, transfer, analysis and interpretation of sports-related parameters and measurements. On the one hand, the combined approach is represented by the use of computing tools and methods in sport science. On the other hand, however, also the integration of sports-related background in computer science is relevant for various engineering purposes including the understanding of the human motor control and its implementation for the design of robots, intelligent and autonomous systems or the realization of optimized Human-Computer Interaction (HCI) tools (Link and Lames, 2009). A more detailed survey on the significance of the interdisciplinarity of the field is described in the above referenced paper.

3.1.2 Historical Survey

The history of computer science in sport is a relatively young field, starting with more general information and documentation activities in the early 1960s. At that time, the application of informatics was mainly important for the dissemination of sport scientific literature such as books and articles by the realization, expansion and maintenance of databases, allowing a more efficient storage and an easier distribution of academic knowledge (Baca, 2006). A crucial step for the development of the field can be also seen in the establishment of the first international organization called International Association for Sports Information (IASI) in the 1970s. This foundation had an initial significant impact on the progress of the area, leading to a more frequent organization and holding of related meetings and conferences. Nevertheless, the main spotlight of the research domain was still the propagation of information, rather than the implementation and application of computer-based routines in sport.

The actual beginning of computer science in sport, however, came with the evolution and further developments in informatics. An important factor was the appearance of the first microprocessors in the mid 1970s, allowing the realization of computers with higher capacities and increasing processing power (Novatchkov, 2008). Based on these progresses, the newly established field began flourishing and expanding, initially starting with the introduction of statistical routines for the analysis of different performance measurements including, for instance, biomechanical data. Obviously, the constant developments in computer engineering started having a high impact on sport science as well.

Later on, in the 1980s, experts began analyzing and interpreting performance parameters in other areas such as game sports (Miethling and Perl, 1981) or human motions (Hatze, 1983; Furnée, 1989). Further advances in hardware and software had not only an influence on informatics with the computerized implementation and use of fundamental paradigms like modeling and simulation but also became important for the establishment of computer science in sport (Baca, 2006). In the course of time, IT-based routines were progressively introduced for different purposes such as performance monitoring or game analysis. In this way, computer science has evolved to an essential element for sport science.

3.1.3 Scientific Research in Computer Science in Sport

Another important stage for the development of computer science in sport (from a scientific point of view) dates back to the late 1980s and early 1990s, when first congresses were organized in Germany as well as Australia and New Zealand. After the organization of several national conferences, more and more international scientists got interested and started doing research in this field and hence the first cross-country meeting was hold in 1997 in Cologne. The success of the event contributed to the biennial organization of further conferences all over the world and the establishment of an international organization called International Association of Computer Science in Sport (IACSS) in 2003 (Baca, 2006).

Meanwhile, various institutions and research groups exist that have focused their research on computer science in sport and also offer specialized modules or courses on this topic. In addition, national organizations have been established in this area and officially recognized in different countries including Austria, China, Germany, India, Turkey and the United Kingdom (UK). But also in other regions like the United States of America (USA) several universities and scientists are getting more interested in the application of informatics in sport.

3.1.4 Research Areas

A number of diverse research areas are meanwhile present and increasingly practiced in the field of computer science in sport. One particular focus is set on the implementation of measurement and data processing tools including the development of computer applications as well as complex information systems. Other research interests concentrate on the adaptation and further realization of IT-based modeling routines and simulation methods, which are significant factors for the assistance and improvement of the training and coaching processes. Finally, the development of the field is also of importance for the design of novel sports equipment and technology or for documentation and education purposes (Perl, 2006). More precisely, the domain of computer science in sport is divided into the following research activities and areas of application (Novatchkov and Baca, 2013c):

- Data acquisition and processing

- Pervasive computing
- Databases and expert systems
- Computer video systems (including tracking and motion analysis)
- Computer-aided applications (software and hardware)
- Modeling (IT-based, mathematical, biomechanical and physiological)
- Simulation (interactive and animation)
- Game analysis
- Presentation and multimedia (including virtual reality and serious games)
- Development of theories
- Education and e-Learning

In terms of data handling, complex sports databases such as the Sports Movement Archiving and Requesting Technology (SMART) framework (Miyaji et al., 2006) are, for example, in use for storing, streaming and searching sports-related motions. On the other hand, the application of expert systems aims, amongst others, at the detection of sport talents (Rogulj et al., 2006), the identification of key constraints of sports performance expertise (Seifert et al., 2013) or the optimization of indoor artificial ice skating rinks (Zhang, 2010).

At the same time, computer-based video systems are getting increasingly popular for a variety of purposes including the tracking of players, balls etc., analysis of movements, position detection and, accordingly, game analysis. In particular, motion tracking is a promising research field in the area of sport. Specific approaches involve the design of optical systems. Marker-based solutions like the Vicon Motion Systems (Vicon, Oxford, UK) allow the analysis of sports movements with the goal of performance enhancement. The implemented computer vision framework by Monier et al. (2009) uses template matching algorithms for tracking players in indoor team sports. Regarding game analysis, not only camera but also radio wave-based systems are widely used for position detection and subsequent data evaluation (e.g. regarding tactical behavior) purposes (Leser et al., 2011).

Furthermore, also sports-related TV events are meanwhile highly influenced by computer-based realizations. The Hawk-Eye (Hawk-Eye Innovations Ltd., Winchester, UK) system, for instance, is used in tennis as decision making tool (for details see also Section 3.2.4.3). As another example, the so-called Dartfish (Dartfish, Fribourg, Switzerland) software is utilized in skiing for the simultaneous and stroboscopic analysis of the athletes' movements based on the individually developed SimulCam™ and StroMotion™ features. The application is regularly in use during World Skiing Championships but also Olympic Games and other tournaments, where it is applied in sports such as taekwondo or handball.

Other implementations focus on the real-time three-Dimensional (3D) representation of competition broadcasts for sports like rowing (Laka et al., 2008). The approach is based on virtual reality methods using 3D information as well as Level of Detail (LOD), culling and Differential Global Positioning System (DGPS) techniques. Virtual environments are also commonly integrated into the sport training. Ruffaldi and Filippeschi (2012), for example, propose a lightweight platform involving digital illustrations in rowing. Tracking and displaying pitches and, in particular, specific zones (e.g. strike boundaries in baseball) are also popular broadcast tools (Guéziec, 2002). In general, computer vision systems are implemented to "help sports broadcasters to illustrate, analyze and explain sporting events" (Graham, 2011). Realizations include rather simple graphics tools like telestrators (e.g. for drawing the player's path taken in soccer) or more complex methods based on image processing for the automatic illustration of key features like virtual lines such as the Virtual Yellow 1st & Ten® method developed by Sportvision® (Sportvision Inc, Chicago, IL, USA). Finally, QuesTec (QuesTec Inc, New York, NY, USA) allows virtual replays and in-game digital analysis from real-time performance data.

At the same time, new media like social networks also have an increasing influence on sport. Many professional and hobby athletes use applications like Facebook® (Facebook Inc., Menlo Park, CY, USA) and Twitter (Twitter Inc., San Francisco, CA, USA) for updating the public including fans and friends regarding the latest events and happenings, in this way allowing an interactive communication opportunity. Sport journalists, on the other hand, are also affected by such platforms (Schultz and Sheffer, 2010) and the Internet in general, facilitating an easier and prompt access to relevant sports data.

Further examples in respect to the listed research areas are discussed in the following sections.

3.1.5 Benefits, Issues, Controversies and Problems

In the light of the highly evolved computing environment including new developments with effective solutions and arising advantages, computer science in sport is particularly dependent on the constant progress of present-day information, communication and sensor technologies (Novatchkov and Baca, 2013c). Up-to-date equipment can be efficiently applied for the measurement of different sports-related parameters and determinants. The gathered information can be easily and promptly transferred (very often even wirelessly) via available transmission protocols to powerful computers, where the data can be saved and thereupon visualized and analyzed on the basis of sophisticated evaluation routines.

At the same time, however, there are various issues associated with the technology-oriented evolution of sport (Novatchkov and Baca, 2013c). Although it is possible to acquire sports-related indicators at almost any place and time as well as to transfer and store them in a prompt way, the big challenge is how to actually deal with this large amount of available data. In particular, it is necessary to extract the crucial information that is of actual interest out of the tremendous quantities of items (Perl and Dauscher, 2006). For such purposes, the development and insertion of intelligent algorithms based on common IT methods are getting more and more significant for the analysis of sport activities. The implementation of such routines is particularly important, as it is not only essential for the prompt evaluation of the performances but also for the immediate return of feedback information to the athletes. Thus, the design of real-time feedback systems (for details see Section 3.2.4.4) is one of today's most challenging and trend-setting research fields in computer science in sport, which is obviously a key point of this thesis. In addition, also the automatization of the developed methods plays a major role in the realization of the approaches.

Another problematic aspect associated with computer science in sport can be generally seen in the complexity of the human body and the performed movements during various sport activities (Novatchkov and Baca, 2013c). Consequently, scientists have to deal with complex and dynamic systems, motions and data measurements. For such reasons, another crucial field of study concentrates on the design of adequate models and simulations for an easier understanding and interpretation of the underlying components and interactions (Perl, 2008).

It should be also kept in mind that the development of motion tracking techniques involves complex procedures as well as rather expensive solutions and equipment (such as the cameras used for the Hawk-Eye system). In addition, most of the camera-based applications require an accurate calibration, which is particularly difficult in the case of zoomed lenses or uncontrolled sport scenes. Moreover, regarding image processing, the segmentation procedure of multiple athletes is often hindered (for example due to occurring motion blur).

3.1.6 Solutions and Recommendations

There are various approaches for the solution of the above mentioned challenges (Novatchkov and Baca, 2013c). In general, current developments and tendencies focus on the implementation of small, easily attachable and preferably wireless sensor and mobile device equipment for data acquisition purposes. In this way, also the interference with the performing sportsmen can be reduced significantly. Particular approaches – such as the framework presented in this thesis – concentrate on the design of mobile coaching systems for hobby and elite athletes or other target groups like pupils.

In order to be able to promptly analyze the gathered information, however, the developed systems are often combined with intelligent methods such as advanced Artificial Intelligence (AI) routines. Throughout the last years, particularly techniques on the basis of pattern recognition (e.g. Novatchkov and Baca, 2012a), Artificial Neural Network (ANN) (e.g. Baca and Kornfeind, 2012), Support Vector Machine (SVM) (e.g. Fischer et al., 2011) or fuzzy logic concepts (e.g. Papić et al., 2009) as well as individually designed antagonistic modeling techniques (e.g. Ganter et al., 2006; Pfeiffer, 2008) have proven to be suitable for the automated analysis of sports performances. Consequently, knowledge-based and expert systems become more and more important for the evaluation of sport-specific challenges (Papić et al., 2011). Detailed information regarding the application of intelligent methods in sports and with respect to the developed mobile coaching systems is described in the Chapters 6 and 7.

For the purpose of understanding the complexity of the human body and movements during various sport activities, it is meanwhile possible to build up specific biomechanical models, simulations and animations on the basis of computerized techniques (Horswill, 2009). These routines are particularly important for the easier simulation and analysis of extensive motions, in this way replacing real experiments and, at the same time, reducing cost and time factors.

More precisely, motion capturing is an upcoming field in computer science in sport (Novatchkov and Baca, 2013c). Especially markerless approaches are constantly evolving and are progressively introduced for the purpose of automatic recording and analyzing of sports movements on the basis of interactive human body models and 3D reconstructions. Such methods do not only contribute to the analytical improvement of the biomechanics research but are also important in other related areas like computer vision and virtual reality applications. Those possibilities also bring many other benefits and implementation potentials including, for example, the design of robot-based realizations (Atkinson and Rojasa, 2009).

3.2 Ubiquitous Computing in Sport

The term ubiquitous computing or, alternatively, pervasive computing describes the currently observable evolution and propagation of information processing in human environment. The main idea behind this development involves the implementation of small, interconnected, intelligent as well as integrated computer devices, technologies and activities in human's everyday life. Accordingly, the concept specifies the modern way of HCI based on embedded systems, objects and activities.

As a consequence of the fast moving trend, this "technologization" is meanwhile fully present in various disciplines and fields of work including sport science and sport, where ubiquitous technologies are widely applied for different purposes and in various contexts (Baca, 2008a). In particular, the integration of pervasive methods and systems is nowadays seen as an essential part for the enhancement (in terms of improvement but also regarding prevention) of the coaching, training as well as competition processes – with modern equipment being applied for the acquisition, analysis and presentation of performance data without interfering the athletes. In this way, pervasive computing in sport has evolved to an upcoming research area of the interdisciplinary field of computer science in sport that has a high impact on the current development of sport (Baca et al., 2009).

The importance and influence of modern technologies on recent developments in ubiquitous computing in sport as well as some of the most current examples of application are presented in the next sections. In addition, the limitations and requirements as well as a couple of recommendations and future research perspectives are discussed.

3.2.1 Background

Going back in history, the idea of a pervasive computing world dates back to the late 1980s, beginning of 1990s, when the chief scientist of Palo Alto Research Center Incorporated (PARC®, Palo Alto, CA, USA), formerly Xerox PARC, Mark Weiser, first introduced this term. Already at that time he believed in an environment with miniaturized technologies available at any place and time (Weiser, 1991). Furthermore, he defined this trend as the "third wave in computing", following the period of the mainframes and PCs. The increasingly powerful, sophisticated, networked and smaller developments of today's pervasive computing technologies lead to an invisibility and unawareness of their actual use. Therefore, the omnipresence of this paradigm is sometimes also referred to as "ambient intelligence", "Internet of Things", "things that thing" or simply "everyware".

3.2.2 Pervasive Computing Influence on Sport

The continuous progress in computer science and especially of pervasive computing has a large influence on the progress of sport (Chi et al., 2005). In practice, the design and application of ubiquitous methods and systems play an increasingly important and beneficial role for a variety of sports-related factors. In particular, the constant advances in the sensor but also ICT sectors enable promising ways for the instant capturing, transmission, storage and further processing of significant parameters. In the first instance, the evolution of today's measuring equipment in terms of smaller designs and wireless facilities enable more convenient opportunities for the acquisition of sport-specific determinants (Novatchkov and Baca, 2012b). Based on the possibilities of recording big quantities of data, also the analysis and assessment of the information becomes a major research topic and goal (Chi, 2008). In this spirit, the increasing computing power as well as higher data and transfer rates of available communication technologies allow the design of powerful approaches for the prompt (if possible even real-time) transfer, handling, analysis and interpretation of the gathered signals.

3.2.3 Sensors and Mobile Devices – Modern ICT and their Influence on Current Feedback Approaches in Sport

One important determinant in the development of today's feedback approaches is certainly the continuous progress in up-to-date technologies such as sensors and mobile devices (Novatchkov et al., 2010). In particular, due to the extensive and powerful functionalities as well as their miniaturization, such (rather high-tech) hardware equipment is more and more applicable for different scenarios such as the monitoring of sport activities based on the design of wearable solutions (for instance in Buttussi and Chittaro, 2008).

Present-day sensors are not only becoming smaller and lighter but also are practically cable-free. This wireless characteristic enables a convenient sensor integration and easier usage during the data acquisition phase. At the same time, the interference with the athlete can be reduced considerably. Furthermore, recent sensor technologies have the advantage of low power consumption, allowing their use during long-term training sessions.

In addition, modern mobile devices provide their users with many gadgets that were rather unrealistic some time ago but are standard features nowadays. Especially the support of different communication tools, such as Internet-related technologies but also various sensor protocols, enable a wide range of mobile applications. For instance, such devices can now be used for the reception, storage and further transmission of sensor data. Even more, their networking abilities and their small design make them applicable at almost any place – in particular at sport training facilities.

A summary of the most important features with regard to the mobile coaching approach is illustrated in Table 3.1.

<table>
<tr><th>Mobile devices</th><th>Sensor technologies</th></tr>
<tr><td colspan="2">Small
Light
Convenient integration</td></tr>
<tr><td>Extensive features</td><td>Wireless characteristic</td></tr>
<tr><td>Support of different communication tools (e.g. Internet and sensor protocols)</td><td>Less interference</td></tr>
<tr><td>Applicable at any place and time</td><td>Low power consumption</td></tr>
<tr><td>Reception, storage and transmission of (sensor) data</td><td>Easy usage during data acquisition phase</td></tr>
</table>

Table 3.1: Crucial features of mobile devices and sensor technologies.

Consequently, one of the main aspects regarding pervasive computing in sport is related to the steadily evolving sensor technology systems. Along with this progress, easier and more effective ways exist for establishing different kind of homogeneous and heterogeneous sensor networks such as Body Sensor Networks (BSN), Personal Area Networks (PAN) or Wireless Sensor Networks (WSN) (Novatchkov et al., 2011a). These possibilities are particularly important for the determination of significant characteristics such as relevant biomechanical or physiological parameters during various sport activities. Today, a variety of miniaturized but, at the same time, very accurate measuring elements are available that are most commonly attached to the sports equipment or even directly to the athlete's body.

One specific approach that was especially designed for sports applications is the so-called ANT+ technology, which is an extension of the ANT™ (Dynastream Innovations Inc., Cochrane, Canada) protocol. Based on its advantages such as simple network configuration, interoperability, reliability or extended battery life, just to mention few, the solution has meanwhile become a common standard and is increasingly integrated into different sensor equipment in sport. In fact, most of the commonly used devices such as Heart Rate Monitors (HRMs), bikepods, footpods and many other sensing elements are compatible with ANT+. Even more, the technology has also been embedded in some of the newest smartphones, thereby allowing an efficient supervision of the athletes' performances. Further details regarding ANT are depicted in Section 4.2.1 of the next chapter.

In addition, up-to-date mobile devices such as handheld PCs get not only smaller but, at the same time, also more powerful and effective. A major advantage is related to the improvement of the offered services including, for example, higher Internet transfer rates on the basis of the enhancement of the third Generation (3G) standard including the Universal Mobile Telecommunications System (UMTS), the improved High-Speed Packet Access (HSPA) consisting of the High-Speed Downlink Packet Access (HSDPA) and the High-Speed Uplink Packet Access (HSUPA) or the Evolved High-Speed Packet Access (HSPA+). The most current evolution is directed towards the development and recent establishment of the fourth Generation (4G) Long Term Evolution (LTE) mobile communication technology. While the improved 3G protocol offers data rates up to 84 Megabit (Mbit)/second (s) on the downlink and 22 Mbit/s on the uplink for HSPA+, the downlink peak rates can go up to 300 Mbit/s and the uplink peak rates up to 75 Mbit/s for LTE.

Other relevant benefits of recent smartphones include their increasing storage capacities or also the integration of real-time sensing techniques such as the prevailing Global Positioning System (GPS), being crucial for the detection of the position in various sports (Novatchkov and Baca, 2012b). In this way, mobile devices offer excellent possibilities for the measurement and acquisition, the local management and immediate retransmission of sensor data.

As GPS is restricted to outdoor use only as well as to good weather conditions, other commonly applied sport approaches for position measuring purposes include the integration of radio signal such as radio wave-based tracking systems (Leser et al., 2011). The so-called Radio-Frequency Identification (RFID) technology is another specific solution that is, for example, used for tracking and monitoring players in ball games (Foina et al., 2010). Further details regarding analysis in game sports including practical application scenarios and a self-adapted approach are described in Section 3.2.4.2.

3.2.4 Pervasive Computing Applications in Sport

Based on the described development of ubiquitous technologies, various frameworks for different purposes have been designed throughout the last years. Meanwhile, there is a wide range of new implementations including technological and computational realizations in the areas of data processing, motion capturing or health monitoring. More precisely, recent application fields can be categorized as follows (Baca et al., 2009; Novatchkov and Baca, 2012b):

- Leisure and health promotion
- Analysis
- Decision making (in competitions)
- Coaching and training

3.2.4.1 Leisure and Health Promotion

Regarding leisure, the main intention is to motivate people in being more active with a rather entertaining background – e.g. with the development of Nintendo®'s (Nintendo Co., Ltd., Kyoto, Japan) Wii™ or Microsoft®'s Xbox® Kinect® (Microsoft Corporation, Redmond, WA, USA). Some of the upcoming research fields in this matter are the so-called exergaming (combining the words exercise and gaming) or serious games areas, focusing on the use of technology for promoting an active lifestyle and better health (Wiemeyer, 2010). Comparative investigations on four different types of video games indicate that, in general, there is a significant increase in energy expenditure (Lyons et al., 2011) with fitness and dance games having the biggest impact. At the same time, exergaming becomes also a more and more important tool for encouraging adolescents in doing physical activity (O'Loughlin et al., 2012).

In preventive and rehabilitative sports, specially adapted sensor and wireless communication networks are in use. Therapy and feedback methods are provided by solutions like the "Therapy Top" (Kranz et al., 2011). Thereby the movements of the users performing on custom-built balance boards are visualized in order to enable the evaluation and control of the motion. Specific studies show that the application of such developments can be a very effective and also low cost intervention alternative regarding health promotion and rehabilitation including the recovery of balance instability (Bainbridge et al., 2011).

3.2.4.2 Analysis

Typical analysis frameworks are most commonly implemented for game sports including commercial systems like Amisco Pro® (Sport Universal Process, Nice, France), ProZone® (ProZone Sports Ltd., Leeds, UK) or LPM/inmotiotec® (abatec group AG, Regau, Austria). The main idea behind is to track the players and/or the ball on the basis of video recordings or radio and microwaves and use the collected data for the evaluation of matches (e.g. regarding strategic aspects).

Other approaches focus on the use of radio wave-based system such as Ubisense® (Ubisense Ltd., Cambridge, UK), which is still not very widespread in the field of sport, since it was originally developed for industrial applications like assembling in car production or logistics (e.g. at airports) but also for military training (Leser, 2012).

Figure 3.1 demonstrates the application of the system in ball games such as basketball. The measuring process involves tags sending Ultra-Wide Band (UWB) pulses, which are absorbed by receiving sensors (Sub-chart 3.1a). The tags needed for determining the position of the players can be, for example, fixed to the player's top of the head with special holders (Sub-diagram 3.1b). The determination of the position (Figure 3.2) is based on calculated parameters like the Time Difference of Arrival (TDA) and Angle of Arrival (AOA). Figure 3.3 illustrates a possible usage scenario of the gathered position data, providing coaches and other experts with (tactical) analysis tools.

Consequently, the constant developments in computer science do not only enable many new opportunities for the ubiquitous measurement, acquisition, collection, transfer, handling and analysis of sport-specific data but also allow the assembly of these computing steps into effective solutions, giving immediate feedback information on the intended purpose of the respective approach. Particularly the described advances in the ICT sectors in conjunction with highly evolved and miniaturized constructions, increasing process power as well as higher data and transfer rates provide nowadays promising means for the processing of sports data in real-time. In terms of such facilities and objectives, many innovative concepts, ideas and realizations are in ongoing development, contributing, for instance, positively to the competition, training and coaching processes in various sports.

(a) Installed signal receiving sensors (base stations) in the corners of a university's sports hall.

(b) Application of the system in basketball.

Figure 3.1: Ubisense system applied in game sports (with permission from Leser, 2011).

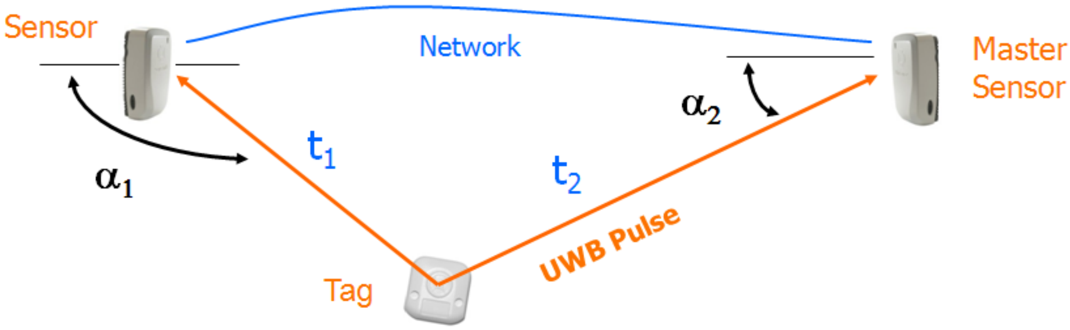


Figure 3.2: Position detection principle on the basis of gathered parameters like TDA and AOA (with permission from Ubisense, 2013).

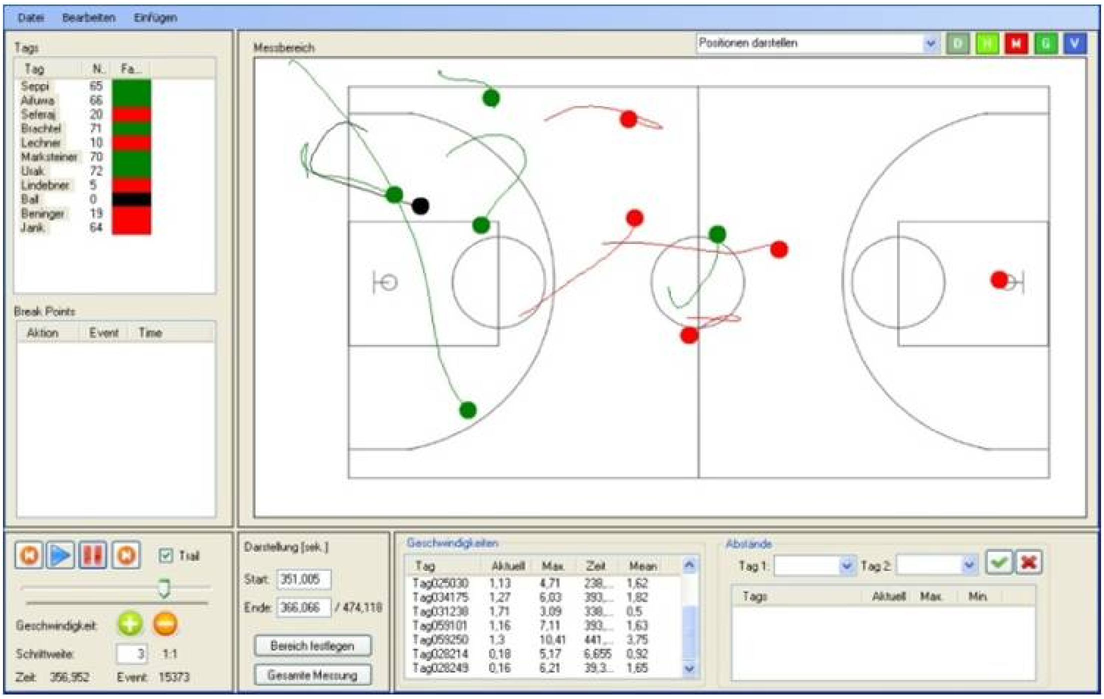
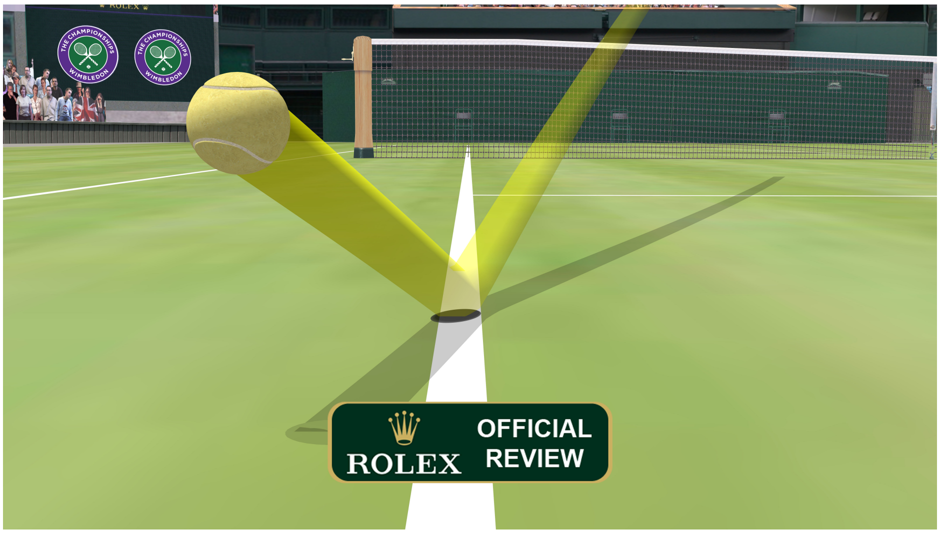


Figure 3.3: Individually designed analysis tool for coaches or other experts, allowing them to evaluate the trajectories of the players (with permission from Leser, 2011).

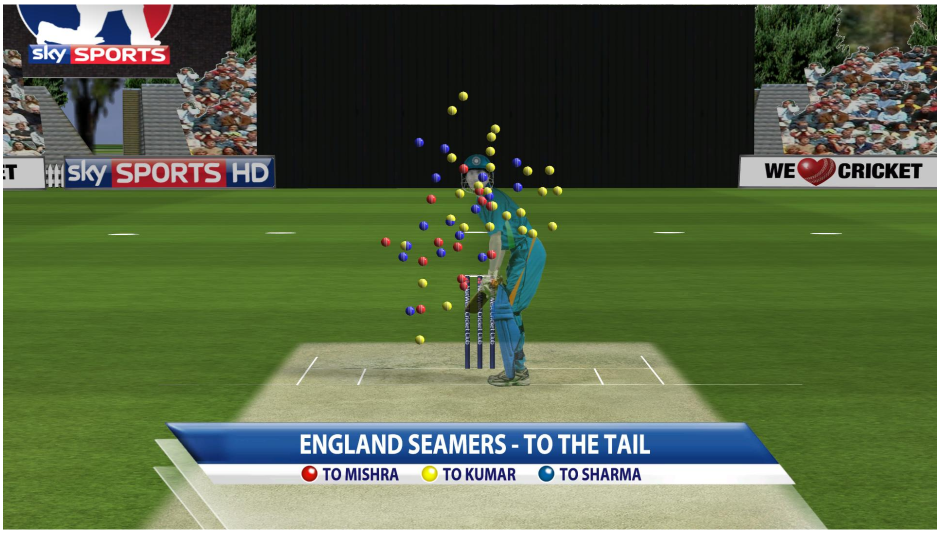
3.2.4.3 Decision Making (in Competitions)

Recently, decision making realizations are getting more and more important for the aid of judges in professional sports competition. The Hawk-Eye framework (Figure 3.4) is one specific example that illustrates the strong application potentials of novel technologies in sport (Novatchkov et al., 2011a). The system determines and tracks the trace of the ball in near real-time based on recordings from high speed cameras and implemented triangulation methods (Sherry and

Hawkins, 2001). It is mainly applied in cricket as well as in tennis, where it was first introduced in 2002 as (amongst other functionalities) decision making aid for the main umpire in controversial situations, detecting whether the ball is inside or outside of the court. In addition to the novel methodology, another particular characteristic for the pervasive method is that the spectators are not directly aware of the presence of the system ("calm technology").



(a) In tennis.



(b) In cricket.

Figure 3.4: The Hawk-Eye system used in different sports (with permission from Hawk-Eye, 2013).

In other sports like, for instance, soccer, similar solutions have been repeatedly considered and discussed but not yet fully introduced. While some approaches propose goal-line technologies based on video cameras and instant replays (D'Orazio and Leo, 2010), others suggest the implementation of an embedded RFID chip inside the ball (e.g. the already available smart ball from Adidas®) for tracking purposes (Kapadia and Chimalapati, 2011). Such methods have been opposed for a long time by various key decision makers in the International Federation of Association Football/Fédération Internationale de Football Association (FIFA®). Meanwhile, however, it was decided by the FIFA to officially introduce the so-called GoalControl-4D (GoalControl GmbH, Wurselen, Germany) technology during the FIFA Confederations Cup 2013 as well as the 2014 FIFA World Cup in Brazil (FIFA, 2013). The system is based on 14 high speed cameras and can be combined with the GoalRef™ wristwatches, providing referees with an immediate (encrypted radio) signal when the ball crosses the goal line. At the same time, the English Football Association (FA) has decided to introduce the Hawk-Eye system to provide goal-line technology, starting with the Premier League 2013-14 season. Consequently and due to the fact that various systems are meanwhile successfully used in a number of game sports, it can be expected that computer-assisted solutions will become standard decision making tools in soccer and other sports as well.

3.2.4.4 Coaching and Training

Meanwhile, the Hawk-Eye Innovations Ltd. company has also released explicit coaching versions of their system, representing "the most technologically-advanced high performance coaching systems in the world" (Hawk-Eye, 2013). It allows a full analysis of the cricket and tennis players' performances, including training and technical support as well as biomechanical evaluations.

Consequently, other important fields of application of pervasive computing in sport involve the training and coaching processes (Novatchkov et al., 2011a). Such approaches usually aim at the real-time monitoring of the athletes' achievements by the integration of sensing devices (Eskofier et al., 2008). Especially the mentioned benefits of today's ubiquitous technologies makes them easily applicable during training sessions, allowing not only an effective way of measuring different kind of sports-related parameters but also an immediate evaluation and feedback intervention regarding the performance.

3.2.4.4.1 Performance-Based Feedback Systems in Sport

The importance of immediate return of notifications to the athlete (for example while performing) has been proven by different studies (for instance in Schmidt and Lee, 2005). In general, the so-called performance-based feedback systems in sport should serve as a support of sportsmen aiming at the achievement of better training results (Baca and Kornfeind, 2006, 2007; Baca, 2008b).

In competitive sports such methods may be employed for the analysis and enhancement of the athletes' performances. Advanced feedback systems could be also integrated in the preparation process and used, amongst others, for the evaluation of the quality of the movement during training. Ghasemzadeh et al. (2009), for instance, suggests a wearable framework on the basis of embedded BSNs, which analyzes golf swings and provides feedback on the motion sequences. In (Jaitner and Trapp, 2008), on the other hand, the authors propose an intelligent system based on a service-oriented architecture for the real-time optimization of the team training in professional cycling.

In addition, though, such feedback systems may be also useful for preventative purposes. In particular, they may be applied for the intention of avoiding overstrain but also underload. Such prophylactic implementations may then involve a lowering of the risk of injuries for both competitive and recreational athletes. Since also the motivation factor plays a crucial role in the design of such intervening frameworks, another practical application includes the encouragement of less sportive people in doing more sports or at least being more active. A particular analysis approach might, for instance, focus on the implementation of routines advising pupils during physical exercise (Preuschl et al., 2010). A detailed review on this idea with regard to the mobile coaching concept is given in Section 8.2.

3.2.4.4.2 Available Tools, their Benefits and Drawbacks

Recently, many innovative approaches for the monitoring of sports performances have been implemented, supporting athletes and coaches in their training and coaching behavior (Novatchkov et al., 2011a). Especially in common endurance sports such as running and cycling a number of frameworks are currently in ongoing development. Several modern software tools like, for instance, the Adidas® MiCoach (Adidas AG, Herzogenaurach, Germany) program – currently available for iPhone®, BlackBerry® or Android™-based phones (Adidas, 2013) – or the Nike+ (NIKE Inc., Beaverton, OR, USA) application – e.g. compatible with Apple® products like iPod® (Nike, 2013) – have been implemented to evaluate and measure running specific data like distance, pace, time, calories etc. in real-time and show the gathered parameters to the athletes. A disadvantage of these systems is that the evaluation is accomplished locally on the mobile device, allowing the access and synchronization of current training data with a computer only at a later point in time.

Other frameworks like the Sports Tracker (Sports Tracking Technologies Ltd, Helsinki, Finland) also display the currently measured data to the athlete. An additional feature includes the transfer of GPS and heart rate data to a server component, which allows other users to follow the performances via the Internet (Sports Tracker, 2013). The system works, though, only with GPS and heart rate information and like also the MiCoach and Nike+ applications does not offer any remote feedback routines via the server. Similarly, also Athlosoft®'s commercial implementation (Spider Network AG, Neerach, Switzerland) for cycling allows users to follow the GPS track in real-time but evaluates the athlete's sensor data only on the mobile device and does not integrate remote experts into the solution (Athlosoft, 2013).

In this thesis, however, the focus is set in addition on the integration of expert and automated feedback methods. Based on that, the concept of the present research aims not only at sensing crucial real-time information by the integration of pervasive ICTs, but also at the immediate support of the athletes' workouts as well assistance of their coaches and other specialists. Due to the flexible and independent way of training intervention, the concept is stated as “mobile coaching” (Baca and Kornfeind, 2007; Novatchkov, 2008; Baca and Kornfeind, 2009; Novatchkov et al., 2009, 2010; Baca et al., 2010).

Recapitulating, current implementations include only local real-time data acquisition and (partially) evaluation opportunities on the mobile device but don’t involve online feedback generation methods based on (computerized) expertise analysis. Considering the results of the conducted literature review, there is no other system available that integrates a web-based bidirectional approach between coaches and athletes by involving a server component into the framework and hence comprising instant live monitoring and intervening opportunities during the workout process, accomplished either by specialists or automated routines.

CHAPTER 4

Methodology

The following chapter introduces the general concept and principal methods of the mobile coaching framework integrating ubiquitous data acquisition technologies and server-based real-time analysis.

4.1 Overall Architecture

Figure 4.1 illustrates the overall architecture of the mobile coaching system (Novatchkov et al., 2010). In general, the framework can be roughly separated into the three subcomponents “Mobile Client”, “Server” and “Remote Client” (Novatchkov et al., 2011a). Some of the most significant functional units regarding the approach as well as their importance and responsibilities are described in-depth in the following sections.

4.2 Mobile Client

The Mobile Client is represented by the athlete and all the equipment required for the accumulation of sport-specific data (including modern sensors and handheld PCs) but also for the exchange of sensor and feedback information with the Server and hence the Remote Client (coach, expert, biomechanist etc.).

4.2.1 Sensor System

As already mentioned earlier, modern sensor systems allow these days an effective way of measuring sport-specific parameter values. The constant enhancement of ubiquitous measurement equipment enables an easy integration opportunity during the workout. Therefore, wearable technologies become significant in monitoring sports performances since also the interference with the athlete can be reduced to a large extent.

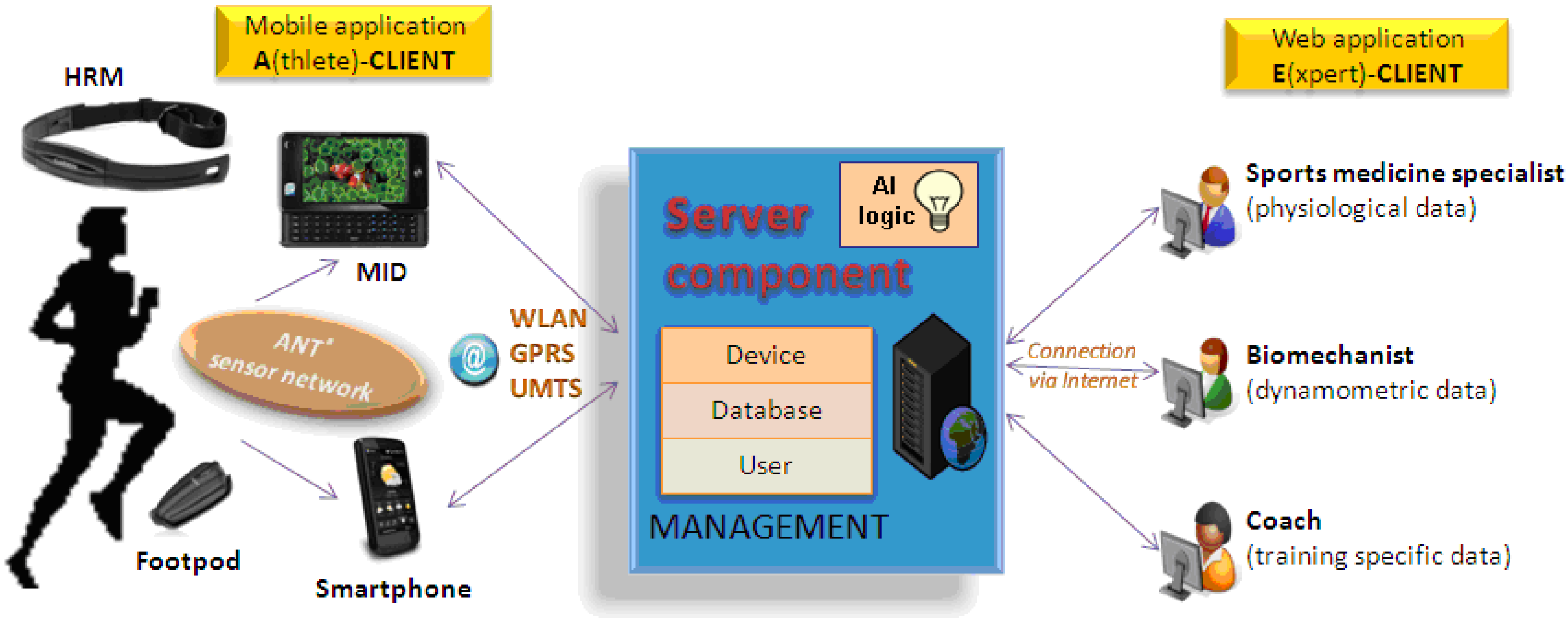


Figure 4.1: Architecture of the mobile coaching system.

4.2.1.1 ANT Technology

Regarding the acquisition of relevant parameters in professional and recreational sports, the establishment and development of robust sensor systems is of high importance for the mobile coaching system. Especially wireless ad-hoc networks are significant due to their ability of autonomous configuration. In particular, this requires the implementation of efficient WSNs, PANs or BSNs (depicted in Section 3.2.3). Established approaches like the already mentioned ANT protocol and the specialized ANT+ extension offer good opportunities for the realization of efficient sensor networks in sports. Currently taking root in the realization of such WSN solutions, the advantages of this technology are seen in its (ANT, 2013):

- Simplicity
- Easy establishment of broadcast, Point-to-Point (P2P), unidirectional, bidirectional and complex network topologies
- Network flexibility and scalability
- Low power consumption
- Reliable data communication
- Affordable costs
- Unique device identification

With the establishment of the ANT+ realization for monitoring wellness systems, the protocol becomes particularly widespread in the field of sports applications. Due to the dissemination, popularity, assertion and effectiveness of the technology, it is meanwhile included in most of the common sports sensor devices (described below).

ANT's progress might be boosted even more with the already mentioned fact that meanwhile there are also handheld PCs available that natively support the protocol. At the Mobile World Congress (MWC) in Barcelona in February 2011 the Sony (Ericsson®) XPERIA™ (Sony Mobile Communications AB, formerly Sony Ericsson Mobile Communications AB, Tokyo, Japan) was presented as the first smartphone with integrated ANT+ technology (XPERIA, 2013). Consequently, the solution is expected to be embedded in the upcoming generations of conventional mobile devices, anticipating ANT to become a common standard such as Bluetooth® in the mobile sector.

4.2.1.2 Sports Parameters and Sensor Equipment

As, in a first instance, a major intention of the mobile coaching approach is to integrate common sensor devices into widely used and easy accessible sports fields like running or cycling, the main focus is put on the following ANT+ compatible wireless equipment (Baca et al., 2010; Novatchkov et al., 2011a):

- HRM
- Accelerometer
- Footpod
- Bikepod
- NEON sensor platform

Meanwhile, a number of wireless sensor devices are available and increasingly applied by athletes for training control purposes. One of the most popular equipment in the application area of monitoring devices is the HRM, mainly used as an essential tool for tracking and improving the cardiovascular strength. It usually provides information about the current heart rate (beats per minute) and determines the Heart Rate Variability (HRV) based on the range between single beats, which is therefore also called inter-beat interval. These factors play a crucial role in tracking the fitness condition of athletes in various endurance sports fields (for details see Chapter 6). Meanwhile, there are also specific HRMs, which are integrated in the sports equipment like, for instance, in the women's sports bra. Such fabric solutions are among the most current trends of ubiquitous systems in sport ("wearable technologies").

In common sports such as running, also other sensor systems are extensively in use. The footpod sensor, as another instance, is a relatively small device that is attached to the athlete's shoe for the purpose of measuring important parameters such as pace, number of strides and running distance. The measuring method is based on the integration of one or more accelerometers, producing electrical signals with each step taken. Similarly, the bikepod monitors the average cycling speed, cadence as well as distance and is usually fixed to the front wheel of the bicycle. The calculated values are determined in accordance with the movement of the bicycle's wheels.

Despite the high number of ANT solutions designed by over 200 ANT+ Alliance members (ANT+ Alliance, 2013), common ANT+ sensors are not always sufficient to measure specific biomechanical or physiological values. Other methods are particularly required when it is of high importance to detect relevant force and strain parameters or weight displacements (for example in sports such as strength training) by integrating specific measuring equipment (for further information see Chapter 7).

Already implemented systems like the so-called NEON sensor platform (Spantec, Linz, Austria) offer compact and easy adaptable solutions (NEON, 2012) for the detection of significant performance values during the workout (Baca et al., 2010). The designed hardware (for details see Figure 4.2) is based on a 16-bit Programmable Intelligent Computer/Peripheral Interface Controller (PIC) microcontroller and has an onboard ANT module (Nordic nRF24AP2) and other useful components such as an accelerometer, gyroscope and temperature sensor onboard as well as up to eight analog and digital sensor input interfaces for further data acquisition equipment (e.g. additional accelerometers, strain gauges, dynamometers, potentiometers or force sensors). The measured signals can be stored locally on a microSD card, while the built-in ANT module provides an efficient communication tool with network compatible hardware. In this way, a

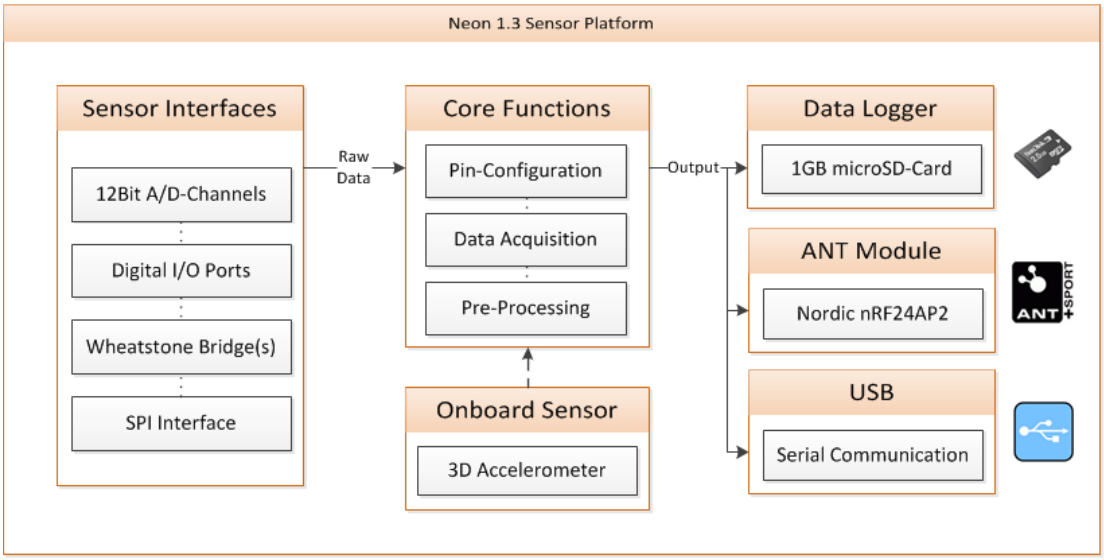


Figure 4.2: NEON sensor platform with integrated ANT chip.

wide range of sensor types can be connected directly to the platform (analog, digital and bridge sensors) and combined into bundled data packages for transmitting it via the ANT module.

For the acquisition of signals at high sampling rates (e.g. from accelerometers or force transducers), the integrated microSD card allows data logger functionality – for example during exercises – and a transmission of the data afterwards. For configuration and/or debugging issues an Universal Serial Bus (USB) interface may be used to access the NEON from a computer via a serial communication protocol. Figure 4.3 illustrates a feasible integration possibility of the NEON sensor equipment in the mobile coaching concept (Baca et al., 2010).

Further training parameters or indicators to be considered include, for instance, the altitude or position of the athlete. Regarding the latter, an often used method involves the tracking of the athlete's route by GPS, which is also integrated in most modern mobile devices and therefore easily adaptable to the mobile coaching framework.

An overview of the relevant sports parameters and appropriate measurement techniques with regard to the chosen sport activities for the mobile coaching system is illustrated in Table 4.1 (Preuschl et al., 2010).

4.2.2 Handheld PC

For the purposes of the present research, mobile devices like smartphones are intended for the reception and further transfer of the obtained values as well as the notification of feedback messages. Hence, the handheld PCs provide an important interconnection between the actual users of the framework – the athletes and the experts.

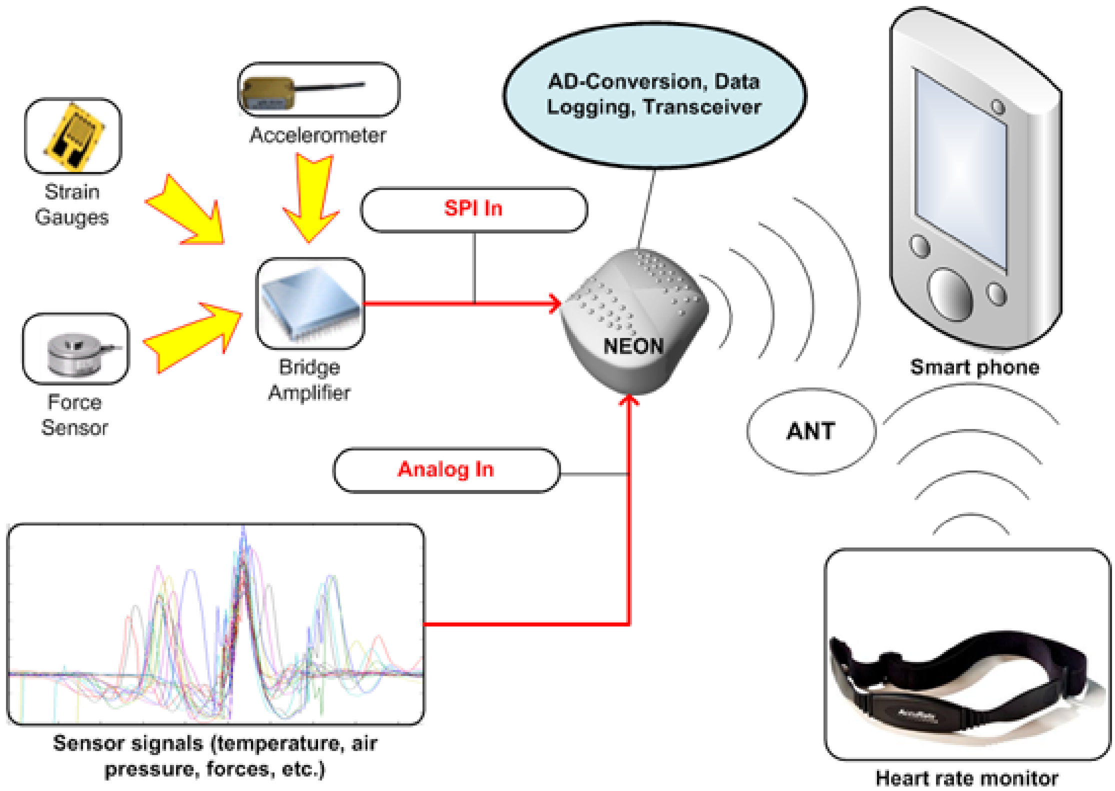


Figure 4.3: Integration of the NEON sensor platform in the mobile coaching concept.

Regarding the bidirectional data exchange with the host computer, a reliable Internet connection is of high importance. Most of today's mobile devices come with the newest mobile communication standards such as Wireless Fidelity (Wi-Fi) and the already mentioned enhanced 3G technology like HSPA+ or the currently upcoming 4G with the improved LTE service, allowing a wireless web connection to various Wireless Local Area Networks (WLANs) with reasonable data rates at almost any place and time.

4.2.3 A(thlete)-Client Requirements and Structure

In addition to the general requirements, the A-Client application running on the mobile device should (Baca et al., 2010):

- Cover a wide range of sports without the need of further software updates
- Include setup procedures for the selection of trainings and authentication of athletes
- Provide methods for correct sensor assignment (e.g. when several athletes are exercising)

Sport	Parameters	Acquisition method
Running	Heart rate	HRM
	Number of strides	Footpod
	Distance	Footpod/GPS
	Position	GPS
Cycling	Heart rate	HRM
	Pedal frequency	Bikepod
	Distance	Bikepod/GPS
	Gear	Shifter
	Inclination	Tilt sensor
	Altitude	GPS
	Position	GPS
Weight training	Heart rate	HRM
	Weight	Manual regulation
	Weight displacement	Rotary encoder
	Force	Load cell
	Repetitions	Displacement-based detection
	Duration	Displacement-based detection

Table 4.1: Sport-specific parameters and corresponding acquisition methods.

- Include a real-time feedback message system
- Transmit sensor data in real-time to the server
- Provide reliable data transmission

In order to reach these goals, the so-called Mobile Coaching-Protocol (MCP) has been developed to configure the ANT hardware module and to receive sensor data (Baca et al., 2010). Furthermore, the protocol defines the message formats used to set up the A-Client based on the athlete's personal aims.

The A-Client can be divided into three layers (Figure 4.4), each of them representing a specific task in the programming logic. The MCP builds the top level of the application and is responsible for the data communication with the server (backend). A more detailed description of the protocol is given in Section 4.4.1.

The "Application Logic" can be seen as the connecting piece between the module for the data transfer and the ANT hardware. It is responsible for the control of all program processes, manages the A-Client setup and provides a Graphical User Interface (GUI) to the user. The lowest level includes a component that enables a direct communication with the ANT device. As shown, the connection between the A-Client application and the ANT hardware may be set up via an USB port, a microSD card, a serial connection, a Bluetooth-to-ANT adapter or a built-in equipment.

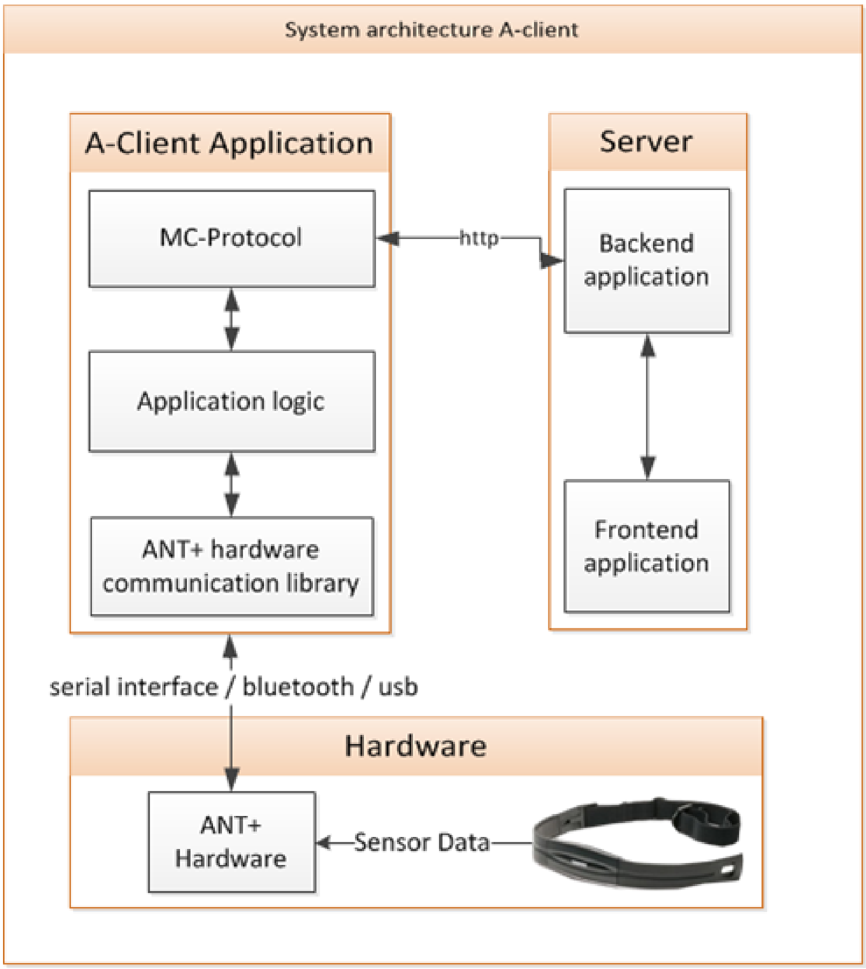


Figure 4.4: A-Client structure.

4.3 Server and Remote Client

The server is the core component of the system, as it is obviously responsible for the storage, administration and management of the sensor, device, user but also feedback information (Novatchkov et al., 2011a). More crucial, however, it represents the most important link between the performing athlete and the expert by integrating remote analysis and feedback routines. A major intention of the system involves the idea that once the sensor values are transferred to the server component, the data has to be accessed instantly by coaches and other specialists. For such purposes, the framework should include routines, preferably realized by web applications, allowing experts to analyze the current performances by looking at the achievements and send personal feedback messages via the Internet.

4.3.1 Automated Analysis

At the same time, also the automatization of the system plays an important role in the design in order to be able to find out specific data characteristics of the current performances (Novatchkov et al., 2011a). Often, the correct interpretation of the values can be made only if the hidden information is discovered. However, due to the often occurring large and complex data structures, such key features are not always directly observable. Consequently, also for experienced coaches and experts it is sometimes hard to analyze the training results correctly and return appropriate instructions to the athletes.

Due to the complexity of the measured data, it is of high importance to implement automated feedback routines, which should be able to detect crucial performance patterns and return appropriate feedback on time, allowing an optimization of the training as well as prevention by avoiding, for instance, underload or overstrain and thereby also injuries. Therefore, the objective of the mobile coaching approach is to integrate such sophisticated evaluation methods directly into the server component. Thereby, a main benefit is that the running host computer can access and take into considerations not only the currently measured data but also previous results and further subject- or training-specific parameters.

4.3.1.1 Intelligent Algorithms

Intelligent realizations commonly involve the development and adaptation of efficient algorithms integrating sophisticated techniques like AI methods or expert- and knowledge-based systems for the automatic recognition of significant data clusters and computer-assisted generation of relevant notifications.

4.3.1.2 Modeling Approach

One particular alternative focuses on the implementation of specific modeling techniques, which can be used for the development of intelligent routines (e.g. meta-models) and the determination, analysis and notification of parameter-dependent interactions in sport training. Practical solutions include the integration of modeling equations and time series analysis for the design of the interdependency of training potentials and impacts of athletes (for instance in Perl and Mester, 2001). The automatic interpretation of the modeled concepts can be then used in order to draw the right conclusion and return machine-aided feedback to the athletes. A detailed application example of such meta-models for running is illustrated in Chapter 6.

4.3.1.3 Machine Learning Approach

Other commonly applied evaluation methods focus on the implementation of machine learning routines. In machine learning, the purpose of the so-called pattern recognition process is to assign an output value (label) to a given input value (instance). In the field of sports, the input usually consists of typical sensor data measurements such as kinematic and kinetic data in biomechanics (Novatchkov and Baca, 2012a). Figure 4.5 illustrates the classical pattern recognition approach (Novatchkov and Baca, 2013a). It consists of several signal processing steps, starting with the acquisition of sensor data and followed by the preprocessing phase including the filtering of the measured parameters as well as the segmentation stage. Thereafter, the subdivided data is parsed to extract a significant set of features characterizing the processed information. The final step consists of the major intention of the pattern recognition method, namely the classification of the data and the development of models that are subsequently applied for the assignment of new data inputs to the specified class labels. Commonly used classifiers are, for instance, ANNs or SVMs. The development of machine learning methods on the example of weight training is discussed in depth in Chapter 7.

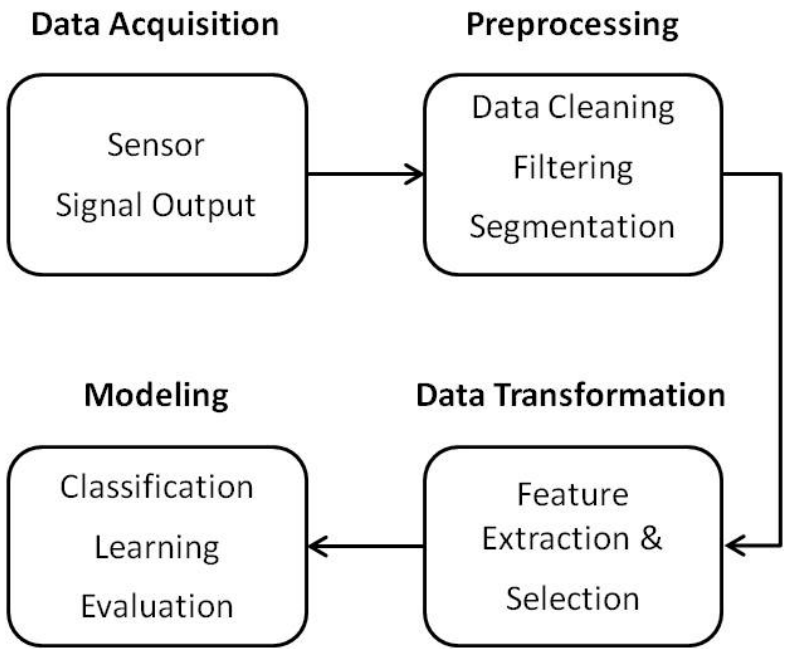


Figure 4.5: Common machine learning approach.

4.3.1.4 Fuzzy Logic Approach

Another possible solution for the intelligent analysis of sport-specific sensor data might involve the design of fuzzy logic methods. As a special form of probabilistic reasoning, the fuzzy logic concept allows the effective realization of approximate, vague, uncertain, dynamic, continuous and, at the same time, more realistic conditions, which are closer to the actual physical world and human thinking (Novatchkov and Baca, 2013b). This many-valued idea involves the definition of fuzzy sets and rules as well as membership functions. These techniques allow the mapping of classes of objects not only – according to the binary logic – to false (0) and true (1) but also to intermediate values in between. Based on this theorem, the particular purpose with regard to the mobile coaching approach focuses on the development of fuzzy logic techniques for the evaluation of performances such as weight training exercises (e.g. by taking into account gathered data from sensor-equipped machines as well as recommended suggestions and criteria regarding a proper execution) , thereby providing a more elementary but still effective alternative compared to standard modeling and machine learning algorithms. A feasible implementation of these principles in strength training is illustrated in Chapter 7 .

4.4 Communication in and between the A- and E(xpert)-Client

4.4.1 MCP

Figure 4.6 shows the internal communication and information flow of the whole system and particularly between the A- and E-Client (Baca et al., 2010). A core element of the system is the already mentioned MCP, which has been implemented in order to be able to configure the ANT equipment, listen to incoming sensor values and communicate with the server. It controls and adjusts the protocol-specific setup (network key, sensor parameters etc.), on the one hand. On the other hand, it comprises special techniques and routines for the authentication and management of the users, their clubs/institutions and the data exchange with the host computer.

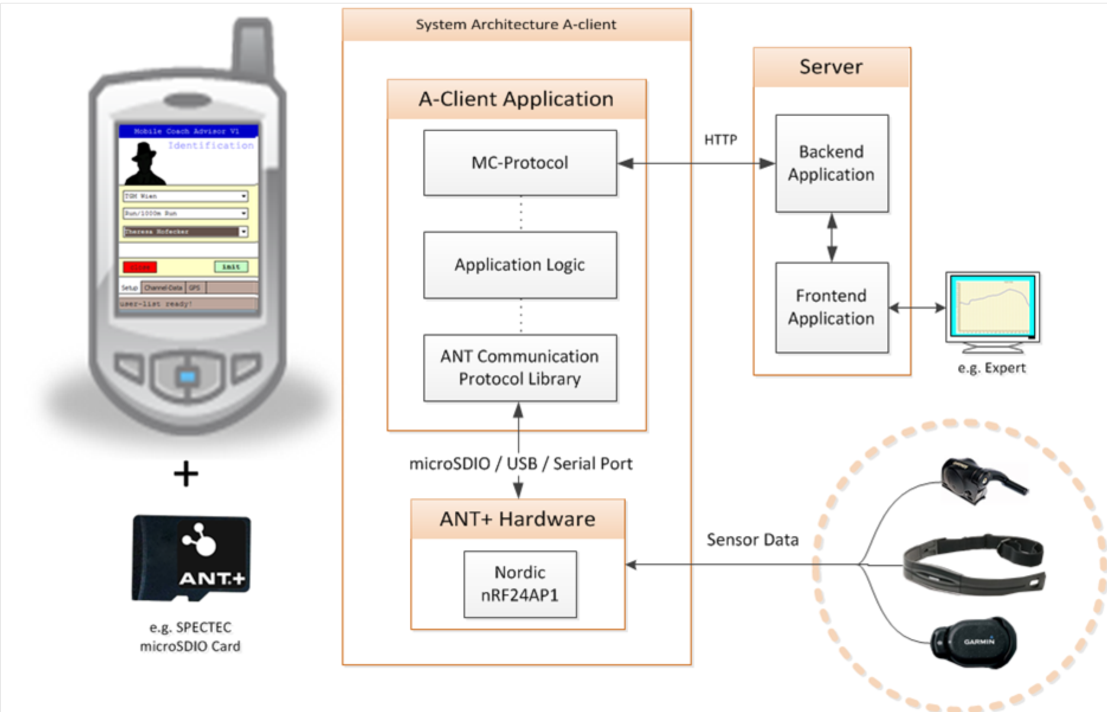


Figure 4.6: Communication between A- and E-Client.

Consequently, the main task of the MCP includes the exchange of information with the server component based on web requests using either the slower Transmission Control Protocol (TCP) or, alternatively, the User Datagram Protocol (UDP). TCP has the advantage of low sensor packet loss, while UDP is unreliable but has the benefit of a prompt transfer. A socket-based TCP approach (an individual socket connection for each A-Client) is another reasonable alternative, thereby reducing protocol burden and allowing a better optimization, identification and reception of data packets.

The developed software routine comprises several types of message formats, allowing, for example, the management of training sessions and performing athletes. All of the requests call the same server address via a Hypertext Preprocessor (PHP) script. The client's actions are defined by a parameter called "type", which is sent via the requests using the Hypertext Transfer Protocol (HTTP) post method. The advantages of the MCP are that it could be also used and adapted for other applications based on ANT+ and that it allows an almost platform-independent development, as networks standards such as 3G and WiFi are supported by common handheld PCs.

The measured data is transferred and stored in a Structured Query Language (SQL) database via timed client pushes. The server module with the E-Client application is typically split up into two units: The backend application manages the incoming requests while the frontend application is an interface between the users (e.g. the experts) and the backend. It implements, amongst others, the GUI of the E-Client, allowing experts to analyze and return feedback to the A-Client. These notifications are sent back to the mobile program via the backend application on the basis of pull technology mechanisms. Since the connection between client and server is based on web requests, an almost platform-independent development is possible. Hence, the method is easily transferable to other platforms as well.

4.4.2 E-Client Algorithm

Figure 4.7 illustrates the server-based analysis routine as well as the algorithm for the generation of feedback information (Baca et al., 2010). As already mentioned, the measured sensor data is sent from the mobile device to the server, and saved permanently – e.g. in a MySQL™ (Oracle Corporation, Santa Clara, CA, USA) database – by the backend application (MySQL, 2013). The module "Analysis & Feedback Generation" runs in the background during the entire training. On the one hand, the routine analyzes the performance information of the athlete while periodically checking for new data. On the other hand, it is responsible for forwarding the training information to the web interface and presenting it to the E-Client. In this way, coaches and experts can look at the parameterized time series and curves visualized by tables or charts. Moreover, they can generate feedback and intervene in the current training based on the presented data and the results evaluated by auto-generated analysis as well as send suggestions offered by the module. The feedback is sent from the E-Client via the component "Analysis & Feedback Generation" to the database and finally forwarded via the backend to the A-Client, where it is displayed – for example as an alert notice including a beep and vibration signal.

4.5 E-Client Training Management Scheme

Regarding data maintenance, it is essential to establish suitable database structures for the management of significant user and training results. This includes, for instance, the storage and

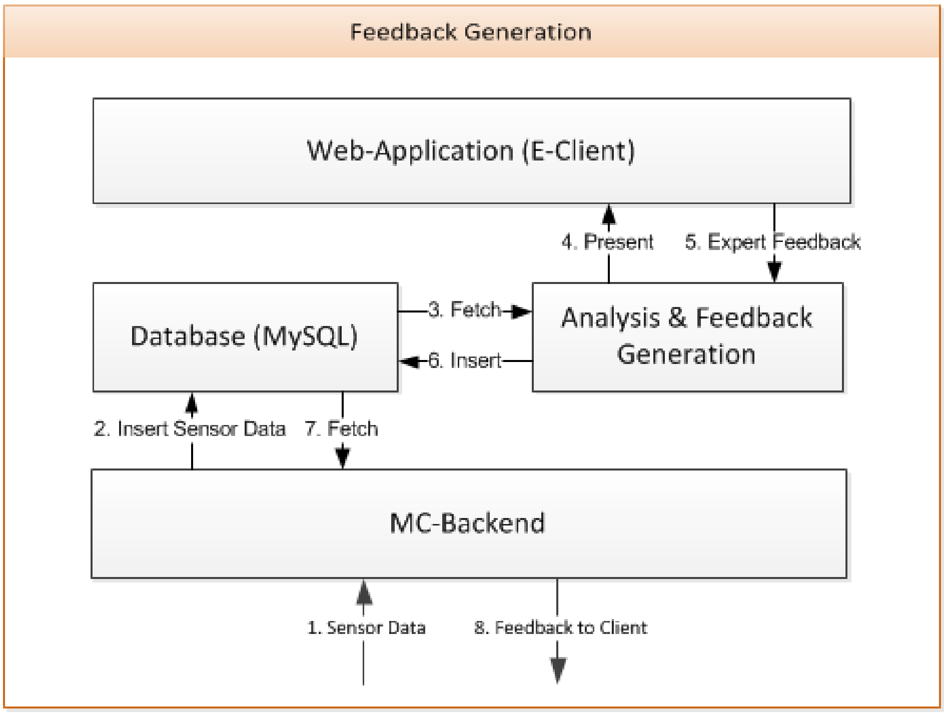


Figure 4.7: E-Client algorithm.

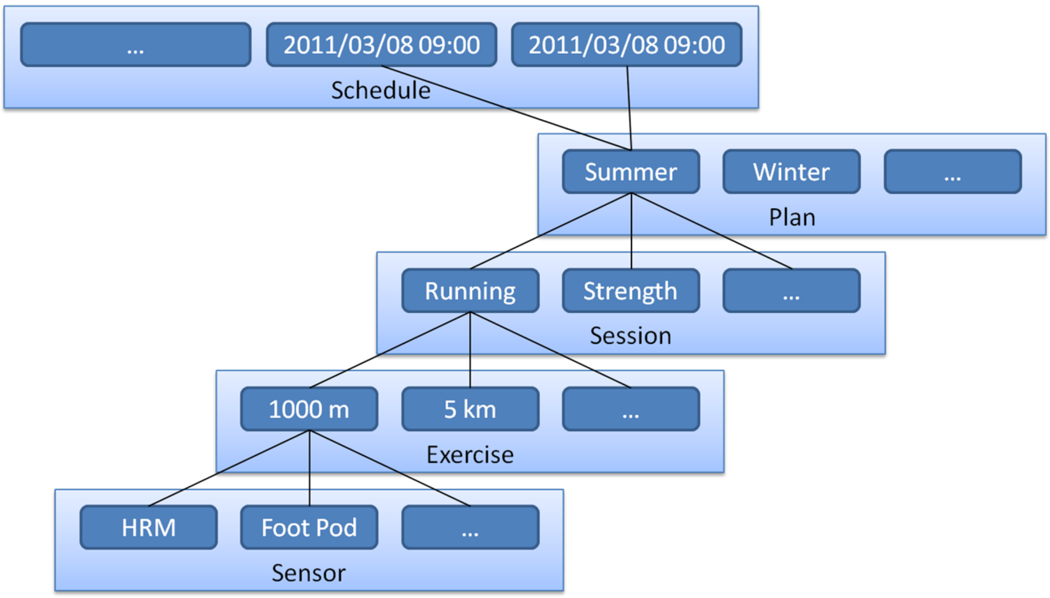


Figure 4.8: E-Client training scheme.

interpretation of the current and past athletes' performances as well as the recording of their achievement potentials.

However, the design of a reasonable database structure is not only crucial for the collection and administration of the sensor results, users and groups but also of the exercises, trainings, plans, schedules, sensors etc. Figure 4.8 pictures a feasible training management scheme, demonstrating the complex design of the generic database structure and, at the same time, building the basis for the web interface component that is responsible for the organization of the workouts.

CHAPTER 5

Framework Implementation

The following chapter concentrates on the implementation of the mobile coaching framework. For such purposes, the most important development versions are presented, demonstrating the impressive progress of the ICT sectors.

5.1 A-Client on a MID

One of the first basic prototypical implementation of the A-Client on a so-called Mobile Internet Device (MID) is depicted in Figure 5.1 (Novatchkov et al., 2009). The shown trial was carried out during a fitness training (push ups, short running periods, squats etc.), which lasted for about half an hour. On the left side of the designed GUI the user could start the training, thereby initializing the ANT sensor module and starting the sensor communication. For the reception of the signal an ANT USB stick was used, while the transmitted signals were saved locally in a file database. If the mobile device was furthermore connected to the Internet, the measured values were immediately forwarded to the server component for analyzing purposes.

On the server, a basic web application representing the E-Client (on the right side of the GUI) fetched and visualized the acquired data. For the depicted test, the athlete's heart rate was measured and illustrated in real-time throughout the entire training. In this way, the athlete could have a look not only at the currently gathered values but also at those from the past. The chart in Figure 5.1 clearly shows the variability of the heart rate throughout the time of the workout, starting with the resting pulse rate in the beginning, a prompt increase afterwards, followed by a recovery stage and a final rise.

The implementation of this client application (a rudimentary realization on a handheld PC is presented in Novatchkov, 2008) was based on the IBM® (International Business Machines) Lotus® Expeditor toolkit (Lotus, 2013). The developed web program included also a basic algorithm for monitoring the athlete's heart rate integrating predefined limits, based on which the user was provided with feedback information and instructions or advices. For example, if the heart rate jumped over a user-specific value, the athlete was requested to calm down. This

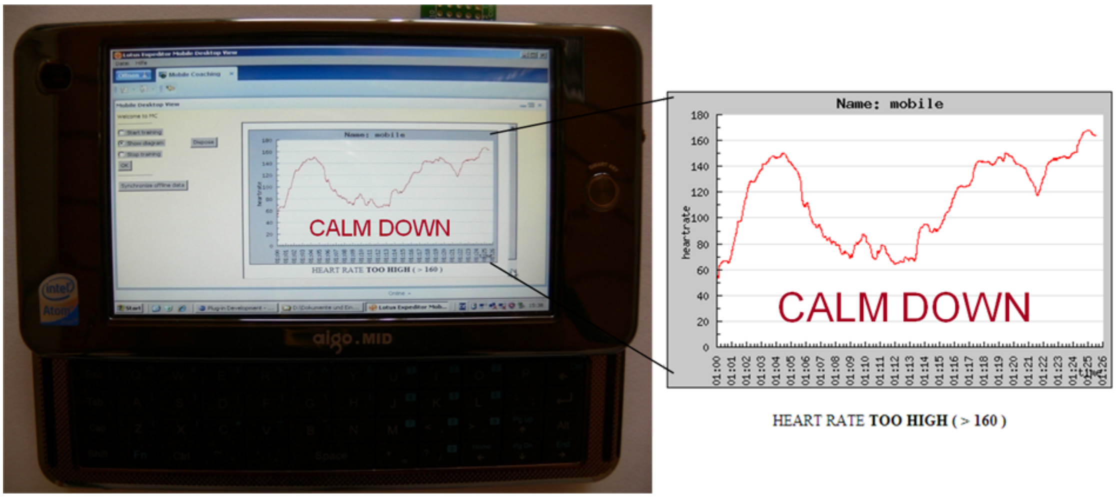


Figure 5.1: Implemented A-Client on a MID.

implementation should illustrate the general idea of computerized analysis routines, providing a basis for more complicated models and classification methods (see Chapters 6 and 7).

An advantage of this A-Client version was that it was also possible to work fully offline, meaning that the locally saved data could be synchronized with the server at a later point in time. A disadvantage of this implementation, on the other hand, was connected with the relatively big size of the device. However, such equipment might be, for example, useful in weight training (see Chapter 7), since they don't have to be worn by the athlete while exercising.

5.2 A-Client on a Windows® Mobile®-Based Smartphone

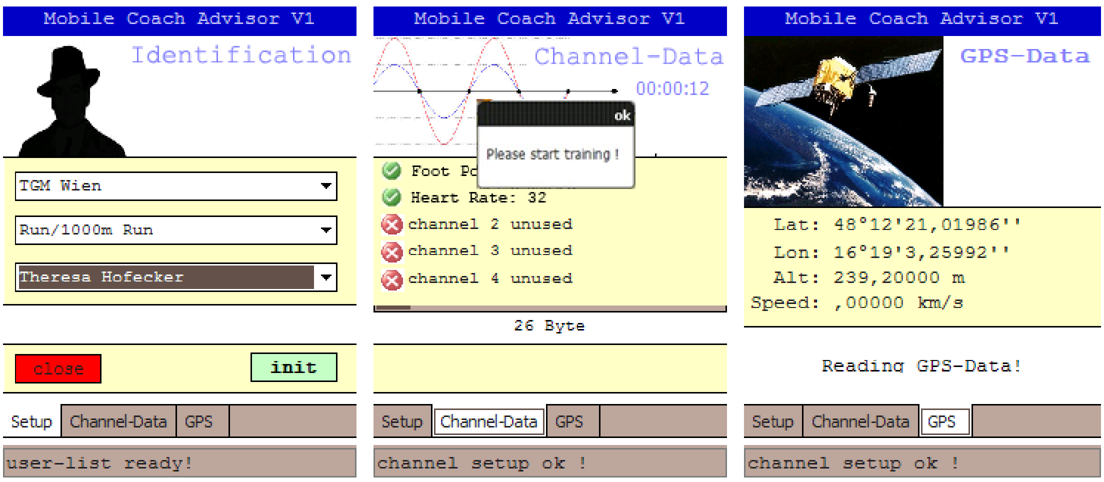
With the advances in the field of sensor technologies, an ANT-enabled SD card (first miniSD and then microSD) released by an Asian company (Spectec Computer Co., Ltd., Taipei, Taiwan) served as the new sensor communication module of the framework in a subsequent implementation of the A-Client (ANT+ SD, 2013). Based on this progress, it was consequently possible to integrate a lightweight device such as a smartphone into the development. In this version, the A-Client was programmed in C# based on Microsoft's .Net Framework and the Windows Mobile Software Development Kit (SDK), while the development environment chosen was Microsoft's Visual Studio Integrated Development Environment (IDE). The implemented applications were initially installed on a HTC® Touch 2 (High Tech Computer Corporation, Taoyuan, Taiwan) running Windows Mobile 6.5 (Novatchkov et al., 2010).

The installed and configured Apache HTTP Server was essential for the development of the web applications and the management of the HTTP requests. For the server's data storage the relational database system MySQL was set up. The centralized E-Clients were implemented in PHP in combination with JavaScript's jQuery library, while the charts were designed with the freely available Open Flash Chart library (Open Flash, 2013). Hence, the server component of this version was based on open source products only. A summary of the development tools is shown in Table 5.1.

A-Client	**Server**	**E-Client**
C# Windows Mobile SDK Windows .Net Framework	Apache MySQL	PHP JavaScript (jQuery) Open Flash Chart

Table 5.1: Development tools in combination with Windows Mobile-based smartphones.

Figure 5.2 illustrates an implemented GUI version of the Windows Mobile-based A-Client during a 1000 meter (m) run using two sensors – a HRM and a footpod (Baca et al., 2010). As shown, the mobile application consisted of three tabs: “Setup”, “Channel-Data” and “GPS”. So before the training session could be started, the athlete had to set up the A-Client to the personal aims. In particular, the user had to select a name and an institution for identification purposes as well as to choose a specific training type. After the setup, the program started listening on different channels for incoming signals from surrounding sensors. All registered equipment was displayed on the screen when selecting the second tab. In addition, also the elapsed time of the training and the current data transfer with the server component was shown. Finally, also the current GPS location and, based on it, the calculated speed of the athlete was identified and displayed in the third tab of the application.



(a) Login tab. (b) Channel tab. (c) GPS tab.

Figure 5.2: Implementation on a Windows Mobile-based smartphone.

The issues with this version, however, were connected with the used ANT+ SD card, since it reduced the implementation to Windows Mobile-based phones only. In addition, occurring hardware range and temperature problems occasionally caused the card to fail at higher degrees. Therefore, in a newer implementation version, the ANT equipment was integrated into individually designed hardware modules – the so-called Bluetooth-to-ANT adapters, allowing a multi-platform development on various handheld PCs. This implementation is described in the next section.

5.3 A-Client on an Android-Based Smartphone

Due to the mentioned problems with the SD card, an individually manufactured Bluetooth-to-ANT adapter has been designed for the communication between the sensor systems and the mobile device in the next version of the system. Figure 5.3 illustrates the final appearance of the customized hardware component before sheltering it with an enclosure (Novatchkov et al., 2011b). It embeds, amongst others, an ANT module (AP2) for the reception of the measured signals and a Bluetooth component (OBS411) for forwarding the data to the handheld PC.

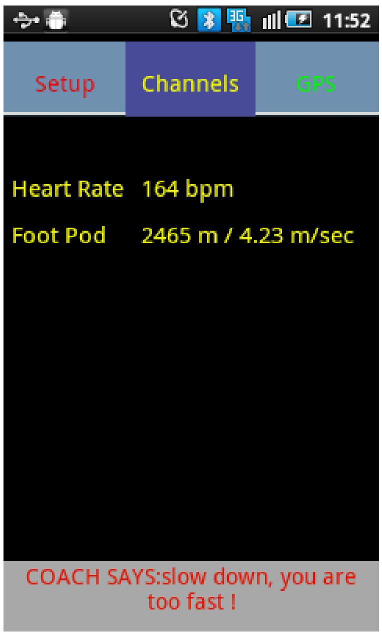
Figure 5.3: Bluetooth-to-ANT adapter.

The GUI of the A-Client on an Android-based Samsung® Galaxy 3 (Samsung Group, Seoul, South Korea) smartphone in combination with the individually designed Bluetooth-to-ANT adapter is demonstrated in Figure 5.4 (Novatchkov et al., 2011a). Once the application was started, the users had to authenticate themselves by entering their user name and password (also required for the access of the web-based E-Client of the framework) and choose the appropriate adapter. In an extended version this login operation was accomplished automatically by the program, identifying the user assigned adapter by verifying it with the server. After a valid authentication and the selection of the correct sensor data reception hardware, the application started looking for the exercise and user dedicated sensors in the surrounding area and displayed the identified devices on the screen.

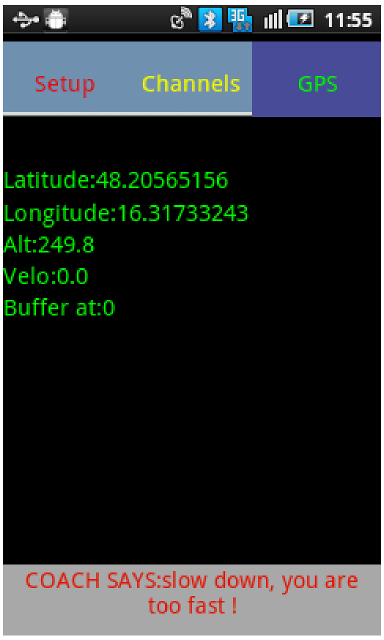
In the meantime, as already mentioned earlier, several mobile devices exist that have even a built-in ANT chip. Therefore, one of the most current developments of the framework includes an ANT-enabled handheld PC, contributing to the initial goal of reducing the interference with the performing athletes. This implementation – designed on the basis of the former versions – is depicted on the example of running (in combination with intelligent evaluation methods) in Chapter 6.

(a) Login tab.

(b) Adapter selection.



(c) Channel tab.



(d) GPS tab.

Figure 5.4: Implementation on an Android-based smartphone.

5.4 E-Client – Visualization Alternative

The remote web-based E-Client is important for the distant communication between the experts and the athletes. As an illustrative example, in one of the developed versions, the realization was based on the open source content management system Joomla!™, while the applications were implemented in PHP and JavaScript. The graphical visualization was realized with the Extensible Markup Language (XML)/Small Web Format (SWF) Charts (XML/SWF Charts, 2013) tool, which uses dynamic XML data for creating the graphs.

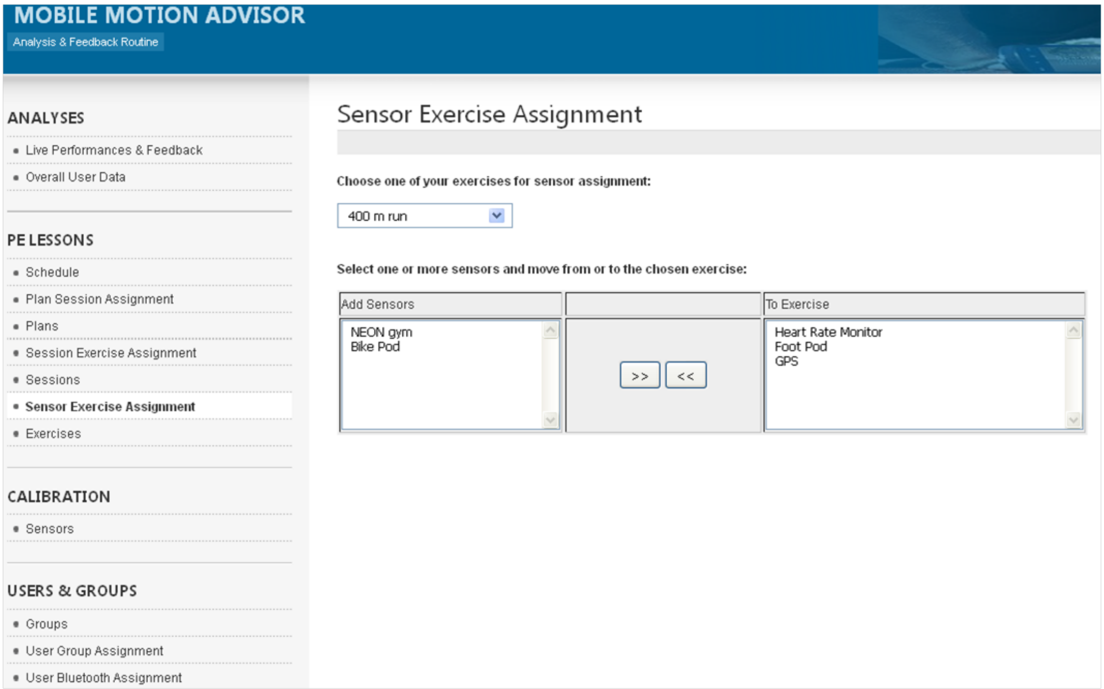


Figure 5.5: Routine for assigning sensors to exercises.

The implemented web applications included routines for the management of training plans, sessions, exercises, workout schedules, users and groups as well as the calibration of sensors like bikepods and footpods. Another feature involved the beneficial possibility of assigning sensors to exercises (Figure 5.5), allowing users to add any available devices to their trainings and in this way to configure their own exercises, contributing to the generic approach of the framework (Novatchkov et al., 2011a).

The program included also integrated real-time data presentation and analysis routines (Figure 5.6), offering specialists the opportunity to monitor and evaluate the current and already finished performances on the basis of charts and graphical visualizations of the measured parameters such as heart rate but also GPS position data as well as to return crucial notifications to the athletes (Novatchkov et al., 2011b). Furthermore, the application provided feedback procedures for the return of crucial notifications to the currently performing athletes. In this way, experts

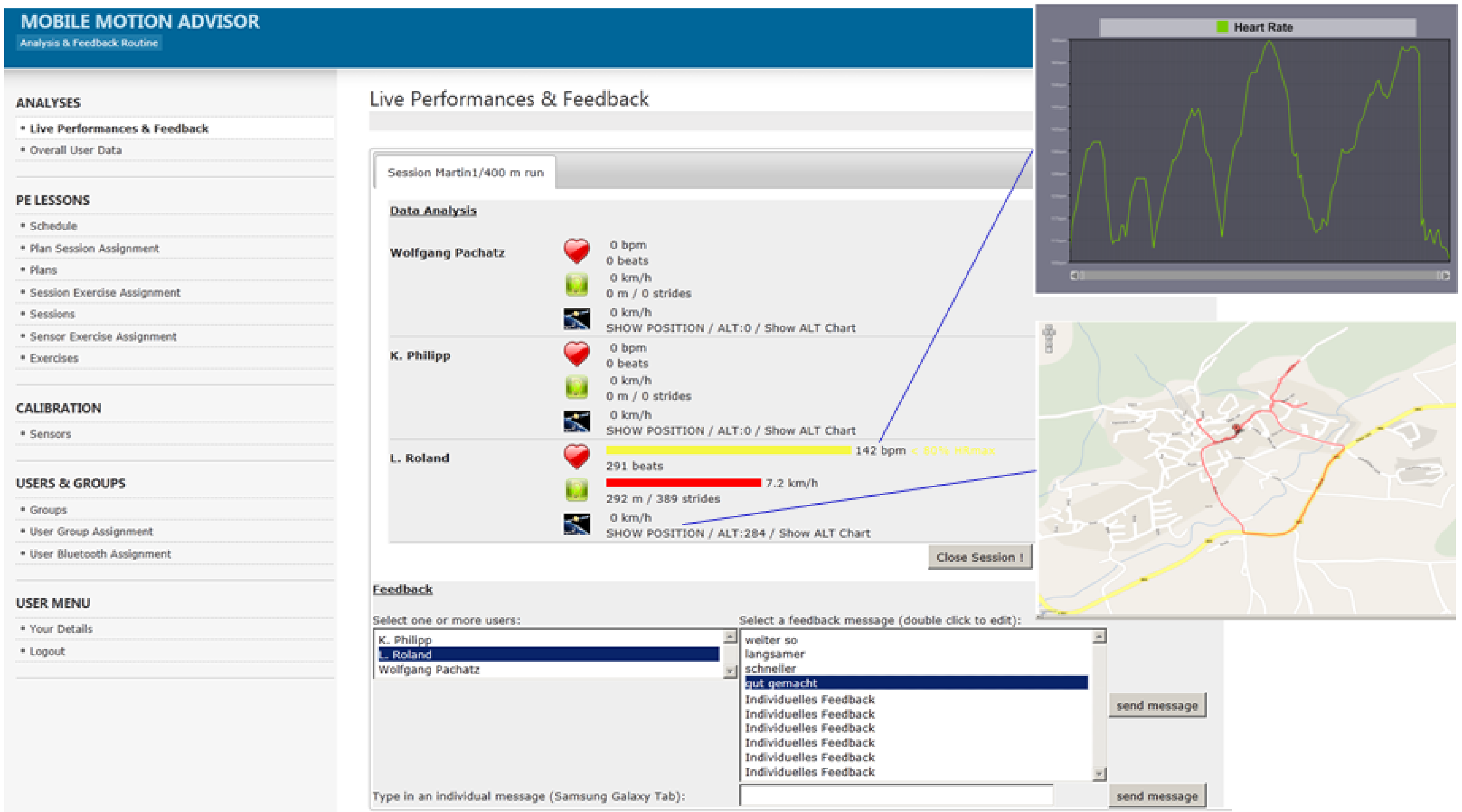


Figure 5.6: Web platform – visualization, analysis and feedback tool.

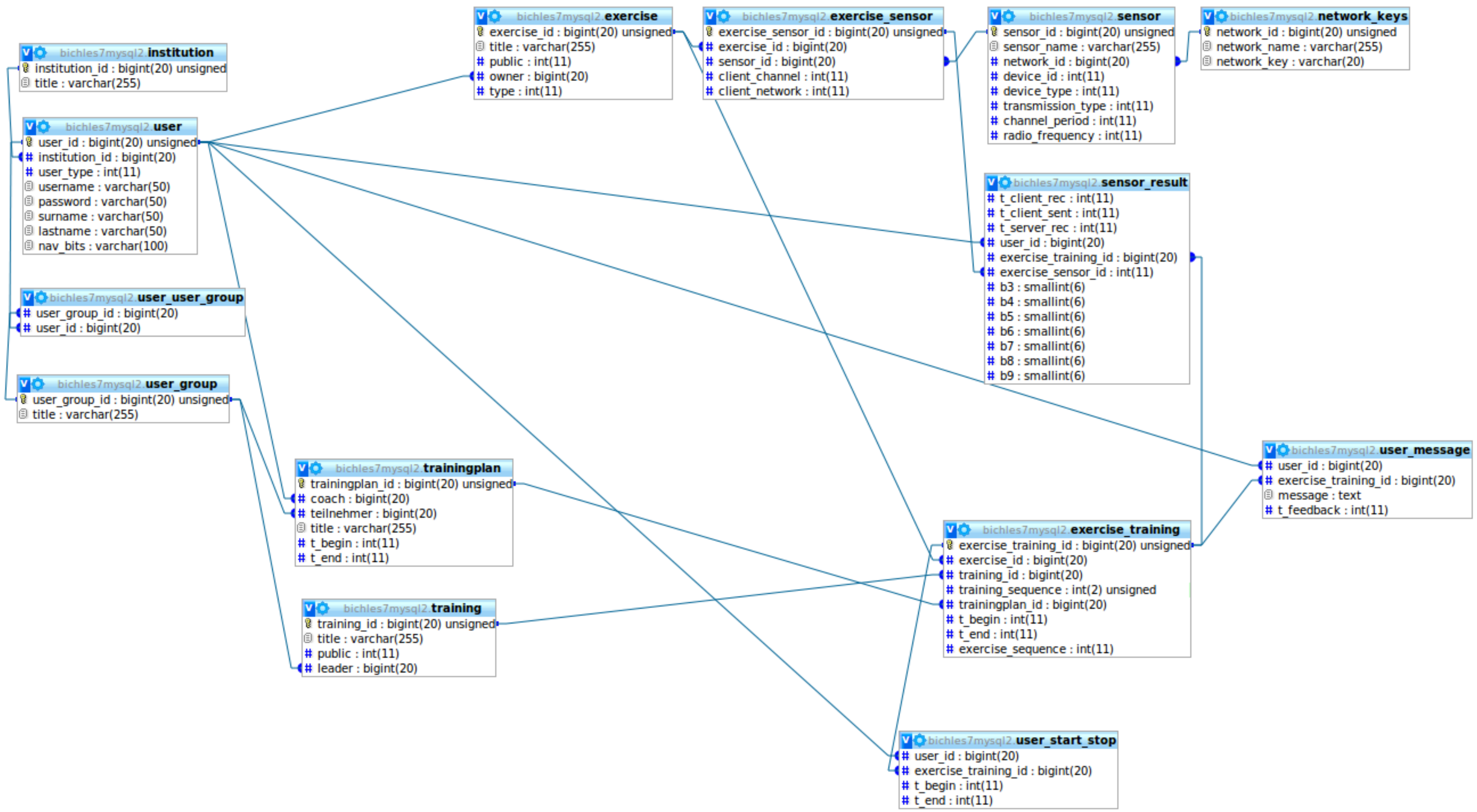


Figure 5.7: Illustrative database design of the framework.

could follow precisely the progress of the measured data and send remote messages in case of fatigue, overstrain, underload or any other abnormalities.

5.5 Database Design

Figure 5.7 represents an illustrative design of the constructed database, demonstrating the complexity of the data structures, including the big number of entities and attributes as well as appropriate relationships.

CHAPTER 6

Development and Application in Endurance Sports on the Example of Running

Sports applications for smartphones are modern and increasingly used by many sportsmen during physical exertions like, in particular, in running. The large number of "sports tracker apps" available on the market – like those mentioned in Chapter 3 or also others such as Runtastic™ (Runtastic GmbH, Linz, Austria) (Runtastic, 2013) and Skimble™ (Skimble Inc., San Francisco, CA, USA) (Skimble, 2013) – implies that there is a great interest in the public in improving the personal fitness and health levels based on modern equipment applied in endurance sports. These frameworks offer various routines for descriptive evaluations and visualizations of measured parameters like heart rate, speed and GPS coordinates illustrated by street maps.

As a consequence of the rapid spread and establishment of various technologies (especially in the smartphone sector), however, the development of intelligent real-time feedback systems for a wide spectrum of possible sports applications becomes increasingly essential (Tampier et al., 2012a).

6.1 Related Work

A commonly evaluated physiological parameter in the assessment of endurance sport exercises relates to the heart rate including specific characteristics such as the HRV (for instance in Kaikkonen et al., 2007; Kiviniemi et al., 2007; Vesterinen et al., 2011; Leutheuser and Eskofier, 2012; Plews et al., 2012), which is important for optimizing the training performances but also for health prevention. Based on such features, a variety of sophisticated analysis tools for different endurance sports have been designed and implemented throughout the last years. Saalasti (2003), for example, presents an ANN approach for the evaluation of heart rate time series analysis. The referenced thesis describes, amongst others, the importance of the HRV as well as the oxygen consumption (VO2) for the identification of fatigue in various exercises. The author presents a model that maps a direct correlation between the heart rate and the VO2 over time based on the collection of 158 recordings from different individuals performing a variety of tasks (Figure 6.1).

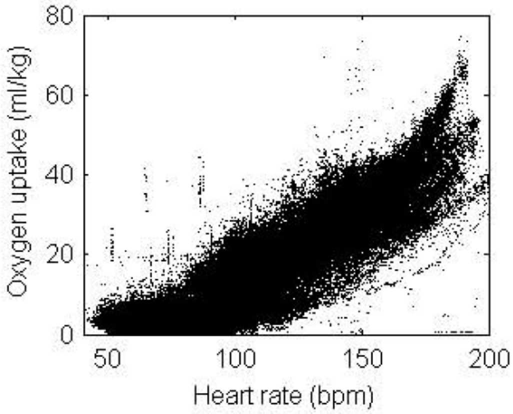


Figure 6.1: Illustration of the correlation between VO2 and heart rate (with permission from Saalasti, 2003).

Other studies concentrate, for instance, on the embedded classification of measures like speed and inclination during running (Eskofier et al., 2009, 2010) by taking into account parameters like pace, altitude and shoe heel compression involving a special Adidas® shoe. The published results demonstrate relatively high agreements, especially when considering the running speed. Regarding the classification of running kinematics, commonly applied algorithms include SVMs. Fukuchi et al. (2011), for example, use such techniques to detect age-related changes and differences in running gait biomechanics. Further approaches focus on the extraction of generic features for the implementation of pattern recognition methods (Eskofier, 2010; Jensen et al., 2012), promising an effective possibility for the application of such models in real-time BSN and feedback systems by assessing the fatigue state during running (Eskofier et al., 2012).

6.2 Mobile Coaching Idea in Endurance Sports like Running

Based on the mobile coaching concept presented so far and the general idea of supporting users with feedback information during various sport activities like marathons without the need of the presence of a coach, the following general and run-specific goals and requirements regarding the use of appropriate technologies (hardware and software) are essential (Tampier et al., 2012b):

- Assistance during running through real-time feedback and training improvement on the basis of feedback loops
- Generation of automatic feedback based on intelligent models
- Increase of motivation by promoting individual performance

- Preventive measures to avoid overload

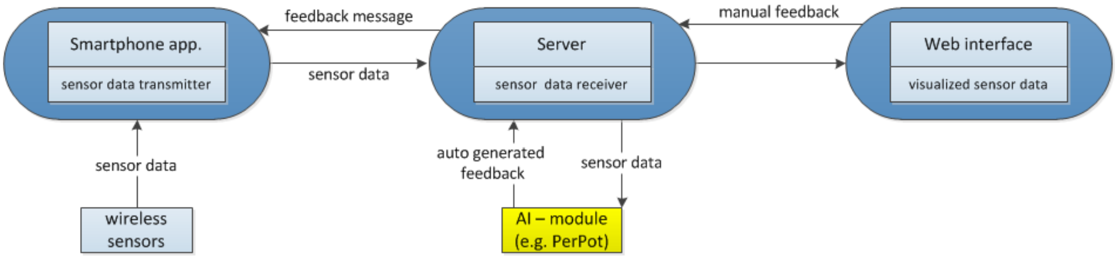


Figure 6.2: Integration of intelligent routines in running.

Figure 6.2 shows the application of the bidirectional data communication interface, illustrating the possibility of involving intelligent routines such as specific meta-models for the practical use in running (Tampier et al., 2012b). In particular, an antagonistic model called Performance Potential (PerPot) (Perl and Endler, 2006) has been integrated into the system. The embedding of this algorithm allows the simulation of load and performance limits during long-distance runs (e.g. marathons) and provides a first successful trial for the generation of automatic feedback messages, giving general insights on the integration of AI modules into the mobile coaching approach.

6.3 The Meta-Model PerPot

In general, the meta-model PerPot maps the interaction between load and performance (Perl and Mester, 2001). The overall concept is depicted in Figure 6.3. The load affects the performance in an antagonistic way, where two internal potentials buffer positive and, respectively, negative effects, which affect the performance potential by delayed flows. As a result, several phenomena of sport physiology like the super compensation effect can be simulated.

In agreement with the limitation of load-bearing capacity of organisms, PerPot is represented by an overflow mechanism: Once the fatigue potential exceeds a limit, another strong negative and delayed effect on the performance is generated, which causes a delayed collapse of the performance.

The reserve describes the available fatigue potential up to the limit. This parameter can help simulating load and performance limits. It is also important for the simulation of practice and competition, since an exceeding of the limit should be avoided (e.g. the reserve shouldn't fall below zero).

6.3.1 PerPot and Running

Theoretically, the load and performance factors are abstract terms, which depend on the specific application. In running, for example, speed is taken as the load and heart rate as the performance

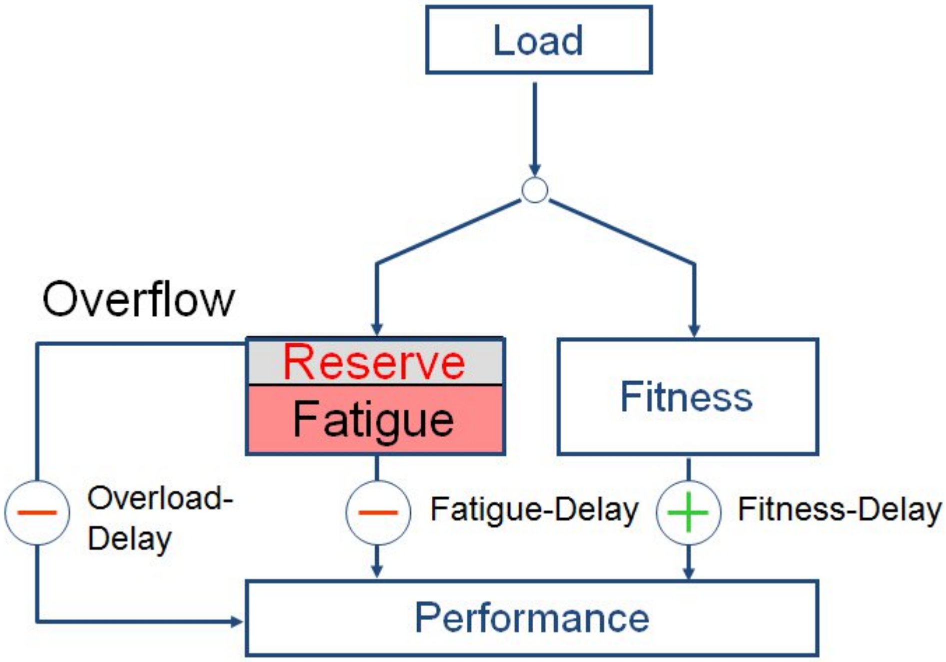


Figure 6.3: The meta-model PerPot.

determinant.

As a prerequisite, it is necessary to adapt the model to the individual athlete using a calibration run. This pre-run involves a similar procedure to a step test used in performance diagnostic analysis in sport science. The step length and increasing level of the speed per step has to be adapted to the capabilities of the athlete. Usually, the step length is fixed to 3-4 minutes, while the speed at the beginning of the step test should be 6-8 km/h and the increase of speed per step is 1-2 km/h. The athlete is requested to raise the speed until the subjective exhaustion is attained, followed by a cool down cycle with the initial starting speed for 3-4 minutes. Figure 6.4 shows a typical step test (step length: 4 minutes; starting speed: 8 km/h; speed increasing steps: 2 km/h) of a well endurance-trained athlete (Tampier et al., 2012b).

Based on the calibration run, it is possible to determine all required parameters of the model individually for each athlete. The most important determinants are, amongst others, the fatigue- and the fitness-delay determinants, controlling the delayed effect of the load on the performance. A specific application of PerPot is the simulation of competitions. Thereby, the speed can be individually optimized for each athlete and a given track by taking into account the computed internal parameters. The speed level is increased gradually during the optimization process until the reserve is exhausted at the end of the simulated competition. In addition, the optimal target time can be determined out of the optimized speed level and the track length.

This optimization was, amongst others, used for more than 15 competitions in 2011 and 2012 (Perl and Endler, 2012). The mean deviation between the simulated target time and the real target time was 1.63 %. However, there were also single competitions with relatively high deviations. One explanation for this occurring might be connected with the actual moment of the calibration run. Since the simulation of the competition is based on the calibration run, changes of conditions – such as the change of weather – are not considered in the simulations. Another reason might be associated with the delay parameters, which may change during a run. As described earlier, though, such variations are considered only marginally in the optimization process. A combined approach integrating the PerPot model in the mobile coaching system, however, solves those problems.

6.4 The Combined System

The integration of real-time measurements including speed and heart rate determinants gathered during a competition appears to be one particular approach for solving the issues discussed above. As the mobile coaching framework measures all necessary information that is needed by the PerPot model, a combined system integrating both concepts was developed.

6.4.1 Framework Design of the Mobile Coaching System in Running

First of all, due to the necessity of more specific research questions and requirements, a specialized mobile coaching version was adapted solely for running. The design of the framework was adjusted in terms of its usability (in particular the usability of the smartphone application) as well as the visualization of sensor data (Figures 6.5 and 6.6).

6.4.2 Integration of PerPot

An important factor of PerPot is that the determined parameters from the calibration run (which should always take place a few days before the competition) provide the basis for the simulation of the competition. In the combined system, the meta-model uses this information to optimize the approximation of the simulated heart rate compared to the currently measured heart rate by slightly changing the delay indicators (Tampier et al., 2012b).

The first framework optimization adjusts the starting value of the delay parameters to the conditions of the day of the competition. For instance, if the weather is much warmer than on the day when the calibration run took place, a fatigue in the performance will occur much faster. In addition, the fatigue delay will be smaller, which also has an effect on the performance.

A second adjustment tries to determine the progress of the delay parameters. Basically, the longer the duration of the run is, the greater is the influence of the fatigue compared to the fitness. Consequently, the fitness delay increases and the fatigue delay decreases, respectively, over time. In a first version of the combined system, a linear gradient of the fitness delay is assumed.

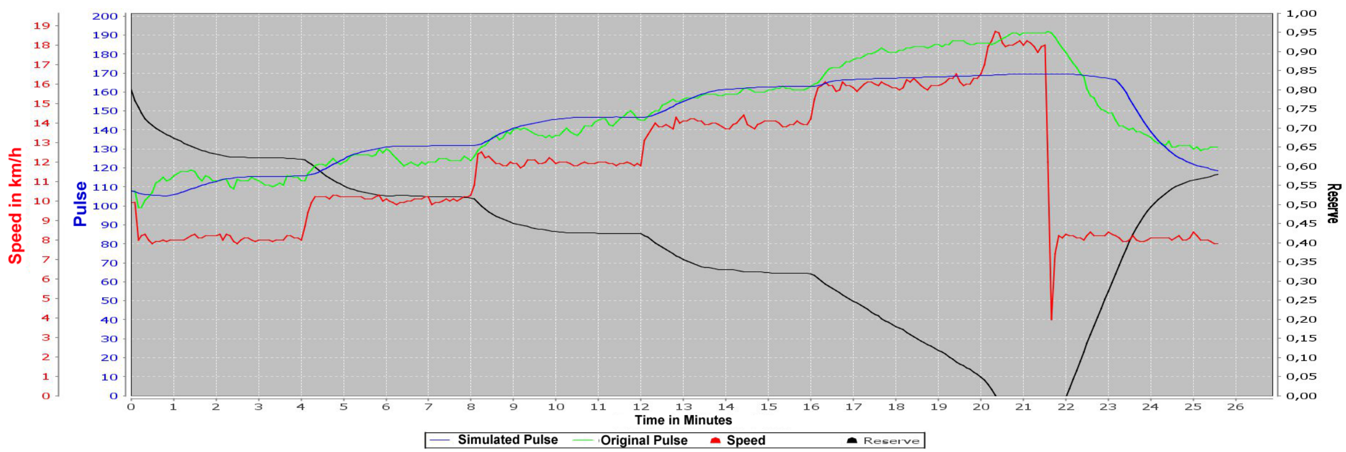


Figure 6.4: Typical step test for the calibration of PerPot.

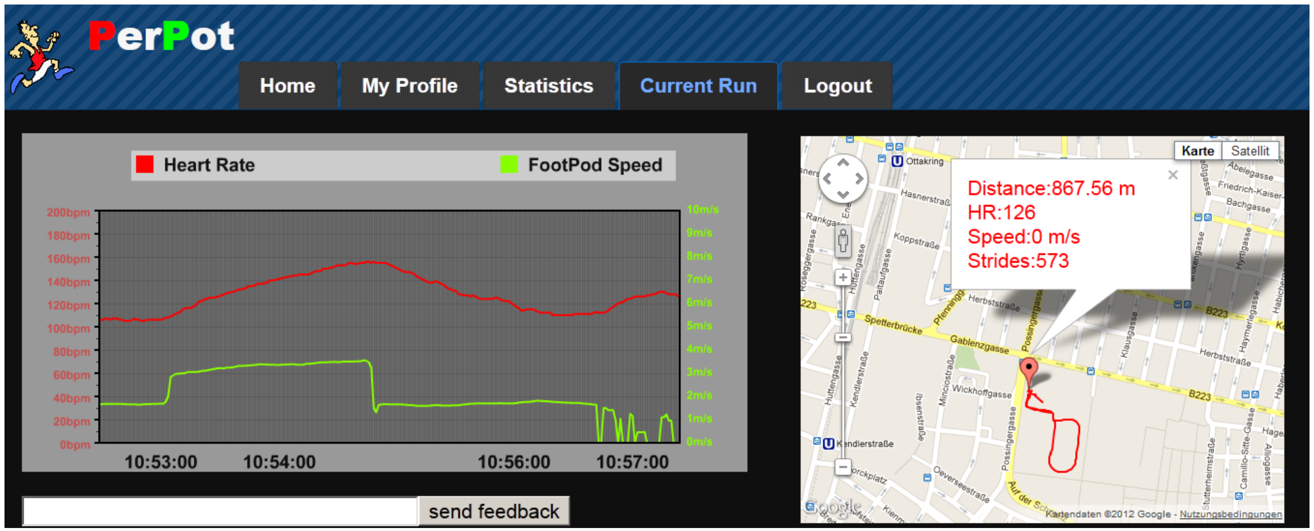


Figure 6.5: Specialized web frontend.

Figure 6.6: Simplified smartphone application.

The rest of the not yet completed running track is simulated in real-time on the basis of the adjusted delays and their progresses. The athlete is regularly provided with a feedback message indicating the estimated target time. Further messages are sent automatically if the athlete leaves the optimized speed zone or if the heart rate exceeds the Individual Anaerobic Threshold (IAT), which is another application scenario of PerPot (Endler and Perl, 2012). The feedback notifications are represented by full sentences, being generated by the voice synthesizer of the smartphone. This routine brings two advantages compared to a conventional HRM:

- The athlete gets simultaneous feedback on the heart rate as well as the speed
- The feedback messages convey much more information compared to a HRM, which only alerts a beep sound, if a certain range is exceeded or has fallen below the fixed target zone

For the moment, in order to limit the number of permanent messages, the optimization of the parameters is accomplished every 5 minutes by taking into account all collected data of the current run. Moreover, feedback messages relating to occurred abnormalities regarding the individual ranges are generated every 15 seconds at most.

The system was tested for the first time in a competition over 11.1 km. The exact target time could be determined already after 5 minutes, whereas the stand-alone version of PerPot had a greater deviation in comparison to the target time.

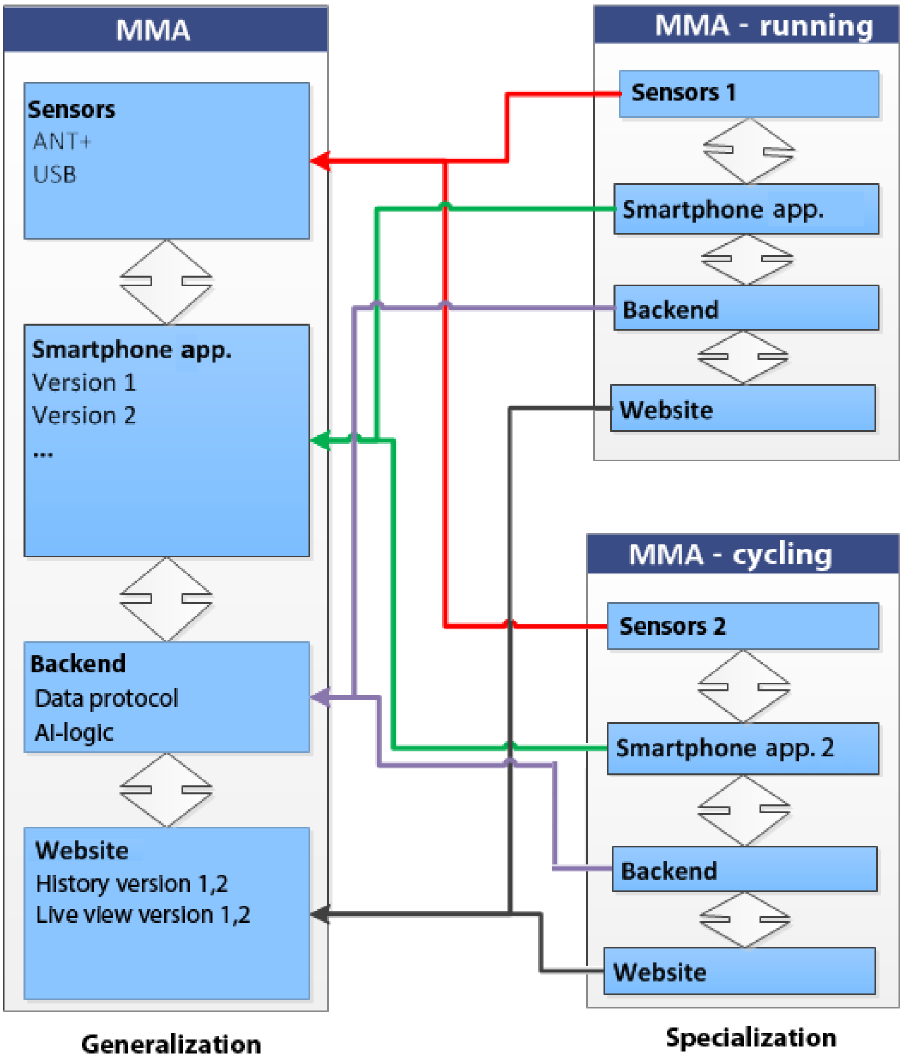


Figure 6.7: Generalization vs. specialization of the framework.

6.5 Outlook, Discussion and Conclusion

Based on the obtained findings, the future work will concentrate on further developments of the combined approach. All field tests conducted so far confirm the assumption that the adaptation of the system (especially of the smartphone application) have positive effects on the handling of the entire framework. Since a specific requirement is to develop a rather generic version, which maintains its usability and, at the same time, supports a variety of movement activities, the intention is to design a modular architecture providing several reusable key components (standardized modules, data protocols, smartphone application, website etc.). The integration of new activities could be then primarily accomplished by the reuse of existing structures (Figure

6.7), and – only if necessary – by the implementation of additional components (Tampier et al., 2012b).

Chapter 7

Development and Application in Weight Training

7.1 Introduction

Throughout the last years, fitness studios are getting more and more popular among professional but especially also amateur athletes for several reasons. In general, today's gyms offer facilities and services that attract the public with a rather simple, autonomous and still beneficial way of sport activity as well as effective opportunities for health promotion and rehabilitation. As a particular example, weight training is gaining popularity as it plays an important role in the overall conditioning of athletes in order to increase strength and consequently to improve their sports performances.

Nowadays, such training and competition enhancements can be furthermore achieved by the design and implementation of innovative systems on the basis of state-of-the-art ICT in combination with sophisticated processing methods, which are becoming increasingly important for the instant collection, transfer, storage as well as analysis of sensor data in sports. Moreover, the integration of machine-aided intelligence into the development of modern sports information systems enables a prompt and automatic evaluation of sport-specific parameter values, thereby allowing the establishment of computer-based feedback and intervention routines (Baca, 2012).

7.2 Weight Training Fundamentals

The intention of this piece of research focused on the implementation of intelligent routines based on AI and fuzzy logic for the automatic evaluation of exercises in weight training (Novatchkov and Baca, 2013a). Weight training is commonly described as a specific type of strength training where lifting weights results in an overload of certain muscle fibers to trigger adaptive reactions of the organism (supercompensation). Also known as resistance training, weight training is nowadays among the most popular stabilizing, invigorating or even prime sport activities at professional and amateur levels.

Positive effects of this type of training include the overall strengthening as well as the improvement of the physical condition, fitness and performance levels. Thus, not only athletes but also non-professional sportsmen can benefit from resistance training. Other known advantages of weight training include prevention (e.g. in case of back pain or osteoporosis), maintenance of muscular functional abilities, fat loss and promotion of a healthy cardiovascular system (Winett and Carpinelli, 2001). Therefore, weight training is often recommended by specialists and professional organizations (Westcott, 2009), as it decreases the risk of injuries and serves as effective prophylaxis compared to other exercises.

Nowadays, plenty of diverse weight training machines exist, aiming at a controlled and hence less risky execution. Particularly inexperienced individuals initially prefer exercising on such equipment due to their convenience, easier use and supporting purpose in comparison to free weights and in order to get used to the movement. However, it is still important that experts like fitness coaches assist and provide advice to beginners, inexperienced and elderly people for the purpose of adjusting and correcting the execution, preventing health and injury risks as well as adapting and improving the overall training.

Today's weight training machines usually include directions on how to use the equipment (meant especially for newcomers), visually illustrating and describing the proper technique (for example: "performing each repetition in a slow and constant manner"). Also in the literature, it is reported that the flexion and extension phases should be executed smoothly and completely with preferable time durations of 2-3 seconds (for instance in Evans, 1999). Similarly, the velocity (in terms of a constant and consistent movement) plays a crucial role for a correct and low-impact execution (Rana et al., 2008).

The graph in Figure 7.1 represents an example of a typical beginner's mistake (Novatchkov and Baca, 2013a). It shows the measured parameters (cable force and weight displacement) on an incline bench press machine, illustrating inconstant and incorrect characteristics with noticeable force fluctuations at the turning point of a single repetition. The visible oscillation in the cable force graph was most probably caused by a sudden release of stress and a consecutive loading, which is a common error among beginners.

Based on such abnormalities, it can be concluded that determinants like force, displacement, velocity and duration are essential for the analysis of the quality of the technique. In particular, these features may be applied for the automatic evaluation of weight training exercises with the help of sophisticated modeling methods. Moreover, such routines could be integrated into the presented mobile coaching system, allowing real-time analysis of the quality of the movement and returning prompt feedback information on the execution. The notifications for the mistake in Figure 7.1 might, for instance, alert on the occurred fluctuation point and provide directions for error correction.

7.3 AI in Sport and Weight Training

In general, AI is derived from imitating human actions and abilities such as thinking and learning. It involves the idea of designing so-called intelligent agents or machines that are similarly

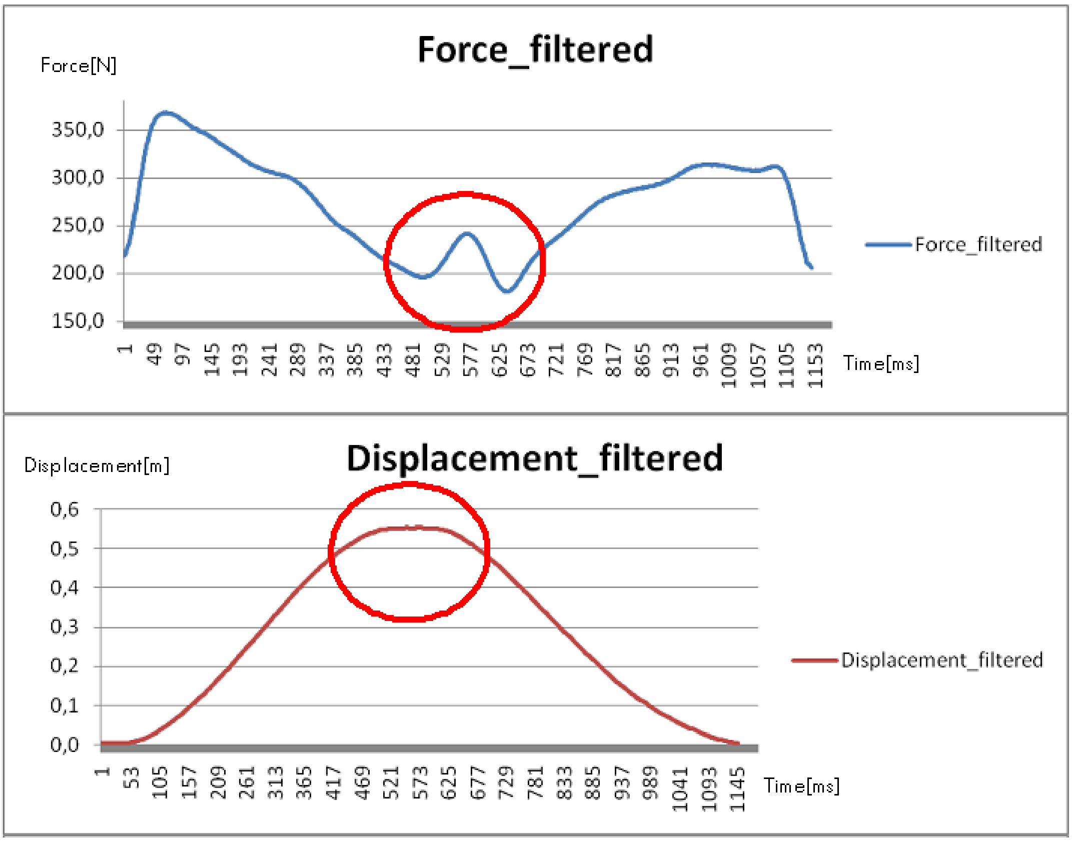


Figure 7.1: Filtered cable force and weight displacement data of an execution by an inexperienced individual on a sensor-equipped incline bench press machine collected at 200 Hertz (Hz) with a load of 30 kilograms (kg). The red circles label the turning point of the repetition, indicating the discrepancy of the measured channels with appearing force fluctuations.

able to acquire, simulate and employ knowledge, analytical capabilities and professional skills for the overall purpose of problem solving (Poole et al., 1998). While AI techniques experienced a boom with the rise of expert systems in the 1980s, such methods are meanwhile mainly applied for rather specific and isolated research topics. Chess and particularly the first win of a computer against a world champion (Deep Blue vs. Garry Kasparov) in 1997 (Newborn, 1997; Campbell, 2002) is an example illustrating the high potential of AI. It has to be considered, however, that such achievements are strongly related to the constant increase of computer power – a main feature and benefit of today's IT environment.

7.3.1 Related Work

In the area of weight training, only few approaches integrating computer-based evaluation routines have been presented in the literature so far. Although Ariel (1984) suggested first ideas for the design of intelligent weight training machines on the basis of AI methods already in 1984, no effective realizations have been constructed up to now. The author proposed the implementation of a feedback-based system involving factors like duration, displacement and force characteristics of the movement, thereby suggesting the most suitable exercise on the basis of computerized loop techniques.

A more recent study (Chang et al., 2007) concentrated on the recognition of various free-weight exercises by applying specific algorithms like Naïve Bayes Classifiers and Hidden Markov Models (HMMs) to measured acceleration characteristics. The purpose of the developed routines was to differentiate between the types of exercises but not how the exercise was executed. Similarly, Chaudhri et al. (2008) presented a method for sensing and monitoring executions (with dumbbells) on the basis of RFID tags. Today's commercial realizations (e.g. FitLinxx, 2013), on the other hand, focus on capturing relevant workout information including the amount of weight or the number of sets.

7.3.2 Specific Research Goals regarding Weight Training

The initial objectives of this part of research were to confirm and demonstrate the high capability and potential of AI and, in particular, of machine learning and data mining methods in the field of sport by the practical and still not well-investigated example of weight training (Novatchkov and Baca, 2013a). A specific aim included the assessment of measured way, force and further derived characteristics by the involvement of common pattern recognition methodologies including automatic classification algorithms. First results (Novatchkov and Baca, 2012a) involve rather basic data analysis, thereby providing a basis for the improvement, optimization and extension of the developed machine learning routines. This includes the enhancement and implementation of more exact, advanced and in-depth modeling techniques and outcomes by applying multi-scale feature spaces and further classification types.

Based on the analysis conducted so far, the ultimate goal is to integrate the machine-aided techniques depicted below into the presented mobile coaching system, providing athletes with automated and instant evaluation and feedback notifications. This system integration would enable a real-time data transfer – for instance via an Internet-enabled portable device such as a handheld or tablet PC – to the described server component (see also Section 7.3.3.3), where the measured parameters would be analyzed and assessed by the developed models. Crucial notifications could be then sent to the exercising person, giving feedback on the quality of the execution as well as providing appropriate advices. This information could be presented to the performing individual via a mobile device, indicating occurred mistakes, suggesting corrective measures and in this way reducing the risk of injuries. In an alternative design of the mobile coaching system, the portable devices could be replaced by a built-in computer device including a screen used for the instant transfer of the measured information to the server component and the prompt display of feedback alerts.

In the following, the overall method including relevant AI fundamentals, main application fields as well as the underlying study design and applied procedure are presented. The rest of the chapter includes current results, a discussion, an outlook and final conclusions.

7.3.3 Methods

7.3.3.1 AI Techniques in Sport

Practical concepts for the realization of AI-based methodologies for sport science disciplines like biomechanics or kinesiology have been already discussed and reviewed earlier (for instance in Lapham and Bartlett, 1995). A commonly used technique involves the development of methods on the basis of AI for the assessment of different sports-related data measurements or game analysis. The so-called Tennis Simulation System (TESSY), for instance, is one of the first knowledge-based decision making implementations, aiming at the supervision, processing and interpretation of results and tactical behavior as well as the subsequent transformation of conclusions into tennis practice (Lames, 1990). Other, more recent, approaches also suggest the implementation of expert systems integrating fuzzy logic procedures for diverse purposes like the evaluation of the fast bowling technique in cricket (Bartlett, 2006; Curtis, 2010) or for the identification of sport talents (Papić et al., 2009). Ratiu et al. (2010) provide an overview on the overall application of AI in sports biomechanics, giving examples of diagnostic tools for the evaluation of movements in different sports.

Specific investigations, on the other hand, focus on the design of machine learning methods for the clustering, classification, recognition and prediction of sports data such as patterns of movement sequences. Today, particularly performance analysis by means of self-learning algorithms like ANNs are increasingly discussed as promising application areas in the mathematics and computer science related sports literature and fields of activities (Perl, 2004a,b; McCullagh, 2010). Successful implementations include also analytical studies for different movement evaluations in sports such as golf or baseball (Ghasemzadeh and Jafari, 2011) as well as handball (Pfeiffer and Perl, 2006), soccer or basketball (Lamb et al., 2010; Bartlett and Lamb, 2011). As another example, Silva et al. (2007) present predictive solutions for the dynamic system modeling and talent identification in swimming. Furthermore, in (Baca and Kornfeind, 2012) a Self-Organizing Map (SOM) is trained for the purpose of clustering the stability of the aiming process of elite biathlon athletes.

But also other classifiers like the k-Nearest Neighbor (kNN) algorithm or SVMs are commonly applied modeling tools, providing good opportunities for the analysis and recognition of sport-specific data patterns. In the approach by Acikkar et al. (2009), for instance, SVMs are used in order to predict the aerobic fitness of athletes. A number of further studies are related to running (for details see Chapter 6), aiming either at the built-in classification of track inclination and speed parameters (Eskofier et al., 2010) or the identification of differentiation of kinematic characteristics (Fischer et al., 2011).

7.3.3.2 Design and Procedure

Based on the above described methodologies, the present study was built on a typical pattern recognition approach including the following distinct and successive phases: data acquisition, preprocessing, feature extraction and classification. Figure 7.2 shows in detail the connections, purpose and significance of each step in respect to the gathered weight training sensor informa-

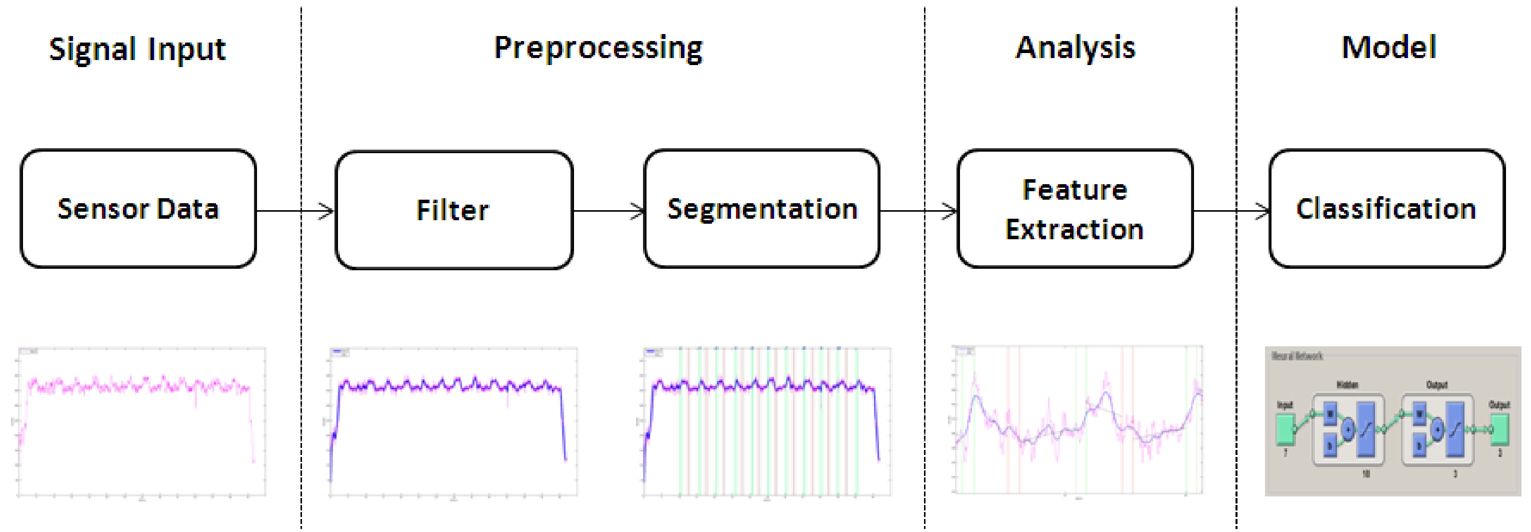


Figure 7.2: Applied pattern recognition approach.

tion (Novatchkov and Baca, 2012a).

In the following, all stages are described individually, giving an overview on used equipment, participants, applied data processing as well as analysis and modeling techniques.

7.3.3.3 Data Acquisition and Equipment

The data acquisition procedure involved sensors attached to various exercise equipment, allowing the collection of crucial characteristics during the workout. More precisely, the measurement of the present study was based on a weight leg press machine equipped with a load cell (PW10A or PW12C3, Hottinger Baldwin) and a rotary encoder (DP18, Altmann). In this way, significant force and displacement parameters could be measured directly and thereupon used for the detection of single repetitions and extraction of further determinants such as time periods, velocity, acceleration or power. The data was acquired at a sampling of 100 Hz for each channel. Figure 7.3 illustrates the university's sports hall with the installed weight machines and embedded sensors (Novatchkov and Baca, 2012a, 2013a).

In addition, the already described NEON sensor construction with integrated microSD card served as collection point of the measured values. As the sensor platform supports wireless sensor transmission on the basis of the ANT+ protocol, one future aim is to immediately forward the gathered information to a handheld PC such as the mentioned smartphones with built-in ANT technology or a more powerful laptop including an USB reception hardware.

7.3.3.4 Participants

The current study examined executions by 15 individuals with a rather inexperienced background in weight training, performing 3-5 sets of 10-12 repetitions on a leg press machine (Waltersam, 2011). Descriptive details regarding the participants including Standard Deviations (STDs) are shown in Table 7.1.

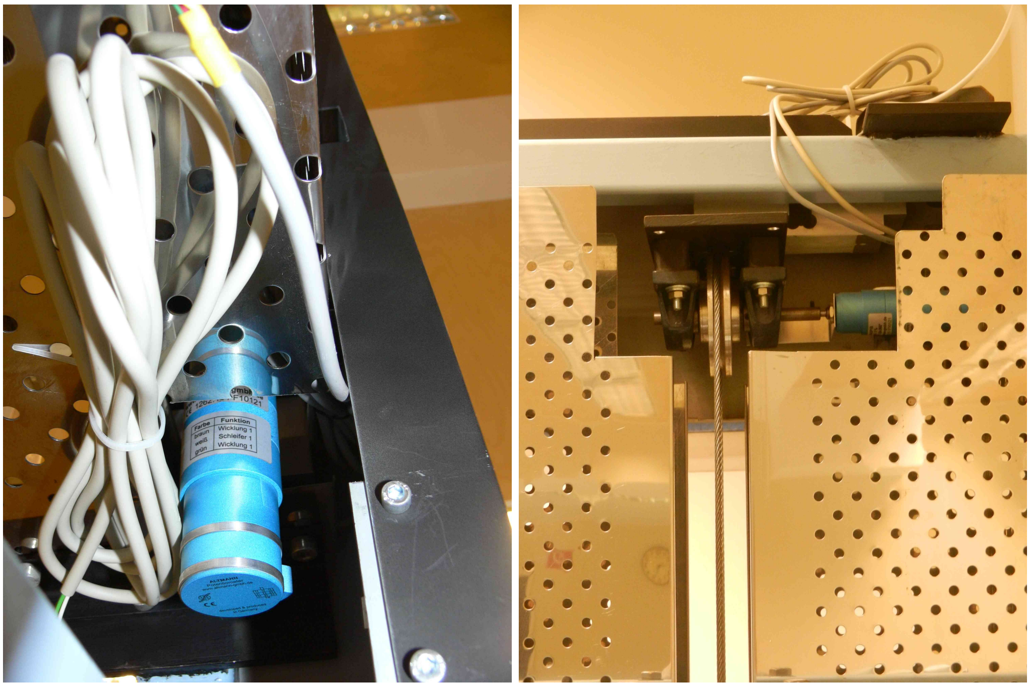
Men	8
Women	7
Mean age (± STD) [years]	24.6 (2.7)
Mean height (± STD) [m]	1.73 (0.1)
Mean body mass (± STD) [kg]	63.6 (13.8)

Table 7.1: General biographical characteristics of the study participants.

All subjects gave written informed consent for the study procedures, which were reviewed and approved by the research Ethics Committee of the Medical University of Vienna.

Table 7.2 gives an in-depth description of the subject's biographical characteristics, experience levels and used load for each of the performed sets (Waltersam, 2011). The participants in this study were primarily inexperienced and slightly experienced individuals, since the overall goals were to assess the quality of the movement focusing on beginners and to identify significant characteristics regarding the performances of unskilled people.

(a) Sensor-equipped weight training machines.



(b) Attached force (load cell) and way (rotary encoder) sensors.

Figure 7.3: University's sports hall.

Subject Number	**Age**	**Sex**	**Height (m)**	**Mass (kg)**	**Experience**	**Load Set 1 (kg)**	**Load Set 2 (kg)**	**Load Set 3 (kg)**	**Load Set 4 (kg)**	**Load Set 5 (kg)**
1	22	female	1.62	49	Yes	30	40	40	50	60
2	30	male	1.72	66	Yes	110	120	110	100	
3	22	female	1.63	46	Yes	40	50	60	70	
4	27	female	1.68	55	Yes	50	70	80	90	
5	21	male	1.80	73	Yes	120	100	90	90	
6	21	female	1.80	63	Yes	60	60	60	60	
7	23	male	1.73	80	No	40	60	60	80	
8	24	male	1.76	72	No	40	60	90	120	
9	27	male	1.78	71	No	40	60	60	70	
10	24	male	1.72	79	Yes	50	100	110	120	
11	25	male	1.90	72	No	50	70	100	120	140
12	31	female	1.62	43	No	30	30	30	30	
13	27	male	1.93	85	No	40	60	70	80	100
14	25	female	1.64	51	No	40	40	40		
15	20	female	1.62	49	No	40	40	40		

Table 7.2: Detailed biographical characteristics of the participants, experience levels and used load for each set.

Hence, the initial intention was neither to investigate the maximum load and force potentials of the participants nor to examine the condition and improvement in performance, power and muscle gain. The actual research idea was rather to evaluate and classify the performed exercises according to crucial criteria such as duration, constancy and completeness and not to analyze the effects of different exercise methods. Therefore, commonly recommended exercise prescriptions with a reasonable amount of sets, repetitions and loads for basic resistance training were selected to be followed (Garber et al., 2011). The variable selection was chosen in accordance with the literature-based importance of the mentioned criteria as well as today's effective possibilities to instantly measure, derive and assess significant parameters by integrating modern sensors into the equipment. Finally, another major aspect refers to the applicability of the measured data to AI-based modeling techniques for automatic classification purposes.

7.3.3.5 Data Preprocessing

Once the raw sensor output was collected, the subsequent step included the preprocessing of the acquired measurements. This procedure was necessary for the preparation of the data without any loss of significant information, the improvement of its quality and, consequently, the final outcome and performance of the applied machine learning method on the refined training set. In particular, this comprised the processes of cleaning and filtering the measured parameters. The cleaning routine involved procedures such as detecting, correcting and removing unreliable, incorrect and irrelevant data. Filtering, on the other hand, had the goal of smoothing the time series by the reduction of the effect of noise. A detailed survey regarding the most useful preprocessing methods is described by Kotsiantis et al. (2006). In addition, also the segmentation of the gathered data was closely connected with the preparation step, as it was essential in forming the basis for the fragmentation (particularly into single repetitions).

Since it was necessary to preprocess the time series before analyzing and classifying them, after several trials, the measured displacement values were refined by a strong low-pass filter (with a passband frequency of 0.1 π radians/sample, stopband frequency of 0.3 π radians/sample, 10 dB (decibels) of allowable passband ripple and a stopband attenuation of 20 dB) in order to simplify the process of segmenting the data. On the other hand, the force input was essential for identifying possibly occurring fluctuations (relevant for the classification of the data) and was therefore smoothed by applying an average digital low-pass Butterworth filter with normalized cutoff frequency of 0.02 radians/sample, which is equivalent to 1 Hz. Figure 7.4 shows the measured and subsequently filtered force and displacement data of a rather well-performed and, in comparison, a poor execution (stable/complete vs. instable/incomplete movement range and constant vs. inconstant time and force characteristics) of the same participant (Novatchkov and Baca, 2013a).

Figure 7.5, on the other hand, illustrates the acquired signals of an inexperienced in relation to a slightly experienced female individual (Novatchkov and Baca, 2013a), both with similar biographical data and identical load set-up (subject 1, set 4 and subject 15, set 1 from Table 7.2). Obviously, the execution of the complete beginner is characterized by variable properties including bigger force fluctuations and variable displacement paths, compared to the rather

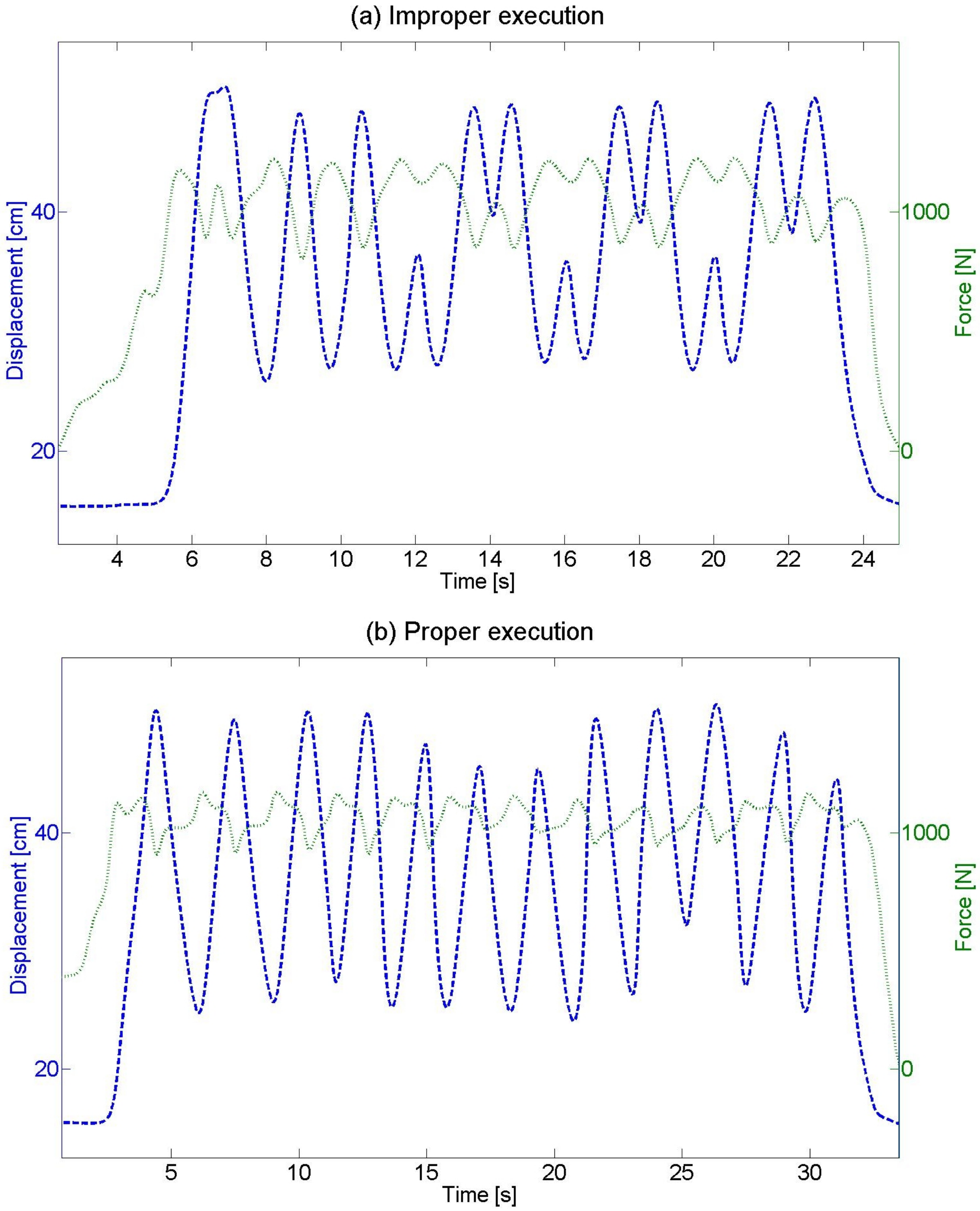


Figure 7.4: Comparison of the time series of improper (a) and proper (b) executions of entire sets by the same subject.

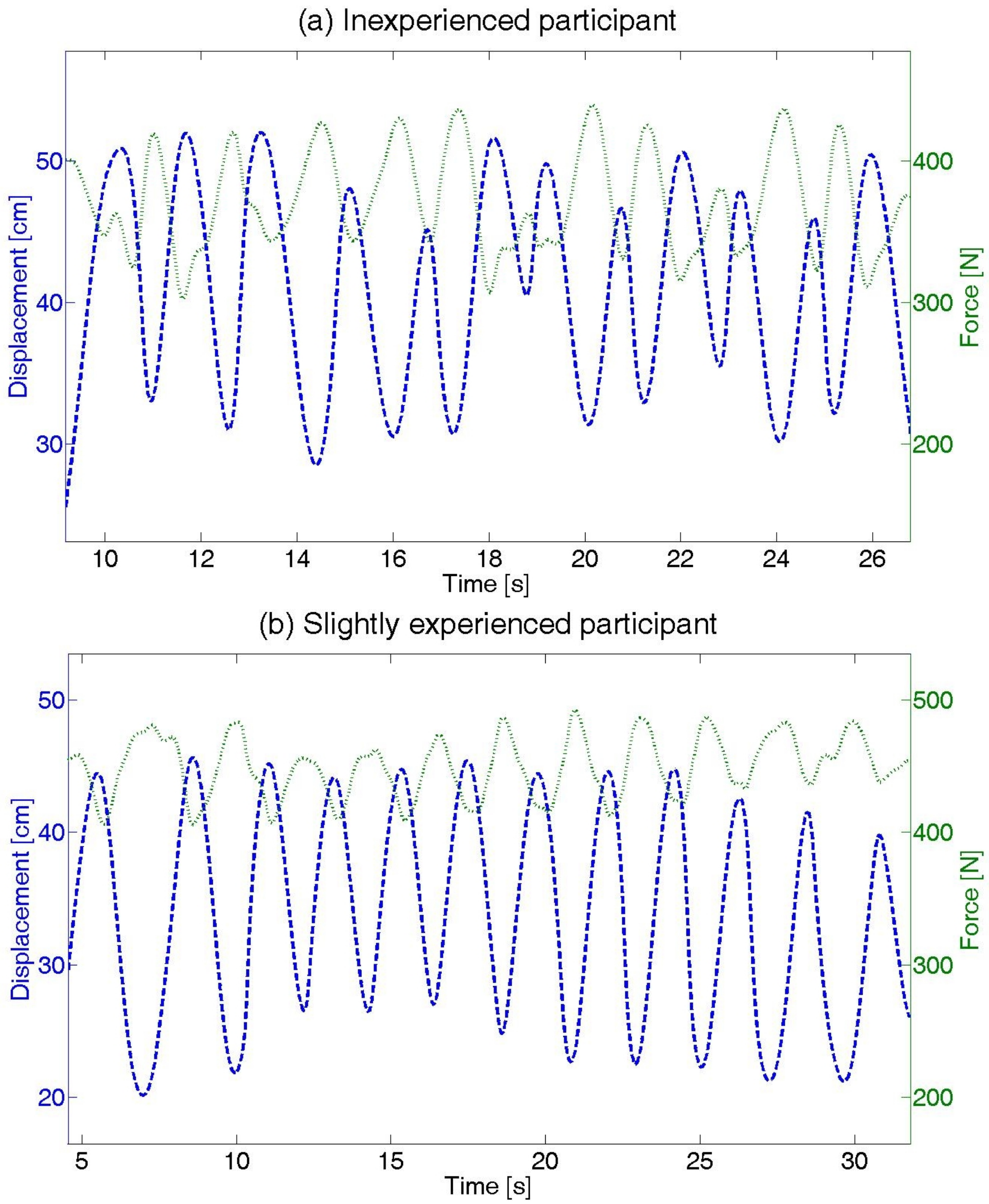


Figure 7.5: Comparison of the recorded time series of an inexperienced (a) and a slightly experienced (b) female participant with similar biographical characteristics using the same load.

smooth completion of the slightly experienced participant.

The last task of the preprocessing step involved the segmentation of the data into single repetitions. This procedure was accomplished on the basis of the filtered displacement measurements by detecting peak regions. In particular, the filtered force characteristics were partitioned into individual cycles by identifying extrema and turning points within the entire data sets.

Since some of the first and last repetitions appeared to be interrupted (e.g. by correcting the feet position just after the initial extension or abandoning the final flexion phase), causing, for instance, "incorrect" time intervals, these sequences were not included in the classification process. Furthermore, the time series were divided into single stages (extension, flexion and holding phases), allowing a precise data analysis in the subsequent transformation procedure.

7.3.3.6 Data Transformation

In the following step, the initially cleaned, filtered and segmented sensor measurements were applied to further data analysis. This mainly included the identification and deduction of relevant information describing the gathered time series. This feature extraction procedure aimed at the data characterization by dimension reduction, detecting and deriving crucial attributes (e.g. durations, amplitudes, fluctuations or ranges) within the segmented periods (Novatchkov and Baca, 2013a). The features were transformed into a vector representing the data in feature space. A selected subset was thereby applied for the classification regarding various criteria including time, completeness and constancy (see also Table 7.3).

Parameters	**Criteria**	**Features**
Displacement Cable force Velocity Acceleration Power	Time Completeness Constancy	Extension/flexion/reversal: Durations Maxima Minima Ranges Relations Fluctuations Amplitudes Inclines Declines

Table 7.3: Gathered parameters, main criteria and exemplary features derived for the applied pattern recognition procedure.

The preprocessing, data analysis and transformation stages were carried out using MATLAB® version R2010b for Windows. The programming environment includes the so-called Neural Network Toolbox™, providing functions for the design, realization, visualization and simulation of various ANNs. The practical application of these routines is described in the following sections.

7.3.3.7 Modeling and Supervised Classification (ANNs)

In the overall machine learning theory, the specific area of ANNs is generally divided into the so-called supervised and unsupervised learning methods depending on the labeling of the data. While supervised techniques require labeled input data, the goal of unsupervised procedures is to find significant patterns from the given examples. A typical ANN structure with input, hidden and output layers is illustrated in Figure 7.6 (Novatchkov and Baca, 2013a).

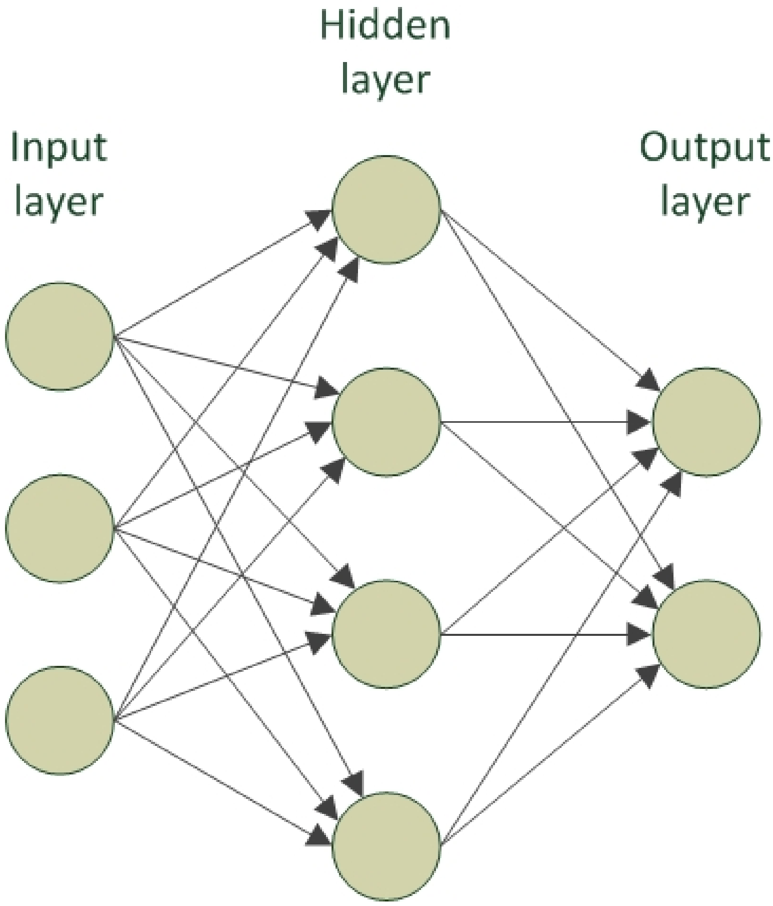


Figure 7.6: The typical design of an ANN with input, hidden and output layers, respectively consisting of three, four and two neurons.

For the present phase of study, the use of supervised learning methods, mapping input objects to desired output values, appeared to be a suitable modeling technique, considering the inclusion of the measured time series and the experts' evaluations of the executions. These assessments in respect to predefined indicators and specifications were carried out on the basis of video recordings with the help of professional coaches. In particular, the chosen evaluation process was based on the available literature discussed earlier and common recommendations stating that factors like time, velocity, constancy and completeness are significant determinants for the execution and the quality of the movement.

The appraisements were furthermore used for training and classification purposes by labeling the extracted feature information in respect to the evaluated exercises. Consequently, with regard to the weight training approach, the application of supervised procedures aimed at the classification of the executions into rather good and bad categories in terms of the mentioned factors. In this way, particularly inexperienced individuals could benefit from the realization of automatic algorithms by optimizing their technique and hence their training.

In the present research, the modeling of the measured signals included the design and realization of conventional ANNs. More precisely, various multilayer pattern recognition networks (special type of feedforward networks) were set up for learning and classification purposes. The first step included the assignment of the extracted information to chosen labels or classes, which were thereupon applied together as training sets for the development of data models. Thereby, the extracted features were combined into input vectors characterizing each repetition and thus defining the shape of the training data and number of dimensions. The output, on the other hand, consisted of the expert assessments, also representing the number of neurons and the respective layer size. Traditionally, the mapping of the data was accomplished by the insertion of hidden layers. The used training function was based on the Levenberg-Marquardt algorithm, which is among the fastest techniques for feedforward networks due to its high efficiency in minimizing a function by applying curve-fitting methods.

In order to enhance and evaluate the learning process, the computed feature vectors were divided into three subsets. This fragmentation was particularly needed for identifying a model fitting the seen set, representing the actual training process. Afterwards the model was pruned based on different techniques such as the estimation of prediction error (also known as validation) and finally evaluated by unseen data (often referred to as testing stage). The division ratio was fixed to 70:15:15.

This split-up was furthermore important for improving generalization, whereas the performances of the created models were measured on the basis of the error rate (where error rate is defined as the number of incorrectly classified instances). For these purposes, the so-called early stopping method was applied, aborting the learning process at the point of minimal validation set error, where the networks usually generalize the best. In this way, the performance was verified and controlled after each iteration and an overfitting or overtraining could be avoided. A practical example including the classification and performance outcome of the designed ANN is presented in the following section.

7.3.4 Results

7.3.4.1 Data Segmentation and Feature Extraction

The implemented algorithm was able to segment all performed sets (more than 60), detecting all executed repetitions (more than 750). The outcome of the segmentation procedure on the example of continuous executions is demonstrated in Figure 7.7 (Novatchkov and Baca, 2013a).

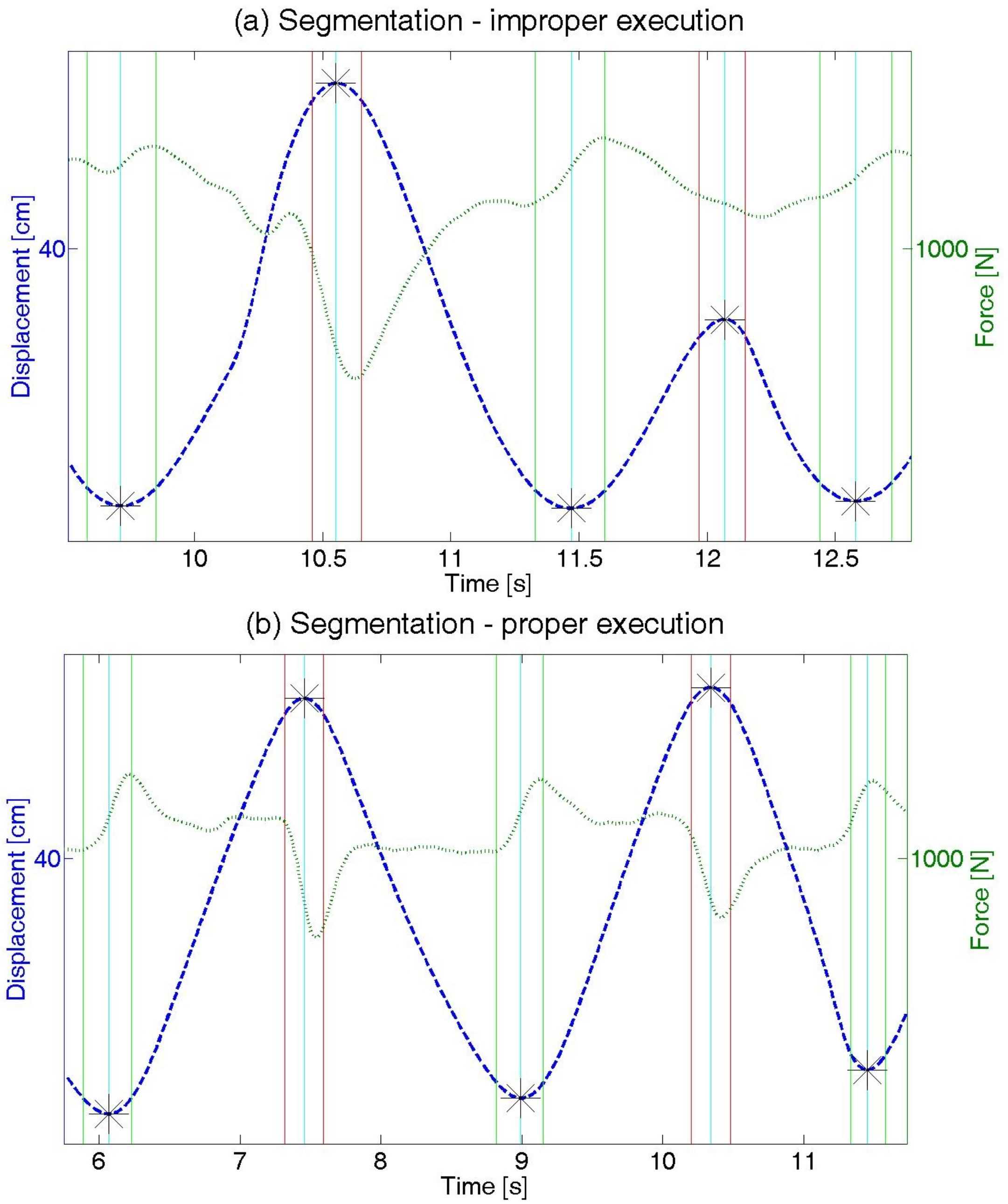


Figure 7.7: Illustration of the segmentation process for an improper (a) and proper (b) execution applied on the same data as in Figure 7.4. The displacement data was segmented into single repetitions based on peak detection techniques (marked by asterisk). The red and green lines indicate the starting and ending points in time of the holding phases after the concentric and eccentric actions.

As shown, the determined peaks (visualized by asterisk markers) were used to detect two subsequent repetitions including the durations of the reversals and the concentric and eccentric actions. In addition, due to further data transformation needs and simplification purposes, the data was not only divided into single repetitions but internally also into extension and flexion phases as well as holding times in between both movements. This division was accomplished by taking into consideration the measured time series and particularly the changes of the displacement values. Moreover, when looking at the force characteristics, similar patterns can be recognized, based on which the application of supervised machine learning techniques appears to be a suitable classification method.

Figure 7.8 shows another representation of the segmentation process, focusing on the measured and filtered force data (Novatchkov and Baca, 2012a). It furthermore depicts the feature extraction procedure on the example of plotted regression lines, indicating the inclination and declination of the eccentric and concentric actions. In addition, various other specifications including time, force, velocity, consistency, range and completeness factors were defined for feature extraction and selection purposes (see also Table 7.3).

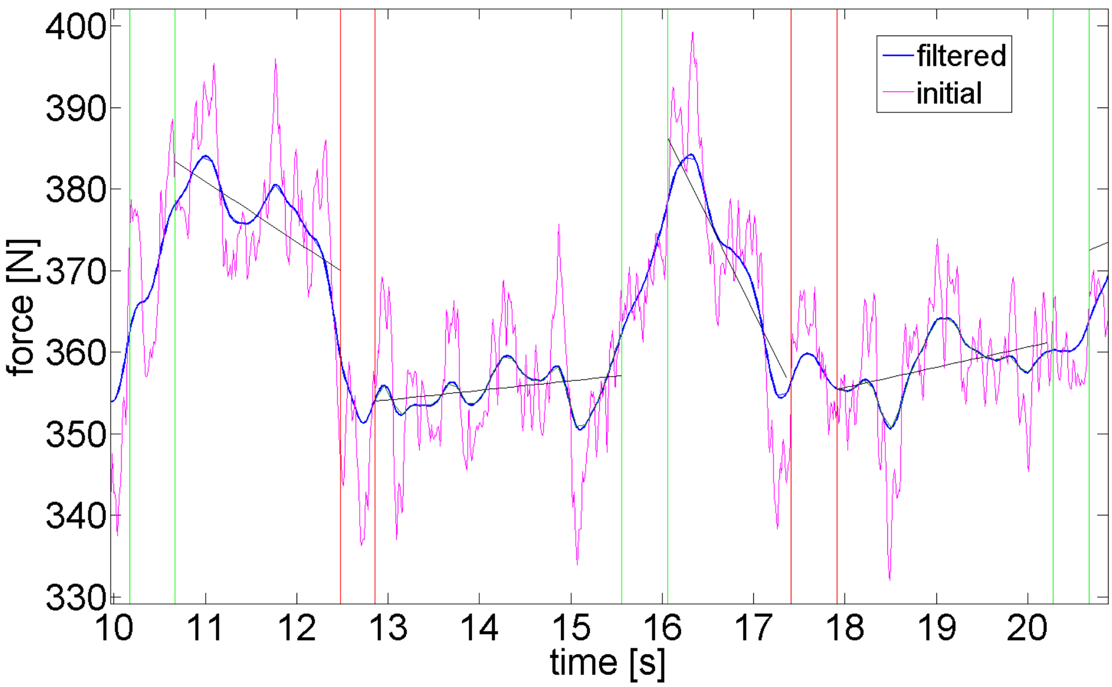


Figure 7.8: Segmentation of the force data into two repetitions and exemplary feature visualization (regression line).

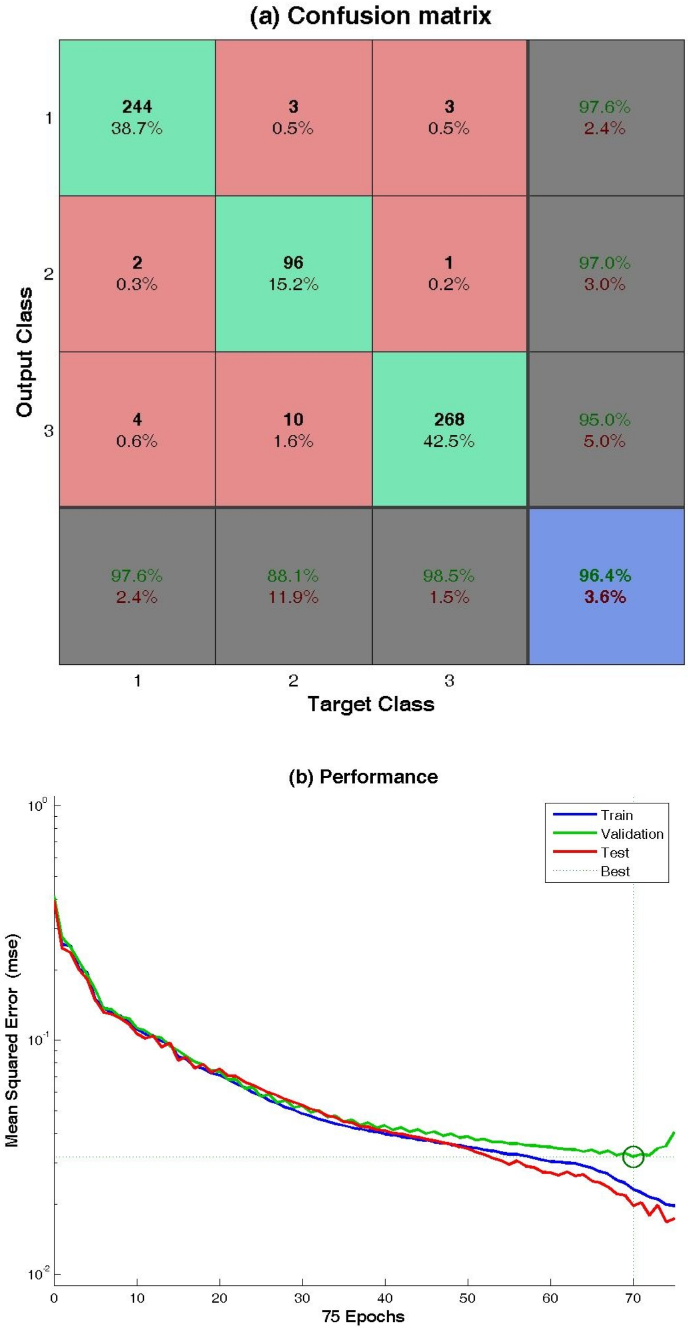


Figure 7.9: Classification results illustrating the outcome of the confusion matrix (a) and performance curves (b) for the trained ANN in respect to characteristics regarding the overall stability of the executions.

7.3.4.2 Modeling

Figure 7.9 shows the classification results of the applied pattern recognition network in respect to the overall execution based on the specified constancy, time and completeness criteria, considering duration, force and velocity dependent features (Novatchkov and Baca, 2012a). The layer sizes of the networks were fixed as follows: seven (input), ten (hidden) and three (output). The applied network is shown in Figure 7.10. The selected labels are demonstrated in Table 7.4.

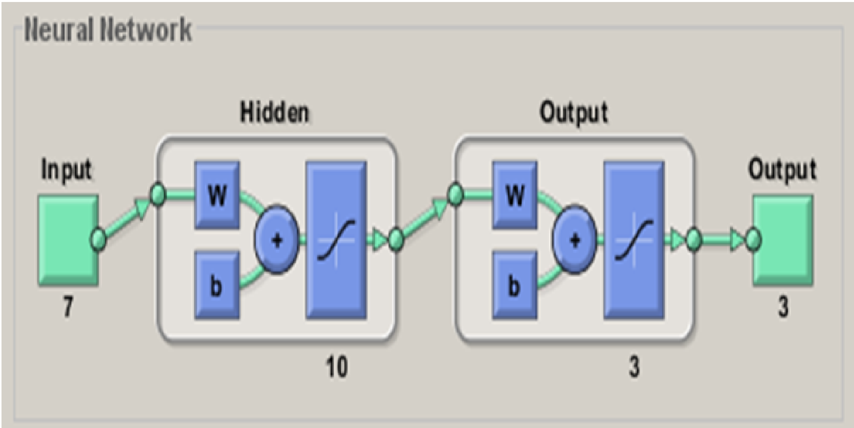


Figure 7.10: Applied ANN.

Label/class	Definition
1	Stable execution
2	Instable eccentric stage
3	Instable concentric stage

Table 7.4: Definition of three labels for classification purposes regarding the overall stability of the executions.

Sub-chart 7.9a reflects the classification outcome in form of a confusion matrix, indicating the correlations of the labels. Apparently, the agreement is quite high for all three labels, demonstrating the high potential of the applied pattern recognition method. Sub-diagram 7.9b, on the other hand, highlights the performance development of the ANN throughout the training stage, illustrating also the application of the used stopping methodology. Thereby, the best performance was reached at epoch 70 (with a maximum failing rate fixed to 5). As the displayed training, validation and test curves represent quite similar characteristics with likewise and constant slopes, the performance outcome appears to be an adequate foundation for the developed techniques and further applications.

7.3.5 Discussion

Nowadays, due to the progress of ICTs including simplified and convenient implementations of WSNs for data acquisition and mobile devices for processing purposes, the integration of intelligent methods becomes increasingly important for the automatic analysis of measured sports parameters and the realization of prompt intervention routines.

AI concepts appear to be particularly suitable for the design of effective evaluation and feedback frameworks in sport. After the initial boom in the 1970s and 1980s, the use of AI techniques is meanwhile limited to rather specific application fields including also sport, as their application gets essential for the assessment of sports-related data. Recent examples include the development of mobile monitoring systems integrating classification algorithms for the real-time analysis and feedback generation in sports like, for instance, running (Kugler et al., 2011) or golf (Eskofier et al., 2011). Similarly, the presented research investigated the application of AI methods in combination with novel measuring instruments in the field of weight training.

Today, due to the advances in measuring technologies, effective hardware implementations exist that enable the integration of modern sensors into the fitness equipment itself. For example, it is possible to attach load cells or rotary encoders directly to weight training machines, allowing the measurement of relevant force and displacement characteristics. The gathered data can thereby be used for the implementation of sophisticated routines by means of machine learning techniques, automatically analyzing the exercises. Particularly supervised ANNs appear to be promising classifiers, as they offer effective methods for mapping input data into already labeled output information.

In light of the current boom of fitness studios and the broader usage of weight training machines, also the accuracy and correctness of the performances and executions on the offered equipment has become crucial (particularly for inexperienced or elderly individuals). Practically, the quality of the movement plays a significant role, as it contributes to the efficiency and value of the workout. Therefore, a particular focus of the illustrated AI approach was to provide automatic analysis on the technique as well as appropriate interventions and suggestions. The development and integration of such models and routines might thus enable new facilities for the support of sportsmen and injury prevention.

The target user group includes, in the first instance, inexperienced and elderly individuals, who can benefit from the modern sensor equipment and measurements in combination with the realization of the developed assessment routines. Their systematic integration in intelligent weight training machines would allow an automatic analysis of the quality of the execution on the basis of the predefined criteria, thereby providing appropriate feedback during or just after the performed exercise.

The most suitable field of application of such developments including the intended design of automated resistance training equipment can be seen in the increasing amount of available regular but also exclusive fitness clubs. In these facilities the personal and individual care, assistance and mentoring of the members play major factors. Sportsmen can improve their technique on the basis of the automated evaluation routines and the return of instant notifications regarding occurred mistakes by receiving appropriate corrective advices and improvement suggestions. Based on this feedback information, also the risk of injuries can be reduced, which is another significant objective of the approach.

At the same time, the application of the developed procedure would bring valuable advantages to professional sportsmen. In this context, the aim of monitoring velocity characteristics and action forces of exercising movements might be to determine the contraction force specificity. Well-trained athletes need to optimize their training to their sport requirements and to improve their functional ability more specifically. In order to achieve the desired adaptations, it is therefore advisable to choose particular exercises that meet the force-velocity needs of the sport. Hence, the presented approach would allow professionals but also their coaches to analyze in detail the athletes' executions and improve their performances by looking in real-time at the measured force and displacement time series or also calculated acceleration, velocity and power properties. Consequently, the possibility of immediate control and comparison of the results could lead to a considerable training enhancement for elite sportsmen.

7.3.5.1 Limitations

The restrictions of the present study are that, for the moment, the implemented data analysis and feedback methods are narrowed down to the mentioned criteria such as time, constancy, velocity and completeness. In particular, it is not possible to observe other pre-conditions like, for example, the correct sitting position or placement of the feet, which would be important parameters for the application of the implemented models in conjunction with the sensor-equipped leg press machine.

Furthermore, the developed routines are not able to directly monitor the posture of the body throughout the movement including, for instance, the knee or upper body and particularly the lower back motions. Such factors, however, might be, for example, detected and assessed on the basis of the integration of other measuring devices such as goniometers, torsiometers or pressure sensors.

7.3.5.2 Outlook

On the one hand, the future work of the presented research will concentrate on the adaptation of the developed models for different sensor-equipped machines including lat biceps curl, lat pull-down and shoulder press machine. At the same time, another particular aim will focus on the development of further models and solutions for the computer-based assessment of weight training data. One promising approach would, for instance, involve the implementation of fuzzy logic concepts, which are also commonly applied in the area of AI (for details see the following section). As part of the probabilistic logic, such methods might be suitable for the realization of other effective possibilities for the automatic evaluation of weight training exercises.

On the other hand, it is intended to include the implemented procedures into the presented mobile coaching system by integrating the mentioned ANT technology as well as computer devices into the measurement process. Thus, a bidirectional data transfer between the weight training machines and the implemented evaluation routines on the server could be accomplished. This system integration would contribute significantly to the idea of instant data acquisition, automated analysis and prompt feedback routines.

7.3.6 Conclusion

Computer-based feedback frameworks integrating sophisticated assessment techniques become increasingly essential for the instant analysis and appropriate intervention during workouts. The present piece of research suggests a novel evaluation approach involving AI methods for the machine-aided appraisement of weight training exercises. The implementation included the use of modern sensor technologies attached to the training equipment, allowing an effective acquisition and collection of sport-specific data. The gathered parameter values were applied for the automatic analysis of the performed exercises. The modeling of the data was based on supervised learning procedures such as ANNs. The preprocessed sensor input was used for the classification and autonomous appraisal of the executions. The developed techniques showed good results and performance outcomes, raising promise for their practical application in integrated feedback systems. Further research, optimizations and hardware realizations would then allow the intended implementation of a supportive coaching system that provides professional and hobby athletes as well as coaches with prompt assessment and feedback tools in weight training.

7.4 Fuzzy Logic in Sport and Weight Training

7.4.1 Introduction

In general, the fuzzy logic concept involves the idea of a vague rather than exact probabilistic reasoning with different degrees of truth. Basic ideas on many-valued logic systems were already investigated by Łukasiewicz (1920), who proposed the use of three-valued logic by adding the indeterminate condition in addition to false and true. The first mentioning of the term fuzzy logic, however, dates back to the year 1965, when Zadeh published a couple of scientific research papers in which he introduced the so-called fuzzy sets as an effective tool for the definition of more realistic classes of objects taken from real life (e.g. animals) (Zadeh, 1965a,b). In particular, the author suggested the use of membership functions and set of rules in order to be also able to represent ambiguous states (e.g. bacteria in the class of animals) by mapping them to intermediate (rather than binary) values between 0 and 1. In this way, this theorem can be seen as an enhancement of the boolean algebra (Boole, 1854), consisting of more than just two truth values.

Based on these principles, the major goal of the present research was to apply the idea of fuzzy logic and vague states for the evaluation and classification of exercises performed on sensor-equipped weight machines in respect to continuous strength training recommendations and criteria.

7.4.2 Related Work

Fuzzy logic methods have been increasingly introduced for a variety of purposes and application fields including modeling, data mining, decision making, expert systems, prediction, forecasting, computer vision, image processing, pattern recognition and robotics. In the area of sport, the use of fuzzy logic techniques is still a rather new but, at the same time, upcoming field of activity.

However, as the following literature review shows, procedures based on the idea of uncertainty have not yet been investigated in the field of strength training.

One of the early fuzzy research interests in sports involves the implementation of intelligent decision systems for choosing a proper strategy in the game of pool (Chua et al., 2002, 2004, 2005). The realization by Riley (2005), on the other hand, applies continuous inference mechanisms for the purpose of scoring a goal in soccer simulation environments.

Other application areas include the domain of video processing. A generic fuzzy scheme for the semantic characterization and classification of sport videos such as sequences from games like football, cricket and volleyball is presented in (Jadon et al., 2000). The study by Refaey et al. (2009) illustrates the successful use of fuzzy logic methods to identify concurrent transitions and detect shots in football videos.

Specific investigations propose the development of expert systems based on vague conditions for the analysis of fast bowling in cricket (Bartlett, 2003, 2006). Similarly, Curtis' scientific papers suggest a training system integrating Zadeh's theory for the classification of batting strokes (Curtis, 2009, 2010). The study by Singh et al. (2011) focuses on the evaluation of performances of cricket players based on a number of approximate input parameters. The implementation calculates the ranking of the athletes for different scenarios.

Modeling based on fuzzy techniques is another common procedure, which is, for instance, used to measure daily activity (Olaru and Smith, 2002, 2003). A muscle model and control simulation for approximating dynamical behavior of motor units is presented by Heller and Witte (2006). In other areas like, for example, swimming, the design of fuzzy-based machine learning algorithms aims at the modeling of sport training (Mezyk and Unold, 2011).

As yet another example, kinematic data is utilized in combination with many-valued algorithms to recognize movements such as different giant swings (Hansen, 2006). Other approaches concentrate on the identification of sport talents via an implemented web platform integrating ambiguous expert knowledge and suggesting the most suitable discipline for a certain child (Papić et al., 2009).

7.4.3 Proposed Work

7.4.3.1 Background

The present idea and work originated from the already described studies (Novatchkov and Baca, 2012a, 2013a) done in the area of strength training (see also Section 7.3). Figure 7.11 demonstrates another comparative example of the gathered force and weight displacement data of two consecutive repetitions performed by the same athlete on the sensor-equipped leg press machine. As shown, the execution in Sub-chart 7.11a is clearly identified by an instable technique with fluctuating time, force and displacement characteristics. Sub-diagram 7.11b, on the other hand, illustrates a stable performance with smooth and constant sensor output. Such distinctive features were thereupon applied for the development of AI and particularly ANN modeling methods, allowing an automated evaluation of the gathered data.

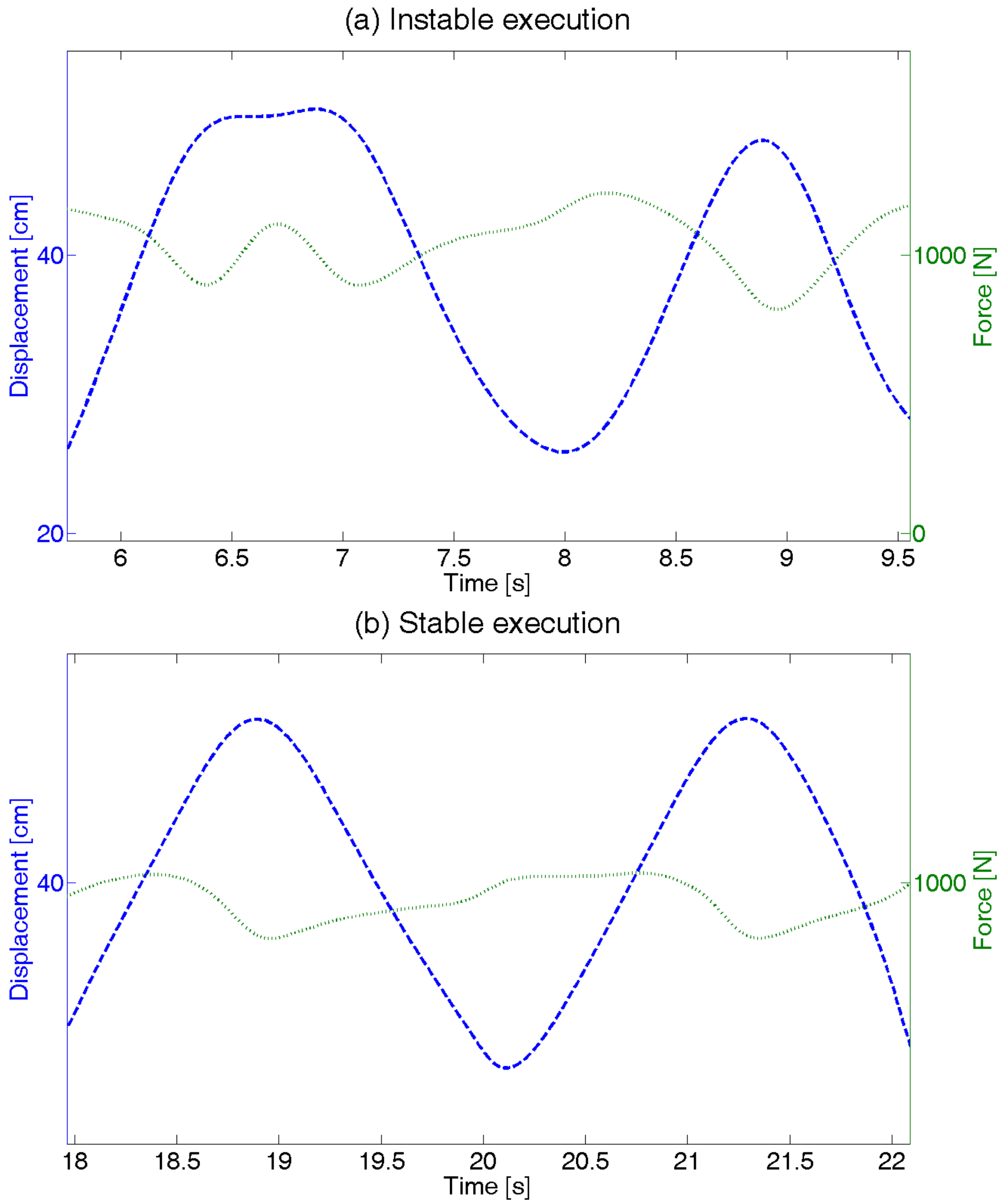


Figure 7.11: Comparison of instable (a) and stable (b) executions of two consecutive repetitions by the same athlete.

Based on the obtained results with high classification and performance outcomes as well as drawn conclusions, it was implied to design fuzzy methodologies as another suitable (yet more elementary but still effective) alternative for the assessment of performed executions. The reason therefore lay also in the appropriate circumstances and applicability of vague conditions for the analysis of the used technique by the involvement of professional coaches. Similarly to the previous research, also in this study the evaluation criteria included common strength training recommendations such as time, constancy and completeness (Westcott, 2009; Evans, 1999; Graham, 2008), which can be rated on the basis of deduced parameters like duration, displacement or force and velocity (depicted in the following). Such determinants can be automatically estimated by the implementation of appropriate segmentation procedures and calculations, dividing the data into single repetitions as well as extension, flexion and holding phases (Novatchkov and Baca, 2013a).

7.4.3.2 Design Methodology

The present research suggests the design of a Fuzzy Inference System (FIS) mapping given input data regarding the execution of the flexion and extension phases into an output value, determining the overall rating of the technique.

All the development work was carried out in MATLAB version R2010b for Windows using the so-called Fuzzy Logic Toolbox™, which provides routines for the realization, visualization and simulation of FISs. The interference type was based on the more general Mamdani method due to its advantages of intuitive formation, widespread acceptance and suitability to human input (Sivanandam et al., 2007).

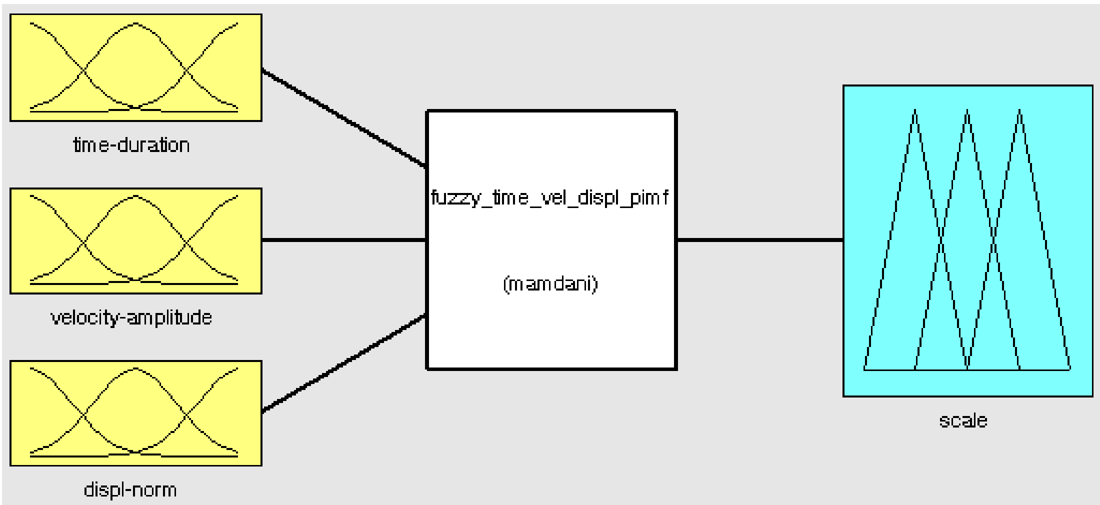


Figure 7.12: Feasible FIS in strength training with three input and one output parameters.

Figure 7.12 illustrates a feasible example regarding the realization of a FIS in strength training. As shown, three different input parameters regarding the eccentric and concentric actions (in respect to the specified criteria) were defined:

1. Duration (time)
2. Amplitude between the minimal and maximal velocity values (constancy)
3. Normalized displacement (completeness)

Further details on these determinants, their realization in the FIS and their specification on the basis of the definition of membership functions are described in the following section.

7.4.3.3 Input and Output Parameters and their Realization in terms of Fuzzy Sets and Membership Functions

The time duration is a crucial determinant for the efficiency of the exercise. In general, for beginners and elderly as well as for health and injury prevention purposes, it is suggested to perform each repetition in a slow manner with a moderate speed and an approximate duration of 6 seconds per repetition (Westcott, 2009) or 2-3 seconds for the flexion and extension (Evans, 1999). These recommendations were realized in form of five fuzzy sets (very short, short, optimal, long and very long), mapping the time duration to the according degree of membership (from 0 to 1). Figure 7.13 illustrates the representation of this input variable.

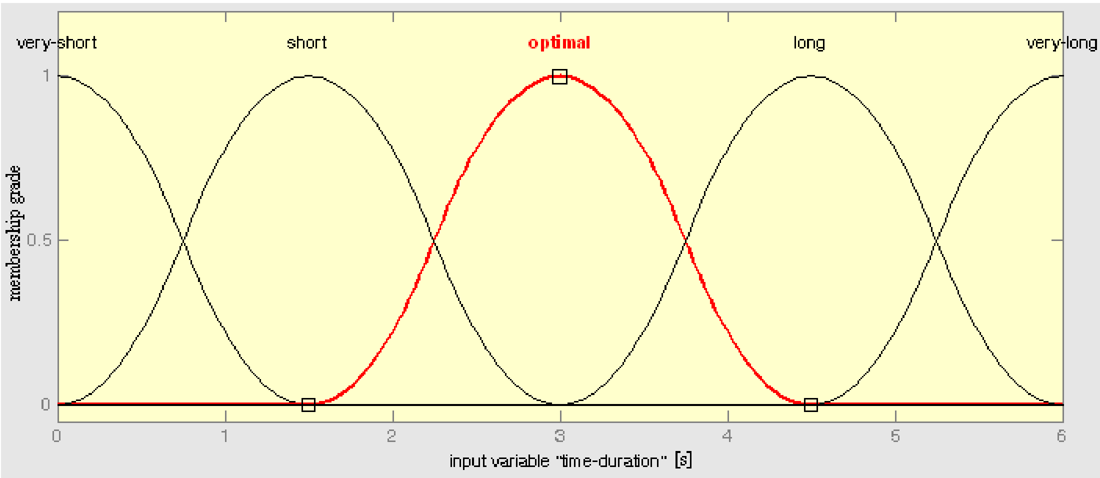


Figure 7.13: Exemplary fuzzy sets for the input variable mapping the time duration to a value between 0 (improper) and 1 (proper).

As already mentioned, besides the time factor, constancy plays a second important role regarding the quality of the execution. One realization alternative for the stability in terms of a fuzzy set implementation might, for instance, focus on its representation on the basis of the performed velocity, which can be deduced from the measured sensor signals. A particular approach could involve the determination of the velocity amplitude representing the difference between the minimal and maximal velocity values of the extension and flexion phases. This solution was realized by the definition of three fuzzy sets (low, high and very high velocity amplitude), where a lower amplitude (in m/s) means a more constant execution.

The third significant criterion refers to the completeness of the exercises. Based on the gathered weight displacement values, one direct representation might integrate these signals into a number of fuzzy sets (such as very short, short, optimal, long and very long). In this case, the displacement variable has to be normalized accordingly – for example by the height and leg length of the individuals. A second opportunity would be to take into consideration the appropriate weight configuration of the leg press machine. Another practical mapping method is presented in the discussion section. Figure 7.14 illustrates the implemented relation between the variables representing the constancy and completeness of the execution and the according scale values between 0 (improper) and 1 (proper). The purpose of the output variable, on the other hand, is to map the three input parameters into an overall rating on the basis of the constructed fuzzy rules. Figure 7.15 demonstrates an exemplary output configuration integrating five different categorizations (improper, poor, average, good and proper).

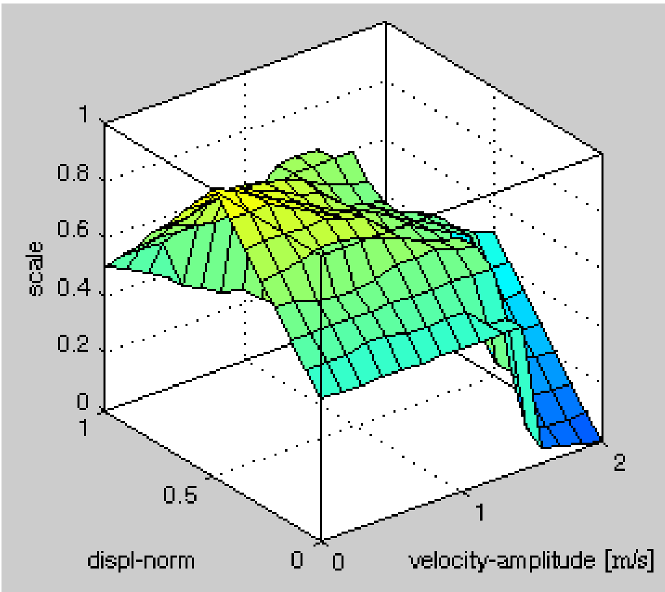


Figure 7.14: Relation between velocity amplitude, normalized displacement and respective scale values.

In general, the membership functions for all input and output parameters were defined by spline-based Π-shaped curves (named after their appearance). This type was chosen due to the narrow peak with a relatively high degree of membership within an acceptable limit and a gradual fall afterwards, which appeared to represent the data the best. In addition, such functions have been recently successfully applied to solve challenging classification tasks based on the advantages of easier adaptation and hence flexibility as well as generalization in respect to the requirements of the problem (Ghosh et al., 2008; Kulkarni and Shinde, 2011).

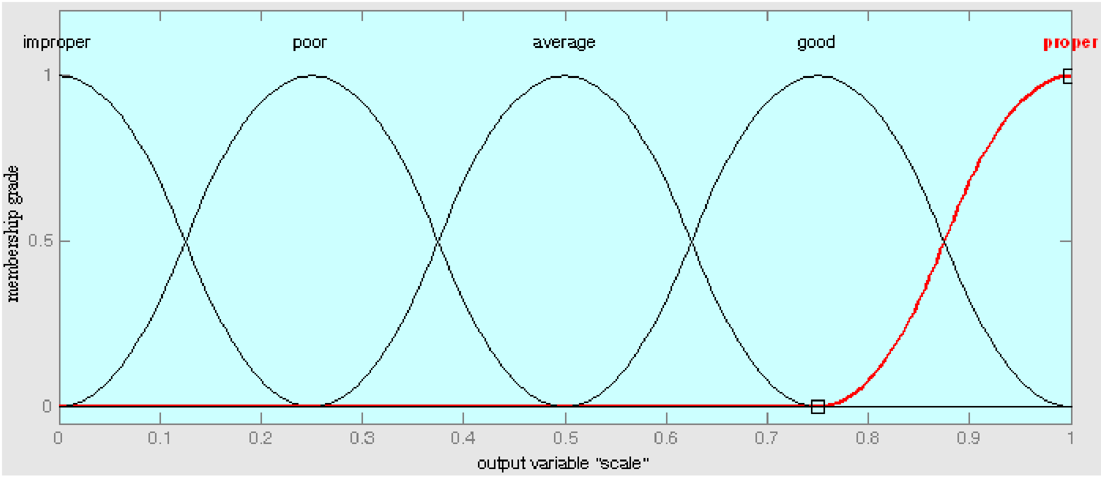


Figure 7.15: Exemplary fuzzy sets for output variable representing the overall rating (scale).

7.4.3.4 Fuzzy Rules

Based on the description of the input and output parameters and the respective relations between them, 70 consequential rules were established for mapping purposes. In the following, some of the most illustrative rules (including the specified weights), which are also taken for the subsequent simulation scenario, are depicted:

Rule 12: If (time-duration is optimal) and (velocity-amplitude is low) and (displ-norm is complete) then (scale is proper) (1)

Rule 14: If (time-duration is optimal) and (velocity-amplitude is low) and (displ-norm is short) then (scale is good) (1)

Rule 17: If (time-duration is optimal) and (velocity-amplitude is high) and (displ-norm is complete) then (scale is good) (1)

Rule 19: If (time-duration is optimal) and (velocity-amplitude is high) and (displ-norm is short) then (scale is good) (0.75)

Rule 57: If (time-duration is short) and (velocity-amplitude is low) and (displ-norm is complete) then (scale is good) (1)

Rule 59: If (time-duration is short) and (velocity-amplitude is low) and (displ-norm is short) then (scale is good) (0.75)

Rule 62: If (time-duration is short) and (velocity-amplitude is high) and (displ-norm is complete) then (scale is good) (0.75)

Rule 64: If (time-duration is short) and (velocity-amplitude is high) and (displ-norm is short) then (scale is average) (1)

7.4.3.5 Practical Scenario

Figure 7.16 illustrates a feasible scenario for a rather good execution resulting in an overall rating of 0.9. It furthermore shows the chosen parameter for each input variable as well as the most significant rules (depicted in the previous section), which affect the actual outcome. The gathered surface (lower right corner) demonstrates the aggregation process combining the outputs of each rule into a single fuzzy set.

The final score was calculated on the basis of the defuzzification method using the "mean of maximum" technique, which is commonly applied in combination with the Mamdani inference type. The benefit of this method is that it "selects the typical value of the terms that is most valid, rather than balancing out the different inference results" (Sivanandam et al., 2007). Consequently, the determined scale output in the illustrated scenario returns an exact and plausible value, which represents the resulting area the best, providing an overall rating of the performance and giving hope for the integration of such fuzzy logic implementations into immediate feedback routines and control systems in strength training.

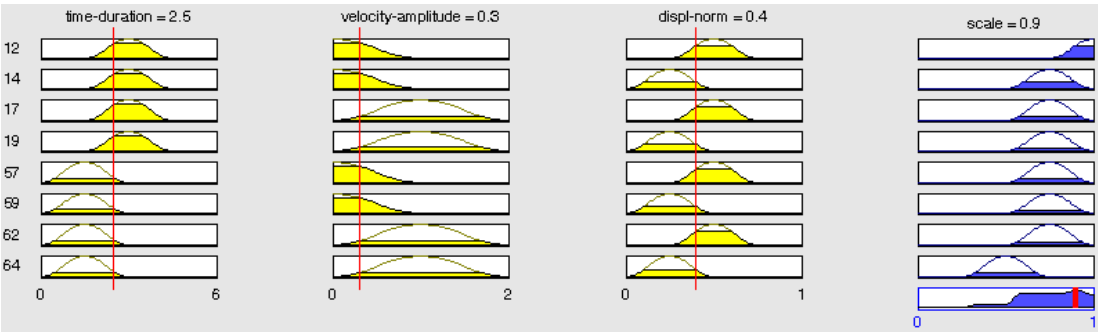


Figure 7.16: Feasible scenario for a rather good execution with an overall rating of 0.9.

7.4.4 Discussion

Fuzzy logic provides effective techniques for the representation of uncertainty and is therefore often used for the handling of vague conditions in a variety of application areas. In the field of sport, Zadeh's proposal from 1965 is still in a nascent stage, being applied in robotics, video processing, modeling and simulation but also for the analysis and classification of sport-specific executions such as strokes in cricket.

The present research suggests the design of fuzzy logic techniques for the evaluation of exercises performed on weight machines equipped with way and force sensors. The realization takes into account different essential assessment criteria and maps them to a cumulative scale, on the one hand. In addition to the accumulated rating, however, it is also possible to determine specific abnormalities such as occurred mistakes by considering the defined input variables including the specified fuzzy sets and respective membership functions. In this way, feedback on the overall execution as well on particular factors and characteristics can be given, contributing to the diversity of the approach. In this regard, other major advantages of the presented fuzzy logic idea are also the flexibility and simple adaptation facilities to various strength recommendations like, for example, specific training programs for muscle hypertrophy.

Another benefit of the conceptual design is that there is no necessity of large training data in comparison to other applied classification methods such as ANN modeling. In general, this kind of machine learning techniques require large volume of input information covering sufficient variations of possible situations. Consequently, more computing time is needed for building the models, while, at the same time, it has to be ensured that overfitting is avoided. Such long-lasting learning and data mining procedures can be prevented in the case of fuzzy logic.

Finally, and most importantly, the application of fuzzy logic concepts for the evaluation of exercises allows not only a reasonable but also a direct and efficient integration of expertise knowledge and common strength training recommendations. Moreover, as the proposed work is natural and closer to human thinking, it is consequently easier to understand and use, promising hope for a convenient integration facility in machine-based routines, which can automatically assess the quality of the performed technique.

7.4.4.1 Further Work and Outlook

The future work will concentrate, on the one hand, on the optimization of the designed methods and the development of further intelligent techniques in strength training. For example, another opportunity for the definition of the completeness criteria might involve the consideration of additional determinants like the Range of Motion (ROM). Figure 7.17 illustrates a realization alternative for this kind of input variable in form of fuzzy sets, where a ROM (usually measured in °) of 90 ° is considered to be optimal for a proper execution (Housh et al., 2008). Such solutions, however, require the integration of further sensors such as goniometers in order to be able to obtain the needed distance information.

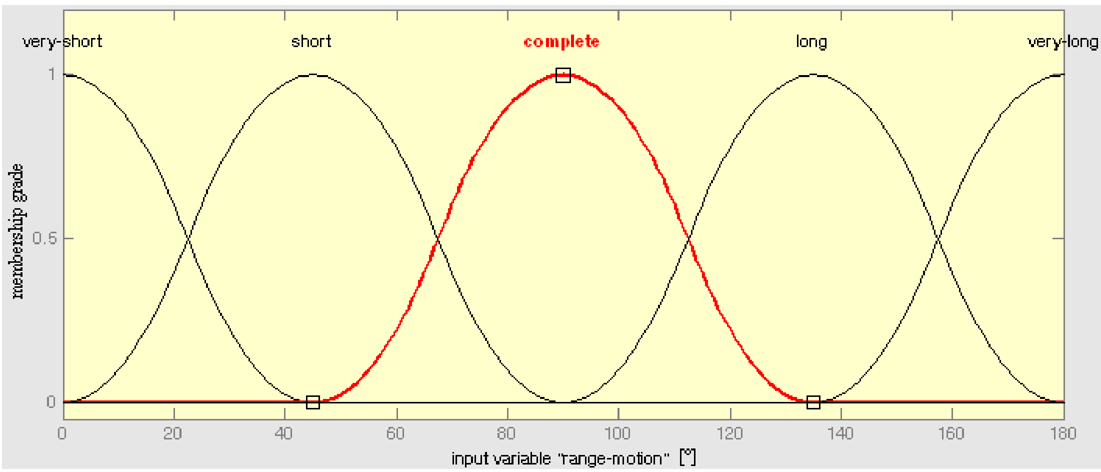


Figure 7.17: Exemplary fuzzy sets for the input variable representing the ROM.

The ultimate goal of the present study, on the other hand, is to integrate the proposed techniques into the developed mobile coaching framework, which would allow an immediate analysis and feedback on the execution.

7.4.5 Conclusion

The current research reviews the use of fuzzy logic techniques in the field of sport and illustrates their general applicability and promising implementation opportunities in the sport-specific context. In particular, the study proposes the development of fuzzy logic routines for analysis and evaluation purposes, demonstrated by an illustrative case study in strength training. The future scope of the approach will focus on the embedding of the presented methods into the server-based coaching framework for the individual and automated analysis of the gathered sensor data. This system integration would enable new facilities for the support of sportsmen and injury prevention, thereby also providing coaches with the opportunity to analyze and optimize the athletes' performances.

CHAPTER **8**

Other Application Possibilities

Based on the wide range of data acquisition possibilities, also the variety of applications involving ICT for the (server-based) mobile human support is steadily increasing. This includes not only other sports-related scenarios including, for example, rowing or school sport but also further fields like medicine, where the instant collection and analysis of relevant information is of high importance for patients such as cardiac persons.

8.1 Rowing

8.1.1 Introduction

Besides running and cycling, rowing is another, still less investigated endurance sport where the technique – similarly to weight training – plays a major role for the efficiency of the performance. In particular, a good coordination and cardiovascular fitness, perfect timing, skilled sequencing and minimal loss of power are important conditions for the actual execution in the boat (Hill, 2002). Significant biomechanical factors include, for example, forces such as those applied to the oars (Baudouin and Hawkins, 2004), allowing an effective evaluation of the quality of the motion. Consequently, these parameters can be used for the instant analysis and immediate feedback generation in rowing. The presented mobile coaching concept provides all necessary prerequisites for the implementation of such a real-time evaluation framework.

8.1.2 Related Work

Only little real-time feedback approaches have been presented in the field of rowing so far. Since, in general, on-water rowing is difficult to analyze, most of the research focuses on the implementation of land-based systems involving rowing simulators. Page and Hawkins (2003) present an ergometer-based real-time framework, providing athletes and coaches with instant kinematic and kinetic training data. The realization by Baca and Kornfeind (2006) allows the parallel analysis of the measured ground reaction and pulling forces during the execution by integrating a screen for the immediate display of the data curves. Other studies concentrate on the improvement of the stroke technique of rowers by the use of accelerometry-based feedback (Anderson et al., 2005).

Regarding on-water rowing, on the other hand, Collins et al. (2004) propose the use of a Personal Digital Assistant (PDA) for collecting the gathered sensor information and forwarding it to the laptop of the coach for evaluation purposes. A prototypical implementation of the approach providing quantitative analysis of the rowers' technique is presented in (Collins et al., 2009). The augmented feedback generation is based on the integration of low cost electronic sensors as well as wireless communication technologies.

8.1.3 Conceivable Scenario

8.1.3.1 Real-Time Training Supervision in Rowing

Figure 8.1 represents a conceivable usage scenario regarding the application of the mobile coaching system in rowing (Preuschl et al., 2010). As shown, the idea is to send directly measured parameters including not only heart rate and velocity but also other important characteristics such as the pulling force, oar angle or stroke rate in real-time to the application server. In this way, coaches can continuously access the performance data and assist the rowers by analyzing the gathered information (e.g. via a mobile device) and optimize the training by giving immediate feedback and advices to the athletes.

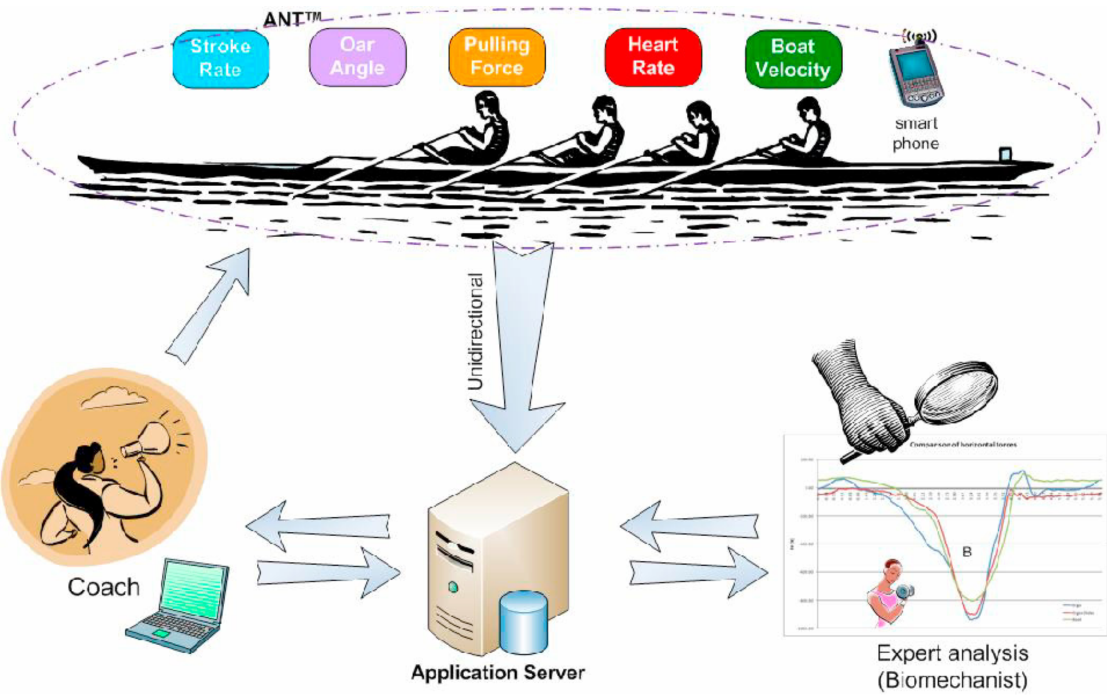


Figure 8.1: Conceivable scenario in rowing.

8.1.3.2 Visualization Alternative

The chart in Figure 8.2 represents a specific E-Client prototype for rowing coaches and should serve as an example for a visualization alternative on a PDA for the discipline rowing, illustrating measured force data during a performed stroke (Novatchkov, 2008). Each of the visualized channels picture a specific force factor (such as the pulling force on the handle or the force applied to the foot stretcher). The time series specify the applied force values in Newton (N) throughout the time, which obviously change in accordance with crucial factors such as the momentum and the applied power.

Such diagrams can be, for instance, used by experts for analyzing purposes and extended with sophisticated segmentation routines, which can divide the time series automatically in the executed cycles and strokes (for details see Sections 7.3.3.5 and 7.3.4.1). Furthermore, this scenario – similarly applicable in other sports like weight training – demonstrates one example for the application of visual analytics methods by combining the strengths of humans and computers.

8.2 School Sport

8.2.1 Introduction

Physical exercise at young age is a good disease prevention measure (e.g. against obesity, diabetes etc.) and has beneficial effects on the individual's adult life (Martinez-Gomez et al., 2010). Today's social surroundings, however, do not create intrinsic motivation for doing sports in a child or a teenager. This coincides with the increase of civilization diseases connected with lack of physical exercise. Considering this, how can pupils be motivated to exert themselves to the physical strain experienced during exercising? Since, at the same time, high-tech gadgets are getting very popular among the young (which is also a reason for their inactive lifestyle), one alternative could be to obtain and increase motivation by using ICT in physical exercise and sports (Preuschl et al., 2010).

8.2.2 Related Work

The physical activity of adults and particularly children is reported to be steadily decreasing throughout the last years (Dür and Griebler, 2006; Hesketh et al., 2006; Sigmundová et al., 2011). Weiss et al. (2012) cites the lack of motivation among kids in doing sports as being one of the most problematic factors. This trend is alarming, especially when considering that adolescents acquire athletic skills through physical experience, which later may help to lower the risk of degenerative diseases (Baschta, 2008).

The use of modern technologies, however, appears to be a promising solution for motivating people to do regular physical exercise. A number of commercial computer games have been implemented to increase physical activity with specially adapted consoles. The already mentioned Nintendo Wii (for details see Section 3.2.4.1) might be taken as a typical example offering a comprehensive sensor environment as well as graphical interfaces, providing gamers with the opportunity of combining fun and sport.

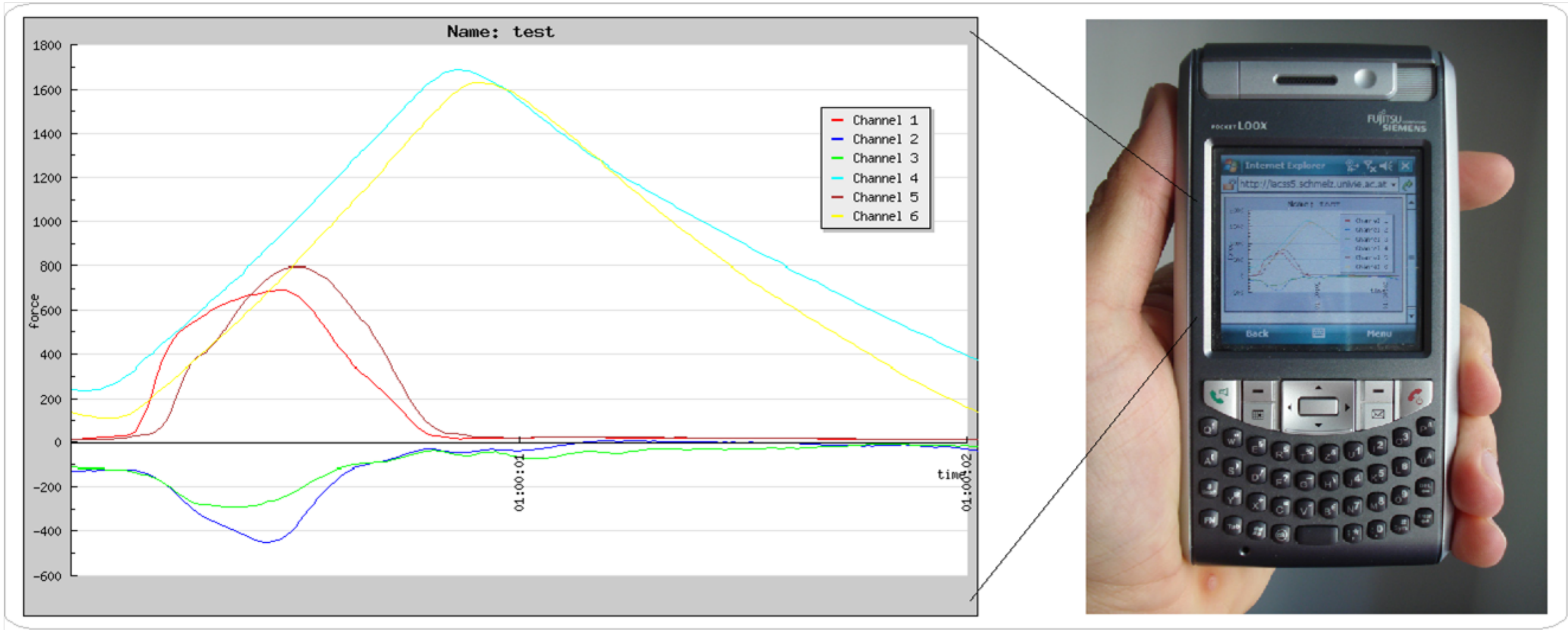


Figure 8.2: Forces in rowing – visualization alternative on a PDA (from Novatchkov, 2008).

Another approach focuses on the implementation of web-based training assistance applications (for instance Traineo, 2013). Users are provided with the possibility to select their favorite sports and to join virtual communities that match their athletic interests. Furthermore, they are able to document their training progress in blogs and contact experts regarding their concerns. The high numbers of members and their positive arguments seem to confirm that such web portals have positive effects on the physical activity level.

8.2.3 Conceivable Scenario

The already mentioned lack of motivation among pupils for sports implies the need of a system providing activity feedback and interactive communication (Preuschl et al., 2010). The mobile coaching implementation appears to be a suitable approach, offering beneficial effects on the stimulus of young people to be more active. Adapted from the server-based concept, the idea is to establish a comprehensive Mobile Motion Advisor (MMA) framework, providing interactive communication technology to teachers and students as well as helping to adapt and evaluate certain performance parameters in respect to the individual health levels.

A main benefit involves the possibility of continuous recording of the characteristic performance parameters of the whole class. In this way, teachers are able to supervise a higher number of pupils individually, while students get feedback on the quality of their motion, allowing them to interpret their body's reactions to physical strain. The permanent data storage allows the documentation of bodily changes throughout the time, identifying directly the effects of physical exercise. Other advantages might be connected to the promotion of health-conscious behavior and the improvement of the willingness to participate in physical activity. Finally, a sophisticated regulation of physiological stress can prevent pupils from demotivating experiences due to fatigue.

8.3 Medicine

8.3.1 Introduction

Recently, a number of research studies have shown the significant role and positive effects of sport exercises on patients with documented heart diseases (with or without acute coronary events such as myocardial infarction) or recent cardiac surgeries (Piepoli et al., 2010a,b; Smith et al., 2011; Zwisler et al., 2012). Thereby, the main goals are to decrease the cardiovascular risk factors and improve the well-being, morbidity and mortality of cardiac persons. The Cardiac Rehabilitation (CR) is commonly started almost immediately after the surgery with an inpatient phase (I) based on rather basic motions in order to improve the overall health. By definition, the initial center-based CR is a supervised group program conducted in a hospital, sport or fitness club (Bjarnason-Wehrens et al., 2010).

The intermediate phases (II and III) of the treatment, however, do not have to be carried out in an inpatient environment. In fact, many cardiacs continue the healing process with an outpatient CR, which is regularly monitored by health professionals such as physiologists. The so-called home-based CR is defined as a structured program with clear objectives for the participants, including monitoring, follow-ups, visits, letters, telephone calls from staff, or at least self-monitoring diaries (Dalal et al., 2010). This long-term process includes the permanent evaluation of crucial factors such as heart rate, blood pressure or body weight as well as diagnostic tests, assessing the heart's function during exercise. The final and usually most long-lasting phase (IV), however, is – also due to cost reasons – generally unsupervised and intended for cardiacs with a stable risk factor management. The main focus is commonly set on the maintenance of the health based on daily physical activity.

The literature gives evidence that home-based CR does not appear to be significantly inferior to center-based rehabilitation for low-risk cardiacs (Jolly et al., 2006; Dalal et al., 2010), keeping in mind the need of additional logistics, organizational and medical personnel engagement. Moreover, the health improvement and total health care costs of both rehabilitation programs appear to be similar (Taylor et al., 2007).

8.3.2 Health Care Fundamentals and Approaches

Throughout the last years, an increasing number of frameworks based on ICT have been designed for health support purposes (Husemann and Nidd, 2005; Nangalia et al., 2010; Varshney, 2007). The traditional Electronic Health (E-Health) concept involves the idea of using electronic and telecommunication technologies in the sector of health care. Derived from E-Health, the newly established Mobile Health (M-Health) field deals with "…the application of mobile computing, wireless communications and network technologies to deliver or enhance diverse health care services and functions in which the patient has a freedom to be mobile, perhaps within a limited area" (Pawar et al., 2012).

Similarly, telemonitoring focuses on the supervision of the health status of a patient from distant locations based on audio, video and other telecommunications and electronic information processing technologies (American Telemedicine, 2013). Thereby a differentiation is made between monitoring involving telephones for the contact between the patient and the health professionals ("telephone monitoring") and, on the other hand, the integration of external monitors for the collection and transfer of physiological data.

Commonly measured data in the field of telemonitoring includes (Meystre, 2005):

- Cardiovascular: heart rate, blood pressure and Electrocardiographic (ECG) parameters
- Respiratory: Pulse Oximetry (SpO2) and Respiratory Rate (RR)
- Neurologic: Electroencephalographic (EEG), Electromyographic (EMG) or metabolic sources like body weight
- Others: physical activity using body acceleration or GPS

8.3.3 Related Work

Telemonitoring is meanwhile a widely investigated field of interest in the areas of medicine and engineering. Early research on available wireless telemedicine systems and their application for emergency health telematics, telecardiology, teleradiology, electronic patient record or home monitoring is conducted by Pattichis et al. (2002). Home telemonitoring is also reviewed for chronic illnesses, diabetes and hypertension or under respiratory conditions (Pare et al., 2007; Jaana et al., 2009). Other specific studies focus on the telemonitoring in chronic heart failure diseases (Chaudry et al., 2002; Clark et al., 2007; Dang et al., 2009; Giamouzis et al., 2012; Hasan and Paul, 2011; Inglis et al., 2011; Louis et al., 2003; McAlister et al., 2004). A specific review by Inglis et al. (2010) demonstrates the positive influence and effects (such as improvement of quality of life, cost reduction etc.) of telemonitoring and structured telephone support with respect to mortality and hospitalization.

Further approaches illustrate the significant benefits of Remote Patient Monitoring (RPM) on cardiacs (for instance in Klersy et al., 2009) in comparison to usual care (home visits, frequent visits to chronic heart failure clinics, invasive monitoring etc.). As an extension, the co-called (real-time) Mobile Patient Monitoring (MPM) concept involves the idea of keeping track and controlling medical data not only at home but at any arbitrary time and place. As a particular example, Koehler et al. (2010, 2011) present a telemonitoring system combining a PDA and three different equipment (for the measurement of ECG, blood pressure and body weight) with integrated Bluetooth chips. The measured data is encrypted and sent via a central server to the respective telemedical centers. In another study, the focus of the implementation by Scherr et al. (2009) is set on the evaluation of home-based telemonitoring techniques including Internet-enabled mobile phones as patient terminals.

Recapitulating, there is a large number of E-Health approaches integrating telecommunication equipment for the purpose of the telemonitoring of patients with primarily cardiopulmonary diseases or other chronic illnesses. The main advantages include the possibility of providing health care services without using hospital beds as well as the reduction of chronic disease complications due to a better follow-up, patient travel and overall costs.

An innovative approach would, however, involve the adaptation of the presented server-based system architecture into a real-time M-Health framework that enables a long-term (i.e. several hours lasting measurement) monitoring of instantaneous ECG and RR data during training activities of cardiacs taking place not only at home but at any arbitrary time and location.

8.3.4 Conceivable Scenario

A particular intention of the realization of the mobile coaching idea in medicine might focus on the assistance of outpatient cardiacs in their rehabilitation programs, supporting them during their long-lasting healing processes. The use of computerized equipment should thereby contribute in sustaining, carrying forward and improving the health condition of patients based on the use of modern equipment.

8.3.4.1 Equipment

Today, due to the rapid development of ICT, not only the capturing of heart rate information but also of comprehensive physiological data is meanwhile feasible and integrated into compact solutions, enabling the immediate evaluation of human performance based on (bio)medical parameters. An exemplary implementation for this trend is a recently implemented telemetry device called BioHarness™ (Zephyr™, Annapolis, MD, USA), which consists of a chest strap with integrated electronic module. The equipment is able to measure and store vital sign data including ECG and breathing excursions as well as to retransmit it on the basis of the Bluetooth radio or 802.15.4 protocol (Figure 8.3).

Figure 8.3: Appearance of the BioHarness chest strap with sensor locations (with permission from Zephyr, 2013b).

8.3.4.2 Exemplary Setting

In a first instance, the intention is to monitor the measured medical data continuously (especially during sport activities) and generate an alert to the cardiac's mobile application if at least one of the parameters exceeds a predefined limit. For such purposes, the instant data acquisition and access opportunities have to be combined with intelligent methods for the computerized evaluation of the gathered parameters. The automated analysis can be applied for immediate risk prevention, assisting cardiacs in their outpatient rehabilitation process and thereby possibly increasing their health benefits.

At the same time, sport medicine specialists like cardiologist should also be able to access and analyze the gathered information. Figure 8.4 demonstrates an exemplary visualization alternative regarding the measured values using the BioHarness device. In particular, the application

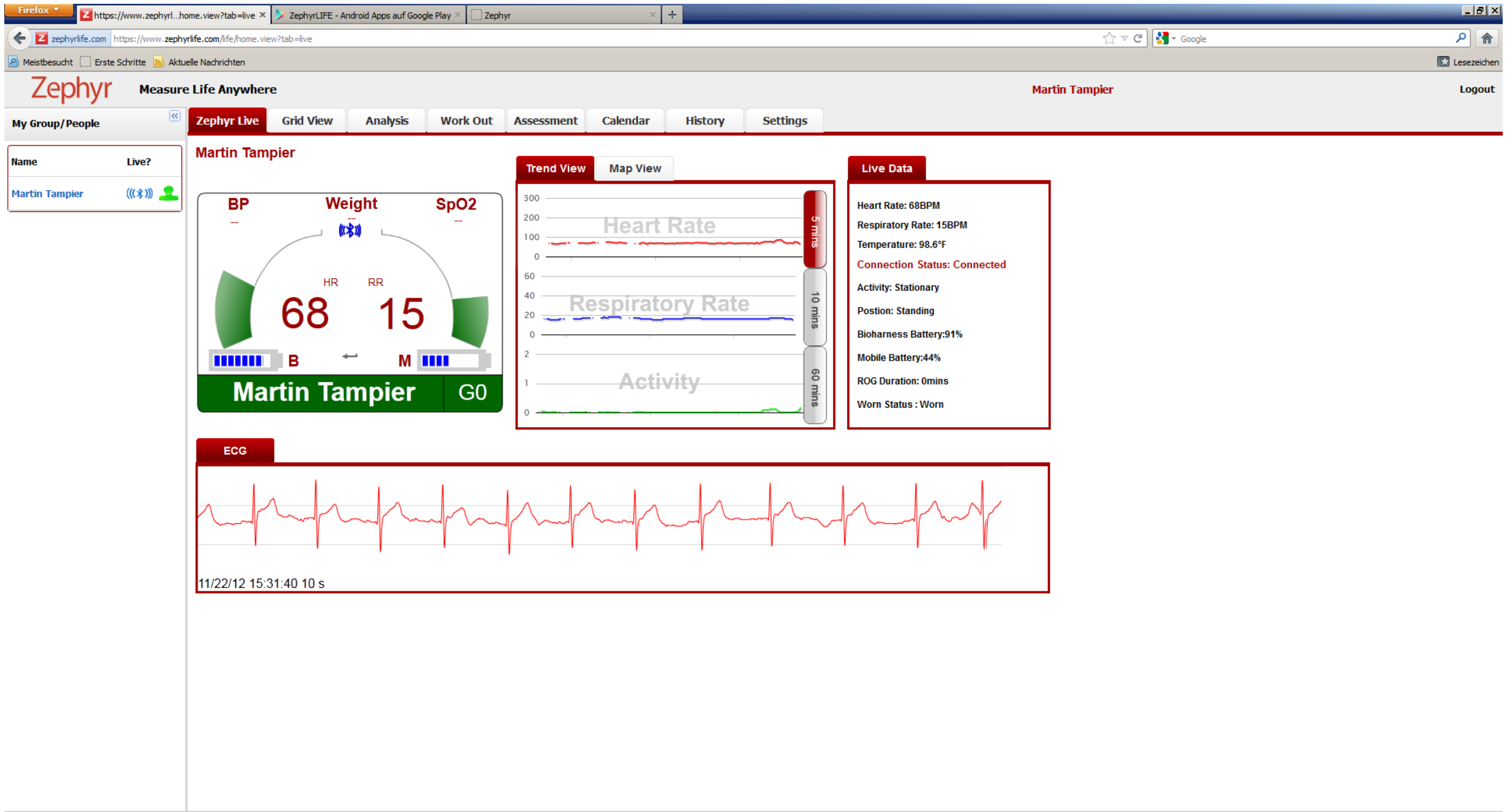


Figure 8.4: Conceivable scenario in medicine (from Zephyr, 2013a).

illustrates a possible realization of a feasible setting in medicine, displaying relevant information such as RR, SpO2, ECG etc. to authorized experts.

8.3.4.3 Security Issues

A significant issue regarding such implementations (particularly in the field of medicine) refers to data security. In order to follow the standards for the handling of medical records, it is, for instance, essential to protect the measured information during transfers over the Internet and encrypt the data by the use of secured protocols such as the Transport Layer Security (TLS) or the older Secure Sockets Layer (SSL) in combination with cryptographic algorithms like the Advanced Encryption Standard (AES). Another important factor relates to mechanisms for ensuring data consistency. For example, in case that a stable connection to the server cannot be established or is lost, it is necessary to buffer the data temporarily on the smartphone (e.g. on a small database) and synchronize it automatically as soon as the access is re-established.

CHAPTER 9

Discussion

Pervasive computing methods have become important integral parts of applied sport science. Based on the technological advances during the past years and decades, modern ICT are of great demand in the market of sports performance monitoring applications. Especially feedback systems profit from the current progress, enabling the development of effective hardware and software training as well as coaching tools. The high potential of recent developments enables new opportunities for the realization of mobile assisting, enhancing and preventative sports frameworks. As a particular example, in the presented research, mobile data acquisition, real-time analysis and intervention solutions are facilitated by the integration of wireless sensor devices and web-enabled handheld PCs.

The mobile coaching approach proposed in this thesis including the discussed development versions and possible application scenarios represent a typical and trend-setting implementation that demonstrates the progress and developments in the evolving areas of computer science and ubiquitous computing in sport. Therefore, before recapitulating the framework itself, a closer look on the perspectives of these areas is taken, as they are closely related to the actual concept and design.

9.1 Future Research Directions in Computer Science and Ubiquitous Computing in Sport

It seems to be evident that the future research directions of computer science and ubiquitous computing in sport will focus on the realization of even tinier and, at the same time, smarter equipment that are able to support athletes during different sport activities and motion sequences or for other reasons like decision making purposes (Zeleznikow et al., 2009). Almost invisible apparatus will be integrated into the sport clothes ("smart clothing" or "wearables"), allowing the direct and undisturbing measurement of relevant information. Also mobile devices and their networking capabilities with wireless possibilities and higher transfer rates will play crucial factors in the prospective design and development, offering opportunities for an immediate and quick transmission of the measured parameters.

Especially positional determinants on the basis of radio-frequency or satellite (like GPS) systems will play a significant role for different purposes such as game and performance analysis, providing an alternative solution to video-based approaches. Such systems will be increasingly used for the tracking of players (or also the ball in ball games), allowing effective evaluation possibilities regarding tactical behavior or (in combination with) physiological criteria when inserting physical parameters. At the same time, the prompt assessment of the performances by the integration of intelligent methods will be important for the enhancement of the training and coaching processes. Consequently, the evolution of all these factors will have a high impact on the progress of sport, thereby leading to fully sensing, networked and sophisticated implementations operating in real-time (Novatchkov and Baca, 2013c).

Another trend will relate to the evolution and expansion of the Internet technology. The simplified communication opportunities will be particularly important for everyday athletes and the establishment of social networks or training groups, allowing convenient facilities for the exchange of results, experiences etc. and building of networks. At the same time, it can be already foreseen that in future many regular classes, courses etc. will be partially or fully replaced by online learning tools ("e-Learning"). Moreover, a growing amount of services, software products, data storage and computing power will be offered via the Internet based on the upcoming cloud computing approach, allowing an easier use and availability of sports applications and general information (Novatchkov and Baca, 2013c).

In summary, it can be concluded that computer science and pervasive computing in sport are very perspective research fields that are constantly evolving along with the progress of computer science (Novatchkov and Baca, 2012b). Consequently, it can be expected that in nearest future sensor technologies and mobile devices will become smaller and more powerful and, at the same, will have the ability to act intelligently by the insertion of sophisticated models and classification routines (Grunz et al., 2012), thereby assisting and advising athletes in real-time during different sport activities (Baca, 2012).

9.2 Differences to other Mobile Coaching Systems

The proposed system suggests an innovative server-based approach for the analysis of real-time data in sports. The main benefit regarding the presented mobile coaching concept in comparison to available realizations (see Section 3.2.4.4) refers to the bidirectional architecture, enabling effective tools for remote real-time data evaluation and intervention routines. In particular, the framework includes novel feedback modules for the immediate return of important notifications to the athletes. Based on the measured parameters, such feedback information can be sent individually by coaches and other experts from remote locations, on the one hand. In addition, however, a major novelty is also the automatization of the feedback generation routine by the integration of intelligent methods.

Obviously, such remote intervention possibilities bring many other positive consequences. Based on the possible distant communication, coaches do not always have to accompany their athletes, which might involve lower costs as well as expertise analysis on the performances by different specialists at the same time (Novatchkov et al., 2011a). Another big advantage arising by the integration of a centralized host computer involves the option of analyzing not only the current training results but also in combination with previous performance outcomes.

In addition to the server-based analysis and feedback approach, though, another big advantage of the depicted framework is the generic and multifaceted approach in the design, making the system applicable for a variety of scenarios and purposes. A beneficial feature includes, for example, the possibility of defining and extending the applied sensors depending on the sport, exercise, goals etc. by fixing the sensor adjustments for each exercise via web-based applications.

9.3 Requirements, Limitations and Considerations

In spite of the permanent development of pervasive computing, a number of factors and issues have to be considered regarding the implementation of ubiquitous sports frameworks. An important aspect for the realization of practical systems includes the instantaneous application of the latest methods, equipment and standards. For example, as the offered mobile services require a lot of power and energy, it is crucial to apply appropriate – but also sustainable – technologies as soon as they become available in order to allow an efficient and enduring use of the developed procedures. Consequently, it is important not to lose track of further advancements in the ubiquitous computing sector and integrate new high-tech equipment for the development of continuatively effective feedback solutions (Novatchkov and Baca, 2012b).

In practice, various other considerations about different challenges and complications have to be made during the design process. For instance, although the mobile Internet access rates are constantly evolving, the transmission of huge amount of information is still limited. Such large data content transfers, however, are commonly needed for dynamic motion measurements in various sports. Therefore, it is important to include alternative solutions such as temporary buffering and exact synchronization techniques. The implementation of such routines is necessary for the timely and prompt handling as well as reception of the measured data or also feedback messages. At the same time, though, it can be expected that with the further expansion and propagation of highly-developed technologies such as the 4G network the mobile communication will continue to improve.

Commonly experienced issues in respect of wireless solutions are often connected with the range and interference of the (sensor) technologies (or also the failure at higher degrees). Such problems might be caused by disturbing factors like electronic components (e.g. battery), which should be always taken into consideration in the conceptual design. For such reasons, other alternatives should be kept in mind (e.g. individually developed implementations such as the mentioned Bluetooth-to-ANT adapter), which, however, might increase the interference with the athletes (e.g. due to the drawback of additional equipment and weight). Moreover, the sustainability of the hardware is an important factor regarding the use of available sensor systems.

When focusing on the detection of the athlete's position, it should be considered that systems like GPS are not always reliable or sometimes even unusable. As the satellite-based approach is limited to outdoor use only, the reception is highly dependable on weather conditions and the signal might be easily interfered by disturbing objects including trees or electronics. Consequently, there are still restrictions regarding the measurement of the position (for example of runners or cyclists) in mountain or forest areas. It is therefore necessary to implement other methods such as radio wave-based techniques in indoor places like sports halls.

9.4 Open Questions – Feedback

There are a couple of open questions regarding the realization and practicability of computer-based feedback systems such as the demonstrated mobile coaching framework. For instance, one particular issue refers to the actual design, content and timing of the generated feedback information. An important factor (also crucial for the usability of the system) relates to the way in which the feedback is presented to the user. In school sport, for example, the returned advice has to be considered and designed carefully in order to allow a motivating effect (Mouratidis et al., 2008). A proper feedback information transfer is at the same time a key element for the training enhancement and the success of athletes in sports (Gould et al., 2002). Such aspects, however, would not only go beyond the scope of the thesis but are also subject to other areas such as psychology and are therefore not included in the present manuscript.

CHAPTER 10

Conclusion

Computer science in sport is a rather young, steadily evolving but still very ambitious research field that is having a remarkable practical and scientific boost. Due to the technical progress of informatics with more powerful, smaller and sophisticated hardware and software realizations, the area becomes more and more significant for sport science and sport in general. Recent technological implementations in this area have brought many new possibilities for the enhancement of sports equipment and the computerized analysis of sports performances.

Especially constantly evolving areas like ubiquitous computing or modeling and simulation are increasingly contributing to the development of new approaches and techniques. Based on the current trend and the growing number of research activities, communities, conferences and courses, it can be expected that computer science in sport will stay a very promising and important domain as well as field of activity for the future of sport.

As one particular example, the recently evolving research field of pervasive computing in sport is getting more and more important for the evolution of sport. The constant advancements, great facilities, feasibilities and diversity of pervasive methods as well as sophisticated sensor and ICT developments including modern handheld PCs or present-day measuring elements enable effective ways for the design of various sports applications such as analysis, assisting, preventive, decision making or entertaining implementations.

The illustrated mobile coaching framework demonstrates a typical example of a ubiquitous training system, assisting athletes and specialists during different sport activities by the integration of up-to-date equipment and methods. Recapitulating, it seems to be evident that the design of such approaches by the involvement of pervasive technologies in combination with intelligent evaluation methods will have a significant impact on the monitoring, support, optimization and enhancement of the coaching, training and competition processes, thereby contributing to the advancement and progress of sport.

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APPENDIX A

Abbreviations

A-Client	Athlete-Client
AES	Advanced Encryption Standard
AI	Artificial Intelligence
ANN	Artificial Neural Network
AOA	Angle of Arrival
BSN	Body Sensor Network
CR	Cardiac Rehabilitation
dB	decibel(s)
DGPS	Differential Global Positioning System
E-Client	Expert-Client
E-Health	Electronic Health
ECG	Electrocardiographic
EEG	Electroencephalographic
EMG	Electromyographic

FA	Football Association
FIFA	Fédération Internationale de Football Association
FIS	Fuzzy Inference System
GPS	Global Positioning System
GUI	Graphical User Interface
HMM	Hidden Markov Model
HRM	Heart Rate Monitor
HRV	Heart Rate Variability
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
HSPA	High-Speed Packet Access
HSPA+	Evolved High-Speed Packet Access
HTTP	Hypertext Transfer Protocol
HCI	Human-Computer Interaction
Hz	Hertz
IASI	International Association for Sports Information
IACSS	International Association of Computer Science in Sport
IAT	Individual Anaerobic Threshold
IBM	International Business Machines
ICT	Information and Communication Technology
IJCA	International Journal of Computer Applications

IJCSS	International Journal of Computer Science in Sport
IDE	Integrated Development Environment
IT	Information Technology
JSSM	Journal of Sports Science and Medicine
kg	kilogram(s)
kNN	k-Nearest Neighbor
LOD	Level of Detail
LTE	Long Term Evolution
m	meter(s)
Mbit	Megabit(s)
MCP	Mobile Coaching-Protocol
M-Health	Mobile Health
MID	Mobile Internet Device
MMA	Mobile Motion Advisor
MWC	Mobile World Congress
N	Newton(s)
PAN	Personal Area Network
PARC	Palo Alto Research Center Incorporated
PC	Personal Computer
PerPot	Performance Potential
PDA	Personal Digital Assistant

PHP	Personal Home Page (Hypertext Preprocessor)
PIC	Programmable Intelligent Computer/Peripheral Interface Controller
P2P	Point-to-Point
RFID	Radio-Frequency Identification
RR	Respiratory Rate
RPM	Remote Patient Monitoring
s	second(s)
SD	Secure Digital
SDK	Software Development Kit
SMART	Sports Movement Archiving and Requesting Technology
SOM	Self-Organizing Map
SpO2	Pulse Oximetry
SQL	Structured Query Language
SSL	Secure Sockets Layer
STD	Standard Deviation
SVM	Support Vector Machine
SWF	Small Web Format (Shockwave Flash)
TCP	Transmission Control Protocol
TDA	Time Difference of Arrival
TESSY	Tennis Simulation System
TLS	Transport Layer Security

UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
UK	United Kingdom
USA	United States of America
USB	Universal Serial Bus
UWB	Ultra-Wide Band
VO2	Oxygen Consumption
WSN	Wireless Sensor Network
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
XML	Extensible Markup Language
3D	three-Dimensional
3G	third Generation of mobile phone mobile communications standards
4G	fourth Generation of mobile phone mobile communications standards

APPENDIX **B**

Author's Contributions and Distinction

In the following all relevant publications of the author as well as subject-specific presentations and honors during the attendance of various international conferences are listed.

B.1 Publications

2013

Novatchkov H. and Baca A. Artificial Intelligence in Sports on the Example of Weight Training. *Journal of Sports Science and Medicine*, 12(1):17–27, 2013.

Novatchkov H. and Baca A. Fuzzy Logic in Sports: A Review and an Illustrative Case Study in the Field of Strength Training. *International Journal of Computer Applications*, 71(6):8–14, 2013.

Novatchkov H. and Baca A. Towards Intelligent Resistance Training Machines. In *Proceedings of the 9th International Symposium of the International Association of Computer Science in Sports (IACSS13)*, Istanbul, Turkey, 2013 (1st Place – Young Investigator Award).

Novatchkov H. and Baca A. Computer Science in Sport (accepted). In Khosrow-Pour M., editor, *Encyclopedia of Information Science and Technology*. Information Science Reference (an imprint of IGI Global), 2013.

2012

Novatchkov H. and Baca A. Machine learning methods for the automatic evaluation of exercises on sensor-equipped weight training machines. In *Procedia Engineering 9, ENGINEERING OF SPORT CONFERENCE 2012 34*, pages 562–567, Lowell, MA, USA, 2012.

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Tampier M., Baca A., and Novatchkov H. E-Coaching in Sports. In Jiang Y. and Baca A., editors, *Proceedings of the 2012 Pre-Olympic Congress on Sports Science and Computer Science in Sport*, pages 132–136, Liverpool, UK, 2012.

Tampier M., Endler S., Novatchkov H., Baca A., and Perl J. Development of an Intelligent Real-Time Feedback System. *International Journal of Computer Science in Sport*, 11(3):58–64, 2012.

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Baca A., Kornfeind P., Preuschl E., Bichler S., Tampier M., and Novatchkov H. A Server-Based Mobile Coaching System. *Sensors 2010*, 10:10640–10662, 2010.

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2009

Novatchkov H., Kornfeind P., Bichler S., and Baca A. Mobile Coaching. In *Proceedings of the 7th International Symposium of the International Association of Computer Science in Sport (IACSS09)*, page 145, Canberra, Australia, 2009.

B.2 Presentations

2013

"Towards Intelligent Resistance Training Machines", *9th International Symposium of the International Association of Computer Science in Sport (IACSS13)*, Istanbul, Turkey, 19.–22.6.2013.

2012

"Machine Learning Methods for the Automatic Evaluation of Exercises on Sensor-Equipped Weight Training Machines", *ISEA's 9th International Sports Engineering Conference*, Lowell, MA, USA, 9.–13.7.2012.

2011

"Real-Time Data Acquisition and Performance Analysis in Sports", *8th International Symposium of the International Association of Computer Science in Sport (IACSS11)*, Shanghai, China, 21.–24.9.2011.

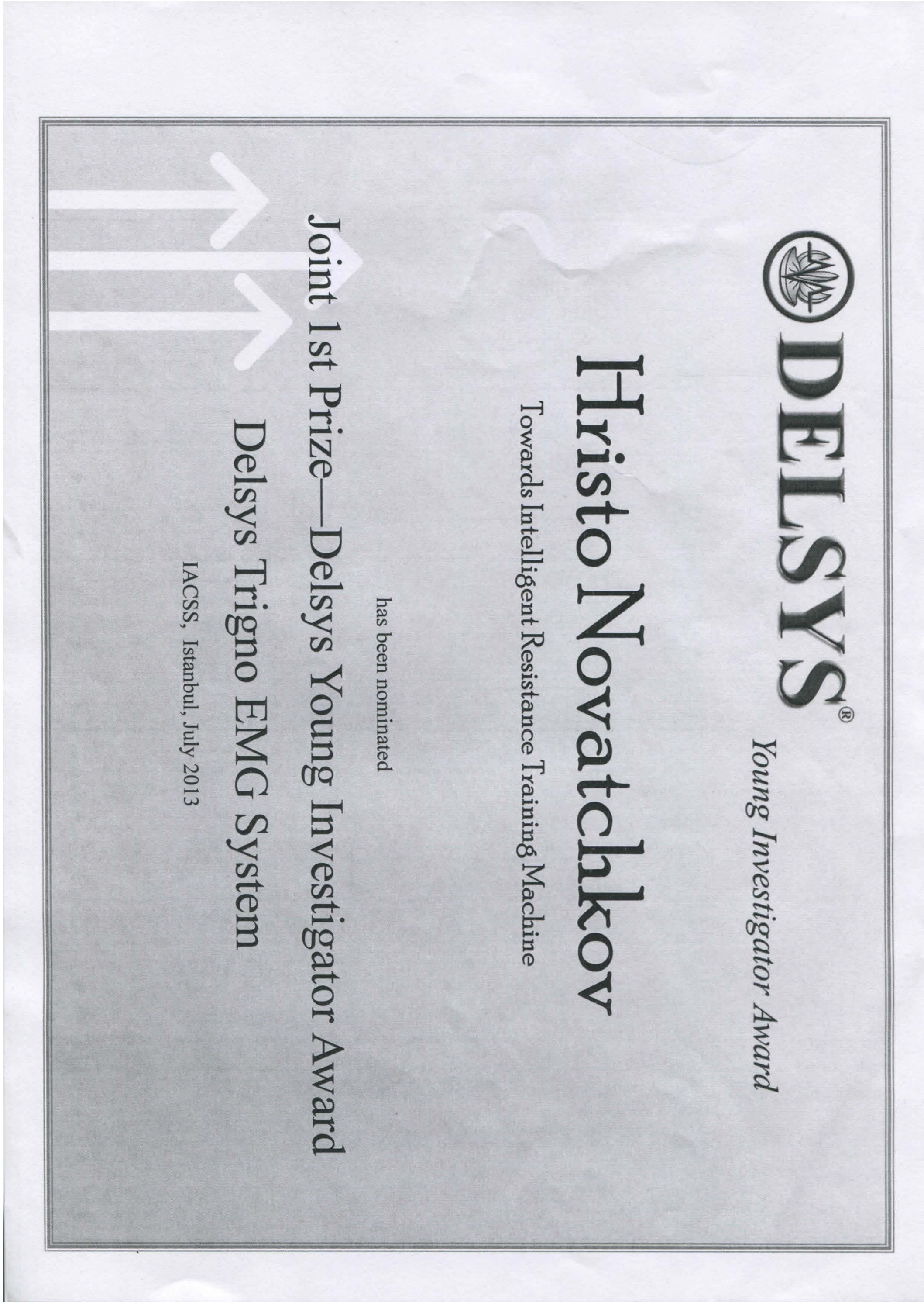
2010

"Current Development of a Server-Based Mobile Coaching System", *Asian Conference on Computer Science in Sports (ACCSS)*, Tokyo, Japan, 24.–25.9.2010.

2009

"Mobile Coaching", *7th International Symposium of the International Association of Computer Science in Sport (IACSS09)*, Canberra, Australia, 22.–25.9.2009.

"A Mobile Coaching Approach", *26th Conference of the Turkish Association on Computer Science*, Ankara, Turkey, 18.–20.11.2009.



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IACSS, Istanbul, July 2013

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(Editor-in-chief, IJCSS / President, IACSS)

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LETTER OF ACCEPTANCE

REF. NO: TYP/71/CU/1123 Date: June 8, 2013

T Y P 7 1 C U 1 1 2 3

TO:
Hristo Novatchkov
Centre for Sport Science and University Sports
University of Vienna
Auf der Schmelz 6a.

Dear Hristo Novatchkov and Arnold Baca,

We are delighted to inform that your research paper has been "**Accepted for Publication"** in International Journal of Computer Applications (IJCA) **June 2013 Edition**.

Paper Title : Fuzzy Logic in Sports: A Review and an Illustrative Case Study in the Field of Strength Training
Paper Reference ID : pxc3888675

The research article will be published in the IJCA Digital Library on **June 26, 2013**.

IMP: The authors are hereby granted for **reuse of the material** in any thesis/presentation.

The article will be published in IJCA Digital Library with initial indexing with Google Scholar, CiteSeer, UlrichsWeb and ScientificCommons Index, University of St. Gallen, Switzerland. The articles are also indexed with SAO/NASA ADS Physics Abstract Service supported by Harvard University and NASA, Informatics and ProQuest CSA Technology Research Database. International Journal of Computer Applications is a voting member of CrossRef, USA and each of its research articles is allotted a unique DOI reference.

Thanking You.

Editorial Liaison Officer
FCS-IJCA, NY, USA

Foundation of Computer Science
244 5th Ave # 1526, New York, NY 10001, USA

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Appendix D

Curriculum Vitae

Hristo Novatchkov

ico@novatchkov.org

Address and Date of Birth

Danhausergasse 10/4
1040 Vienna
Austria

September 24th, 1983

Education, Training and Awards

09/1990 – 06/1991	Elementary school in Sofia, Bulgaria
09/1991 – 06/1994	Elementary school in Vienna, Austria
09/1994 – 06/2002	Secondary school BRG 4, Vienna, Austria (graduation with excellent results)
10/2002 – 06/2006	B.Sc. in computer science, TU Vienna, Austria
10/2006 – 10/2008	**M.Sc. in computer science, TU Vienna, Austria (graduation with excellent results)**
10/2007 – 01/2008	ERASMUS scholarship, exchange program, DTU Lyngby, Denmark
06/2013	Joint 1st Prize – Delsys Young Investigator Award, IACSS13, Istanbul, Turkey

Professional Experience

08/2005 – 09/2005	**Web programmer at flopworx** (2 months internship) **Florian Stocker, Bräuhausgasse 23, 1050 Vienna, Austria** Implementation of web applications; installation, configuration and maintenance of databases
08/2006 – 09/2006	**Software engineer at University of Nebraska** (1 month internship) **Dr. David H. Allen, 114 Othmer Hall, Lincoln, Nebraska, USA** Development and maintenance of software evaluations systems
06/2007 – 08/2007	**Technical engineer at Dublin City University** (3 months internship) **Dr. Alan F. Smeaton, Glasnevin, Dublin 9, Ireland** Hardware-oriented development of RFID systems
01/2009 – 07/2013	**Research assistant at University of Vienna** **Prof. Arnold Baca, Institute of Sport Science, Department of Biomechanics, Kinesiology and Computer Science, Auf der Schmelz 6a, 1150 Vienna, Austria** Development of mobile technologies and client-server oriented web systems; formulation of research papers and project proposals; project management; conference participations; teaching
03/2010 – 08/2010	**Completion of military service at Kommando Führungsunterstützung** **IKT-Technik, Stiftgasse 2a, 1070 Vienna, Austria** Database and web development

Personal Skill and Competence

Mother tongue	**Bulgarian**
Other languages	
German	Fluent
English	Fluent
French	Basic knowledge
Serbo-Croatian	Basic knowledge
Programming	Imperative: C, C++, C# Declarative: Prolog, Lisp Web: PHP, JavaScript, Apache
Query language	HTML, XML, Windows/Unix Shell, SQL
Driving license	Class B

Additional information

Publications and conferences

Baca A., Kornfeind P., Preuschl E., Bichler S., Tampier M., and Novatchkov H. A Server-Based Mobile Coaching System. *Sensors 2010*, 10:10640–10662, 2010.

Lustig C., Novatchkov H., Dunne L.E., McHugh M., and Coyle L. Using Colocation to Support Human Memory. In *Proceedings of the HCI Conference, Workshop Supporting Human Memory with Interactive Systems*, pages 41–44, Lancaster, UK, 2007.

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