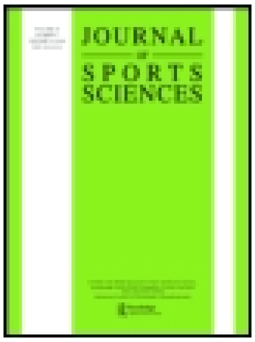

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INVITED REVIEW ARTICLE

# Ubiquitous computing in sports: A review and analysis

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**Abstract**

Ubiquitous (pervasive) computing is a term for a synergetic use of sensing, communication and computing. Pervasive use of computing has seen a rapid increase in the current decade. This development has propagated in applied sport science and everyday life.

The work presents a survey of recent developments in sport and leisure with emphasis on technology and computational techniques. A detailed analysis on new technological developments is performed. Sensors for position and motion detection, and such for equipment and physiological monitoring are discussed. Aspects of novel trends in communication technologies and data processing are outlined.

Computational advancements have started a new trend – development of smart and intelligent systems for a wide range of applications – from model-based posture recognition to context awareness algorithms for nutrition monitoring. Examples particular to coaching and training are discussed. Selected tools for monitoring rules' compliance and automatic decision-making are outlined. Finally, applications in leisure and entertainment are presented, from systems supporting physical activity to systems providing motivation.

It is concluded that the emphasis in future will shift from technologies to intelligent systems that allow for enhanced social interaction as efforts need to be made to improve user-friendliness and standardisation of measurement and transmission protocols.

**Keywords:** *Tracking, pervasive computing, GPS, sensors, feedback*

## Introduction

The inspiration for the development of ubiquitous computing could be traced back to the late eighties when the idea came in the PARC Xerox laboratories. Mark Weiser who is widely credited for this idea had very deep social motivation for the use of computer as he saw the desktops and boards as divisive and alienating people. However, he among many others realised that technology is still lagging behind and prevents the fulfilment of their inspirational ideas so the initial focus was placed on hardware developments enabling the ubiquitous use of computing. The subsequent technological developments have led to the design of powerful small-size sensors, microprocessors and communication devices for collecting, processing and transmitting data wirelessly. Information processing may thus be integrated into everyday objects without even making the user aware of the hardware behind it. This extension of computing devices into everyday lives has become termed "Ubiquitous Computing" ("Pervasive Computing") in a narrower sense in a variety of walks of life. This somewhat restrictive definition is used in the current work.

In sport, these ubiquitous computing technologies are utilised to acquire, analyse and present performance data without affecting the athletes during training and competitions. Sophisticated feedback systems, for example, have been developed in order to reduce time for technique improvement (Baca & Kornfeind, 2006; Liebermann et al., 2002). Furthermore information can be acquired for illustrating performance segments in sports broadcasts.

Sensors are either attached to the athlete's body or to the sports equipment (e.g. accelerometers,

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gyroscopes or global positioning system [GPS]-receivers) or embedded in the environment (e.g. cameras, opto-electronic devices). Radio-frequency Identification (RFID) technology consists of two components. Specific tags, which emit unique signals, are attached to the athlete/equipment and may be identified by short-distance readers set up in the environment.

In a typical (non-video or RFID-based) setup, sensors acquire the relevant performance data; the digitised signals are then transmitted to a mobile client (e.g. a mobile phone) via short-range protocols (e.g. Bluetooth) and from this sent to an internet server (e.g. via general packet radio service [GPRS], a packet-oriented mobile data service) (Armstrong, 2007; Baca & Kornfeind, 2007).

The main new developments could be put into two categories:

(1) technological developments in miniaturisation of the devices and increasing their ability to transmit data at considerable distances and
(2) development of algorithms for fast and/or accurate data processing in (speedy) feedback provision that represents a firm step in the direction towards intelligent systems.

In this review paper, we provide a survey of recent developments in this field as we discuss the new technological developments across the application while the development of new algorithms, smart and intelligent systems is discussed by some representative applications. Applications have been categorised into analysis systems, coaching and training systems, decision systems as well as systems utilised in leisure and entertainment contexts, even though a strict assignment has not been possible in many cases.

## Overview of new technological developments

### *Sensors*

A wide variety of different sensor types are used in sports applications to measure physical quantities, such as force, torque, pressure, acceleration (linear), velocity (linear/angular) and position (linear/angular). Depending on the application, sensors can either be mounted on parts of the sport equipment or directly attached to the subject's body (frequently referred as wearable electronics). The advancement of the latter has presented sport research with a variety of exciting possibilities that are discussed below.

### *Position detection sensors*

GPS-based systems are well suited for the determination of position (and speed) in sports activities, where athletes move along rather simple trajectories, such as in rowing, cycling, running (Townshend, Worringham, & Stewart, 2008). They provide a cheaper and easier means to operate in comparison to the more accurate differential GPS (dGPS) systems, which require a fixed reference station. However, both techniques may only be used outdoors in good weather conditions and require small antennas onto the objects to be tracked. New technical developments like the Leica GS20 Professional Data Mapper (Leica Geosystems, St. Gallen, Switzerland; Leica, 2009), total weight with battery of 0.652 kg if combined with a high precision GPS antenna (AT501)) provide accuracy in position of typically 5–10 mm + 2 ppm (rms) and data collection up to 20 Hz which seems to be quite challenging for a lot of sports applications).

Active (battery-powered) or passive tags transmitting radio or microwaves are also increasingly used to compute the position of freely mobile objects within a local-bounded 3D area. Contrary to the GPS-based systems, this calculation is not done on the object tracked, but in a central control unit. The 3D positions are estimated from the travel time that an electromagnetic wave needs from light-weighted tags (transponders) attached to the objects to be tracked to a certain number of receiving stations using a triangulation method. These stations surround the environment under investigation and are linked to the central station. Active technologies show high resolutions (accuracy $\pm$ 5 cm outdoor) and achieve almost real-time capability, the disadvantages lie in the necessity of additional equipment for objects. Potential applications in sports are analyses of vehicles and drivers in motor sports, athletes' positions, running tracks, game strategies and performance analyses, e.g. in speed skating).

Main advantages of this technique are a high spatial accuracy and a recording frequency of up to 1000 Hz (Baca, 2008).

### *Motion detection sensors*

Accelerometers can be used to measure changes in position. Theoretically, an acceleration signal integrated once gives velocity, and integrated twice the change in position. In practice, even signals contaminated with a negligible noise require accurately weighted corrections. For example, the acceleration due to gravity needs to be discarded in measuring the acceleration and for drift that is a constant presence needs to be accounted for in the respective signal. A 3D-tracking system usable for practical purposes therefore comprises three rotation sensors, (gyroscopes), in addition to at least three accelerometers. Changes in position are calculated from all signals measured. The devices may be small in weight and size, measured data may be transmitted using wireless technologies. One very popular application of such devices is in the area of virtual reality. Computer-Human-Interaction systems incorporating positional tracking have already been designed for different sports. Users' motions are captured and used as input for controlling the virtual run in order to improve the sense of reality and enjoyment during the game experience. Head, hand and body tracking devices have been developed and actively used (Katz, Parker, Tyreman, & Levy, 2008).

### *Equipment monitoring*

The use of sensors for input and validation data has become prevalent in sport design and targeted improvement of sport performance. To monitor loads on parts such as bicycle frames, tennis rackets or golf clubs, for instance, strain gauges can be applied to selected positions to measure the mechanical stress which corresponds well to applied forces or torques (Hoffmann, 1989). Pervasive computing has provided the ultimate means for these developments as it allows testing equipment in field conditions or provides the means for mechanical simulation of sporting action. There seem to be two approaches in the use of pervasive computing in mechanical simulations. The first is to design a robot that performs human-like to allow direct data measurement with instrumented sensors to overcome the complications in attaching sensors to the human bodies. Such devices were used in simulating skiing for measuring and understanding the forces involved (Hasegawa & Shimizu, 1998; Yoneama & Kagawa, 1998). A similar approach was also utilised in swimming to measure the propulsive forces (Dabnichki, 2008a). The computer controls the generation of a specific locomotion and obtains the relevant dynamic data such as kinematic and kinetic variables.

When the equipment design and performance are of main interest, then a human performer can be used and relevant sensors mounted on the equipment. The advantages of such approach over the classic laboratory testing are demonstrated by Foss and Glenne (2007) in the study of material parameters of skis. This study is an excellent illustration of how on field analysis influences the way laboratory tests are developed and ultimately ski and snowboard designs are improved.

One of the most discussed examples in the popular press is the use of active dampening in skiing. The principle is quite simple and many manufacturers claim significant performance improvement. However, there are no proper independent studies published in peer-reviewed journals. However, in breaking the world records in fast skiing this method is an integral part as the speeds reached make it almost impossible for the traditional skis to maintain ground contact and the high lift forces preclude further increase in the records. Such studies have been conducted independently in high-speed wind tunnels suggesting that manufacturers' claims are correct but technical details are not available to make an accurate and independent assessment.

Parameters such as package dimensions, mass, sensor costs and not least accuracy are key factors for the selection of sensors and have to be considered for new measurement setups. The reduction of size of both sensors and data loggers allows not only to collect vast amounts of field data but also to develop effective actuators that improve performance and comfort. A good illustration of this technological approach is the study by Ro, Chien, Wei, and Sun (2007).

They used macro fibre composite (MFC) actuators for active control of flexural vibration of the handlebars of a bicycle. The results obtained suggest that using the MFC actuators is effective. The study shows clearly that this technique relies heavily on modelling prediction of structural responses to external loads such as shocks. Hence it indirectly casts doubts on the effectiveness of active vibration control in skiing where the dynamic loads are stochastic in nature and of extremely high frequencies. The studies discussed above illustrate a growing tendency to integrate mathematical, empirical or statistical modelling and pervasive computing to increase its effectiveness (Dabnichki, 2008a).

### *Physiological monitoring*

There has been a large influx of new devices that allow monitoring of a variety of physiological parameters. It is impossible to cover all novel aspects of development in the framework of this paper and that is why we shall focus on a few prominent non-invasive applications. The systems vary in their degree of complexity. For example, the XC2® system (AWare Technologies, Cambridge, USA; AWare XC2, 2009) represents a simple system that allows integration of an accelerometer in combination with a heart rate monitor. The XC2 AWare™ system software provides Windows software to play back, visualise and convert binary data to a suitable form for import into spreadsheets and sports training tools. The advantages of such systems are their relatively low cost and fast provision of supplementary information to coaches. The disadvantage lies in the fact that they tend to accumulate a large amount of data and in practice could serve a very small population of athletes who have a large number of support staff at their disposal. In today's terms such systems cannot be considered as pervasive computing type systems as their computing abilities are restricted to low-level data processing, data structuring and storage.

The next level of complexity is represented by systems that provide analysis of the collected information rather than passing the sensor data. A good example is a typical activity measurement system (Junker, Amft, Lukowicz, & Tröster, 2008). Such systems provide deeper computational and logical analysis by detecting patterns and synergies and extracting summary-type information that addresses directly users' needs. These systems provide directly a higher level of organised information leaving only the decision-making to the end users. Hence they speed up the interventions when required and reduce the demand for human power to deal with the collected data.

## Communication technologies

### *Devices and protocols*

Mobile phones, personal digital assistants (PDAs) and smartphones may be used as mobile clients to receive data via short-range protocols from the sensors, to process these data and/or to send them to other computing devices such as an internet server via GPRS, a packet-oriented mobile data service, universal mobile telecommunication system (UMTS) or, if available, also wireless local area network (WLAN) (Armstrong, 2007; Figure 1). Relevant standardised short-range protocols for sports applications are Bluetooth®, ANT™ (Dynastream Inc., Cochrane, Canada) and ZigBee®. The following criteria are important for selection: energy consumption, transmitting range, data rate and supported network types. When context-sensitive information is transmitted also security capabilities (ANT™: 64Bit, Bluetooth® & ZigBee®: 128Bit) should influence the selection process. The number of used bits indicates the encryption level.

### *Networks*

Contemporary hardware solutions allow not only point to point or star network connections but also cluster and mesh networks. Hardware which supports these more flexible network types can be used, for example, to build complex wireless sensor networks ("managed networks") with the ability to self-organise its logical design (Pfisterer et al., 2006). Meshed networks, for instance, allow an extending of the range of a single node by routing the data packages along neighbouring nodes and can achieve an efficient usage of the available data rates.

Conventional approaches often use mobile ad hoc networks (along the lines of "sense and send") to monitor an environment, which is in so far absolutely convenient when applied for simple environments (e.g. single athlete with one accelerometer). For team sports and also for time critical measurement tasks, where sensing should happen synchronously (e.g. to capture multiple forces simultaneously), multichannel solutions are needed.

## Data processing devices

### *Microprocessors*

In the recent application of sensors, monitoring and performance assessment, a substantial emphasis has been placed on real-time response by the systems for performance improvement purposes. If such device is to be mounted on a piece of equipment there is a further requirement that the device needs to be minimised in terms of size and needs to be easily used in outdoor environment in different geographic locations. Hence, a full-scale computer is not currently an option and instead microprocessors are used that respond within microseconds to particular signals. The most successful use of microprocessors has been "smart" devices whose purpose is to address a critical narrowly identified problem. One of the most interesting and promising

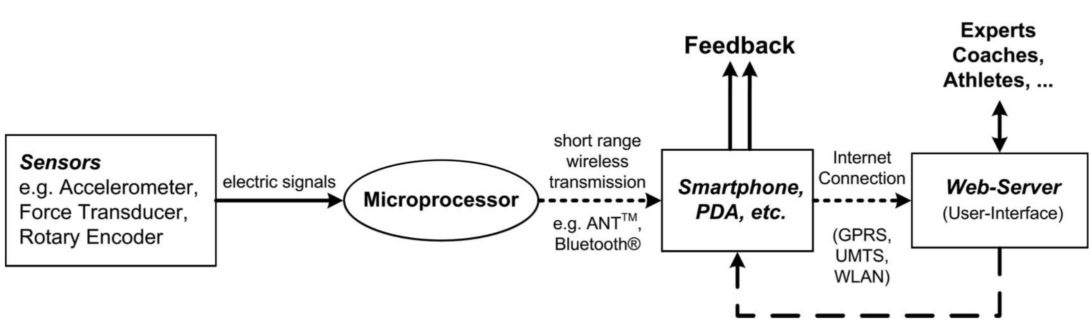


Figure 1. System for feedback provision. Physical performance parameters of athletes are monitored. Feedback may either be given by direct data processing on the PDA/Smartphhone/etc. or via the server loop, which enables to integrate expert knowledge.

developments is the use of microprocessors in different forms of wearable computing including intelligent textiles.

### *PDAs, PCs and servers*

In many cases the heart of the system is the computer with its high processing power while there are associated peripheral devices such as vibration detectors and a digital projector for feedback provision. Such systems often use the now well-established loop

Sensor signal → Receiver → Processor → Analysis → Feedback.

They allow fast and effective feedback and could minimise the use of coaching due to the use of players self-learning skills, a comprehensive review of this type of systems and associated technology challenges is available in Chi (2008).

## Applications

### *Analysis systems*

Sophisticated algorithms from computer vision enable not only to capture the kinematics of an individual athlete's motion without the use of markers (Moeslund, Hilton, & Krüger, 2006) but also to capture the patterns of a group of players in game sports simultaneously (Lames, 2008). A general assembly of a functional taxonomy presented by Moeslund and Granum (2001) is shown in Figure 2.

Mauthner and Bischof (2007) address the task of tracking several similar looking athletes during a beach volleyball competition. Ramanan, Forsyth, and Zisserman (2007) developed a completely automatic tracking system that works in two stages; it first builds a model of appearance of each person in a video and then it tracks by detecting those models in each frame ("tracking by model-building and detection"). A bottom-up approach groups together candidates' body parts found throughout a sequence, and a top-down approach builds people-models by detecting convenient key poses within a sequence. The authors demonstrate the resulting tracker on sports footage (e.g. from the 1998 Winter Olympics). An approach for simultaneous tracking of multiple body parts of interacting persons has been proposed by Park and Aggarwal (2006). In the presence of mutual occlusion and shadow, the framework uses multiple free-form blobs and a coarse model of the human body. Tracking has been performed successfully for various sequences including punching, hand-shaking, pushing and hugging interactions between two people. The method therefore seems to be promising for contact sports.

To recognise human actions at distances, Efros, Berg, Mori, and Malik (2003) introduced a motion descriptor based on optical flow measurements in a spatio-temporal volume for each stabilised human figure, and an associated similarity measure to be used in a nearest-neighbour framework. To classify the action being performed by a human figure in a query sequence, nearest neighbour(s) from a database of stored, annotated video sequences were retrieved. Results are demonstrated on ballet, tennis as well as soccer datasets.

In general, the problem of fully automatic initialisation of model kinematics, shape and appearance for human pose estimation from image sequences remains open for future research (Moeslund et al., 2006). To handle the occlusion problem in temporal correspondence, advances are mainly due to the use of probabilistic classification and stochastic sampling methods. Model-based pose estimation to estimate 3D pose from multiple view images of complex movements remains a future challenge. Approaches containing silhouette extraction based on level sets described by Rosenhahn et al. (2005)

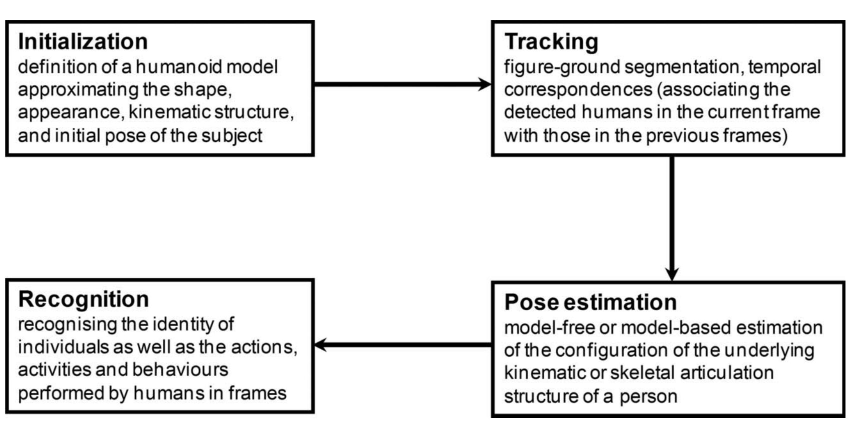


Figure 2. General assembly for functional taxonomy of markerless motion capturing according to Moeslund and Granum (2001).

show potential for markerless sports movement analysis.

In game analysis, one of the potential technological applications is the reliable automatic tracking, reconstruction and recognition of the positions and the movements of the players and the ball on the field. There are computerised match analysis systems like Amisco Pro® (Sport Universal Process, Nice, France) (SUP), ProZone® (ProZone Sports Ltd., Leeds, UK) or TRACAB Image Tracking System™ (TRACAB Image Tracking System, Solna, Sweden) in team sports which use a number of video camera sensors to capture players, referees and ball, not requiring additional equipment. Di Salvo et al. (2006) provide a large-scale study on the motion characteristics of top class soccer players, during match play, according to playing position using Amisco Pro(R)® (Nice, France). Three hundred top-class outfield soccer players were monitored during 20 Spanish Premier League and 10 Champions League games. Current findings provide a detailed description of the demands placed on elite soccer players, according to their positional role at different work intensities, which may be helpful in the development of individualised training programmes. Rampinini, Coutts, Castagna, Sassi, and Impellizzeri (2007) examined the influence of the opposing team, seasonal variations and the influence of first half activity on match performance in top-level soccer players. Physical performance measures were collected using the ProZone(R)® match analysis system from 20 professional soccer players from the same team and their opponents ($n = 188$) during a season. Match activities, distances and other measures including involvement with the ball and peak running speed were collected suggesting that reference team was influenced by the activity profile of the opponent teams.

Beside such systems, the recognition of human actions in soccer videos is a well-studied topic in the computer vision community and various approaches and focuses have been proposed, for example, for robust player tracking (Barcelo, Binefa, & Kender, 2005; Iwase & Saito, 2004; Liu, Liang, Huang, & Gao, 2006; Mavromatis, Dias, & Sequeira, 2007; Zhong, Zheng, & Xue, 2006) or real-time calibration to obtain player and ball positions in real-world coordinates (Farin, Han, & de With, 2005).

Shah, Chokalingam, Paluri, Pradeep, and Raman (2007) propose a technique to classify automatically tennis strokes efficiently under varying circumstances (low resolution, variability in strokes of the same player as well as among players, variations in background, weather and illumination conditions). They use the geometrical information of the player to classify the strokes. Bloom and Bradley (2003) address player tracking and stroke recognition in Tennis.

A more complex system is proposed by Li, Wu, Ba, Lin, and Zhang (2007) who present an automatic detection and classification of complex actions in a changing dynamic background namely diving actions for broadcasting or training diving video sequences. That system comprises three components: a highlight detection algorithm based on dominant motion and semantic colour analysis; a video object segmentation algorithm based on adaptive dynamic background construction and a recognition component using slightly modified Hidden Markov Models.

It can be stated that there is a really far reaching potential in computer-based human motion capture although there seems to be a discrepancy between technical developments which require highly skilled and knowledgeable operators on the one hand, and on the other a feasible use of methodologies in sports.

Beside video technology, radio- or microwave-based systems with active sensors inside the ball (Cairos – Goal Line Technology [GLT] System) or mounted to the athlete (ABATEC® – Local Positioning System LPM; ABATEC Electronic AG; Regau, Austria) are applied in game analysis (Figure 3).

The use of GPS and moreover the phase differential positioning method (dGPS) for the assessment of speed of human locomotion has been addressed a good many times. Larsson (2003) and Larsson, Burlin, Jakobsson, and Henriksson-Larsen (2002), for example, emphasise the use of dGPS in combination with accelerometry and biomeasurements (e.g. metabolic gas, electromyography) for enabling studies of exercise physiology in the field, otherwise restricted to the laboratory environment. Terrier, Ladetto, Merminod, and Schutz (2000) conclude that GPS technique can provide useful biomechanical parameters for the analysis of an unlimited number of strides in an unconstrained free-living environment.

There is a misplaced belief that pervasive computing systems have the simple purpose to acquire and archive data collected by a variety of sensors. In fact the new-generation pervasive computing systems deal directly with the solution of the problem rather than with the provision of appropriate data, such systems could be called problem-centred systems. A novel (Amft, Kusserow, & Tröster, 2007; Amft & Tröster, 2008) for nutrition monitoring was developed and introduced. This system uses context awareness algorithms avoiding the use of tedious questionnaires. They allow estimating calories intakes, monitoring the frequency of food and liquid intake and detecting the changes in person's

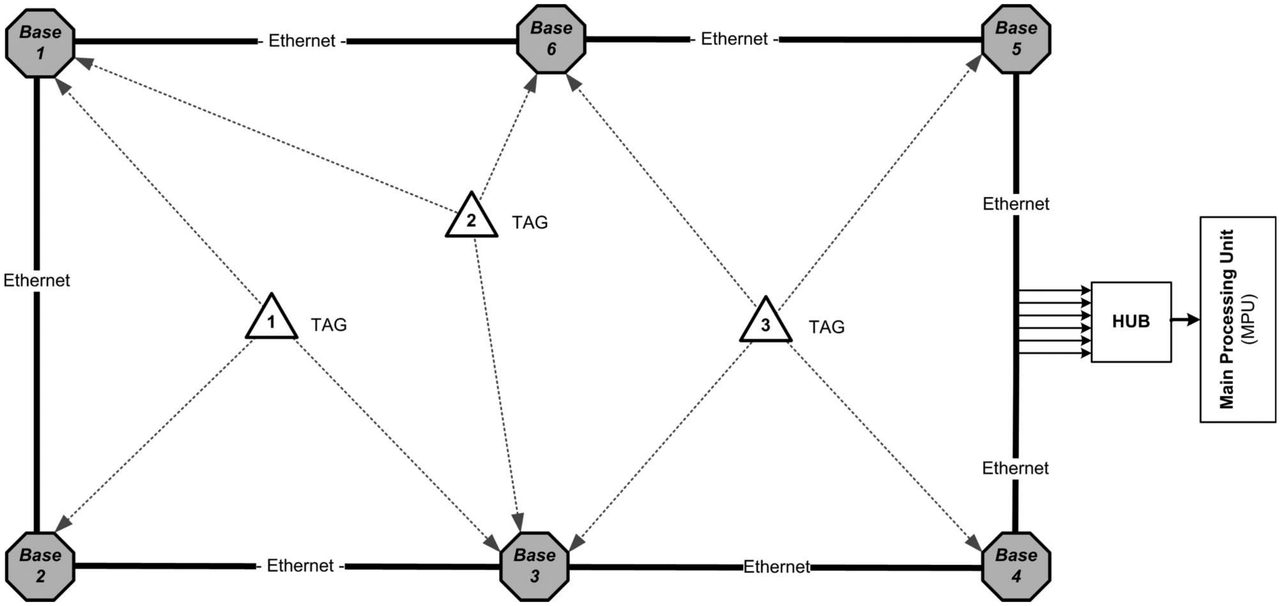


Figure 3. Radio/micro wave based system for player tracking. Active sensors ("tags") transmit unique signals periodically (e.g. 10 Hz). Several base stations receive these signals at different points in time. Applying a triangulation method, the MPU calculates the position of each tag.



behaviour, fitness and weight. The monitoring is based on correlating known activities to given signals – for example, chewing a fruit and candy bar. In essence, they monitor and quantify behavioural patterns. Such systems are at the forefront of new developments as they provide the means for non-invasive monitoring and minimum interference with user's tasks. They are very promising for use in sport as they have the potential to avoid overburdening of athletes that are monitored constantly and tested. The systems are currently being implemented as part of multinational projects on different user groups and their impact is being assessed. These systems represent the relatively new and very promising platform for pervasive computing – wearable electronics. The most appealing trends in it are the smart and functional textiles (Dabnichki, 2008b). These new developments allow weaving or printing electronic circuits on textiles and directly measure a variety of physiological parameters. An example for breathing frequency measurement is presented in Figure 4. Furthermore, a variety of textile sensors have been developed that allow accurate and non-intrusive monitoring and data transmission (Dabnichki, 2008b).

Figure 4. Smart running vest – measures breathing frequency and heart rate and transmits the data wirelessly.

## Coaching and training systems

Real-time performance monitoring systems enabling immediate availability of the information collected are particularly useful. Coaches and athletes may thus be supported during training and competition.

Eskofier et al. (2008) developed a system for real-time athlete surveying and monitoring with emphasis on outdoor and endurance sports. Self-rated information about the psychological state of the athletes as well as speed and GPS position may be collected using a lightweight and highly mobile application.

Baca and Kornfeind (2006) present four feedback systems to be used in training, which provide coaches and athletes with performance data shortly after motion execution. In table tennis, Knowledge of Results information is given either on the impact position of the ball on the table or on the time interval between impacts of the ball during service. Knowledge of Performance information is provided in rowing on a stroke by stroke basis (pulling forces and reaction forces in the foot stretcher) and in biathlon shooting (trajectory of the muzzle immediately before shooting). All measuring systems have been designed so as not to affect negatively athletes in executing their motions.

Hey and Carter (2005) developed a novel and very promising system for tennis training that utilises the advantages of pervasive computing to allow solitary training.

In order to transmit performance relevant information such as position (e.g. Beetz, Kirchlechner, & Lames, 2005), reaction force (e.g. Smith & Loschner, 2002) or heart rate data, wireless technologies are being applied increasingly. Collins and Anderson (2004) report on a system for monitoring performance data in rowing. A PDA with inbuilt WLAN capabilities and a data acquisition board within an expansion box are coupled. The PDA captures the data from sensors mounted on the rowing boat and transmits it to the laptop of the coach, who may give immediate feedback (Figure 5). In a typical practical use the coach gets a live view of the forces (e.g. pulling force) produced by the rower.

Michahelles and Schiele (2005) present an application of wearable sensors in downhill skiing. Various sensors are embedded in the clothing and the ski boots. Information on the athlete's motions is derived from accelerations, angular orientations, forces and pressures. This can improve the quality of data relayed to the trainer and help to understand the athlete's perspective of the information. Walsh, Martinez, and Barrett (2006) propose an approach of that kind in team sports. All players of a team competing in the Irish sport of hurling are equipped with a wireless sensor helmet utilising various embedded sensors to acquire the player's physiological parameters and also to measure the severity of head impacts. The information from all players is transmitted wirelessly to a laptop on the sideline. Coaches viewing this information on a laptop can give adequate instructions; doctors make critical decisions on the player's safety. Baca and Kornfeind (2007) have generalised this concept. They propose a system architecture for monitoring, transmitting and processing performance data in sport. Sensors acquire the relevant data; the digitised signals are transmitted to a mobile client over a wireless interface and from this sent to an internet server (Figure 3). Thus coaches and sports scientists may give fast feedback not only at the training site but also from remote locations. Basically, such framework allows monitoring physical performance parameters of athletes and, moreover, the use the bidirectional route to positively affect the training process.

## Decision systems

One particular aspect when evaluating sporting activities is the compliance with their rules. The Hawk-Eye system used in deciding whether a ball in tennis is out or not is a typical example for such a rule enforcing system.

Wireless sensor technologies may also support judges in making their decisions. Chi (2005, 2008) presents a system used in taekwondo competitions.

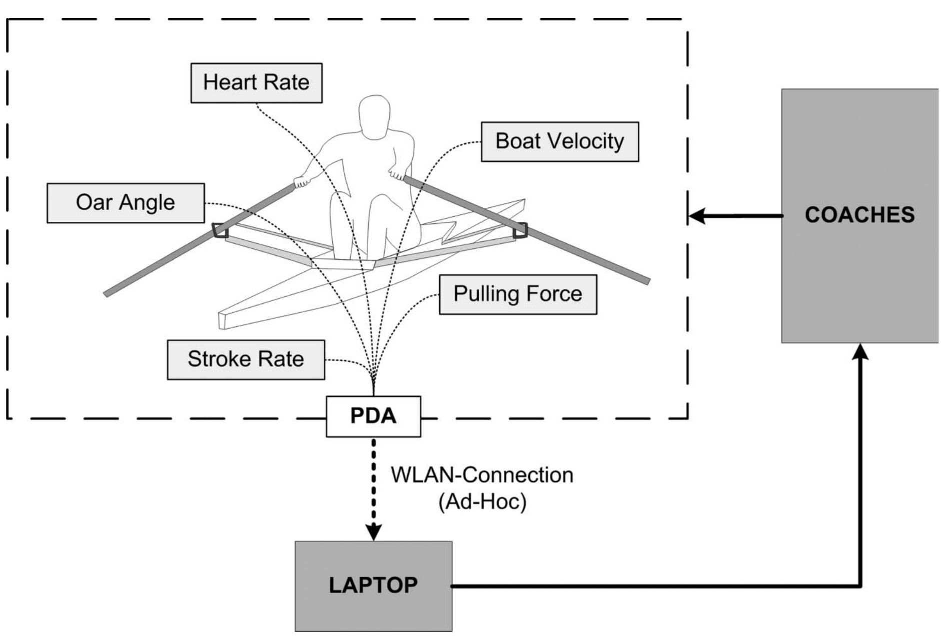


Figure 5. System for monitoring performance data in rowing. During training the acquired data are transmitted wirelessly to the coach's notebook.

The system requires force sensors to be inserted into the body protectors worn by the athletes. Judges are assisted in deciding whether a hit was a scoring point or not. A similar system for use primarily in the sport of boxing is proposed by Partridge et al. (2005). Harding, Mackintosh, Hahn, and James (2008) classify aerial acrobatics in half-pipe snowboarding automatically using data from body-mounted accelerometers and gyroscopes.

Such systems may be able to provide limited help or advice but the decision ultimately lies with the user.

## Leisure and entertainment systems

Systems for measuring activities in sport are applicable in elite sport, but also to sports activities during leisure time and for entertainment. Sports and physical activities can be supported either by integrating technology into the activity or motivated through the technology as is the case in computer games controlled by motor activity.

Hellbrück, Lipphardt, Pfisterer, Ransom, and Fischer (2006) and Pfisterer et al. (2006) propose a system which uses ubiquitous technologies in order to make marathon races more entertaining for runners and spectators. Their application is based on a network of sensors attached to the marathon runners. The sensors exchange messages among each other and with base stations positioned along the route to transmit the collected data to a backend system. From the exchanged data the position and sequence in the field of runners are determined and also forwarded to the backend. In addition, heart frequencies of the runners are recorded continuously. The system is also designed for monitoring additional biomedical data.

If computer and communication technologies are integrated into the sport equipment or in fitness devices, additional benefit for the users can be achieved (Kranz, Spiessl, & Schmidt, 2007; Stevens, Wulf, Rohde, & Zimmermann, 2006). Intelligent fitness devices, for example, could adapt automatically to the users' needs, thereby protecting them from conducting exercises in a way injuring their bodies. Smart systems have been introduced recently from specialised engineering applications into the area of sport and leisure. The advantage of these systems is that they allow avoiding the use of traditional computers and provide simple narrow solutions. The most widespread use of smart systems is in the form of vibration dampening, specifically in skiing and tennis.

Another recent trend is the use of ubiquitous computing in the development of simulators for different sports including even contact sport (Chi, Song, & Corbin, 2004). An interactive bicycle simulator with six degrees of freedom was developed by He, Fan, and Ma (2005) to bring the rider a realistic riding feeling. An important component of the simulator is the full bicycle dynamic model that simulates the two-wheeled bicycle dynamics in terms of stability and vibrations. The stability is simulated under the rider's active manoeuvres and the vibration simulates uneven road surfaces. The advantage of such simulators is that they bring different environments to the laboratory conditions and allow appropriate preparations. For the contact sport they facilitate preliminary assessment of the fighter's ability against a given opposition. Such simulations can be conducted as data are fed across the globe – meteorological conditions terrain, etc. Real-life data are processed and transformed into appropriate sequence of signals that allow athlete preparation in close to real-life conditions.

With regard to sports entertainment, Chi (2008) distinguishes between two possibilities for using pervasive computing technologies. First, they are applied in the area of sports computer games thereby motivating physical activity as has been mentioned previously. Computer-Human-Interaction systems have already been designed for different sports. Users' motions are captured and used as input for controlling the virtual run in order to improve the realism and the enjoyment during the game experience. Head, hand and body tracking devices are designed for this purpose. To capture the motion, various small sensors (e.g. accelerometers, gyroscopes) are used. The data are transmitted by wireless devices. Nintendo®'s Wii™ video game console (Nintendo Wii, 2009) is a typical representative of such systems. Accelerations in three dimensions of a wireless controller are detected enabling to control the game. An optional balance board in combination with specific software enables interactive aerobic exercises, muscle conditioning, yoga poses or balance games (Nintendo Wii Fit, 2009). Hämäläinen, Ilmonen, Höysniemi, Lindholm, and Nykkänen (2005) present a martial arts game motivating training through playful environment. The video image of the user is embedded into a virtual playfield fighting virtual opponents. An interactive fitness game is evaluated by Höysniemi, Aula, Auvinen, Hännikäinen, and Hämäläinen (2004). During the game, players move sideways facing a web camera. They perform punching movements to control a game character. On eight out of 11 participants heart rates at an optimal level for aerobic training were measured after completing the game. Interactive sports simulations based on VR environments may be used to generate realistic game behaviours. Rusdorf, Brunett, Lorenz, and Winkler (2007) developed a real-time table tennis simulation where players are interacting against a virtual opponent. Key features of this system are, among others, a collision detection (between ball and racket), stereoscopic projection of the scenery and a short system latency ($<100$ ms).

Second, data collected can be used by sports broadcasts to help illustrate informative segments. Ski jumping contests are, for example, illustrated by fading in heart rate data from the jumpers, marathon races by showing the position of the runner on a map of the course, table tennis matches by visualising the impact positions of the ball on the table (Baca & Kornfeind, 2006).

## State of the art

The pervasive use of computers in applied sports science is accepted and expected (Reilly, 2006). The last decade of the twentieth century was characterised by a mass use of computers in terms of record keeping and data processing by all support staff – from coaches to psychologists and physiotherapists. The current decade has seen a rapid increase in the field use of computers in combination with sensors and transmitting devices – pervasive computing. Some of the new technologies, such as techniques for player tracking in game sports or such applied in sports computer games, are widely adopted. Others are still experimental mainly, such as intelligent fitness devices or most decision systems, where regulations of the competition need to be changed. Teams prepare for different competitions remotely as the technology allows simulation of distant conditions. Furthermore, athletes have been monitored constantly to ensure them reaching top condition and timing the interventions. All these technological advances facilitated the switch to evidence-based coaching and training. In addition, the non-intrusive monitoring has positive motivational effect on the athletes. It has increased too the potential for global interaction and data sharing.

However, there are a number of shortcomings. The most important one is that most of the devices in use need more rather than less backroom staff and hence can be used only for elite sport. They have the potential to overburden coaches and tend to be left away after the initial excitement is worn thin. There are results demonstrating that the technological efforts may not always be helpful. Computer-based direct feedback in motor control, for example, can even be contra-productive. A majority of the current problems are related to the amount of data and their structure. The data collected are highly complex with many implicit correlations and dependencies. As such data are not shared and discussed, and therefore as secrecy is an inevitable part of elite sport, the decision-making remains subjective and unclear. Currently, significant time is being devoted to data processing and analysis leading to reduced social interaction in the teams and potential personal clashes. Last but not the least athletes' data are shared among a large number of experts posing clear ethical questions on privacy protection.

## Future directions

From the discussion in this work, it is clear that the technological progress in sport in general and pervasive computing in particular has been tremendous. From sensor, transmitters and antennas to computer platforms the components have become smaller, more durable, highly accurate and reliable. Virtually every aspect in athletes' performance and preparation could be dissected analysed and improved. However, it seems that the balance has been tilted towards technological developments that are pushed on athletes and support staff and then have been frequently changed creating confusion and discomfort. Hence there is a clear need for standardisation in measuring techniques, transmission protocols and data structuring. This will facilitate stability and will provide space for both athletes and coaches to learn and embrace the new approaches. Furthermore, such standardisation and data sharing would allow effective surveillance of training to reduce the use of illegal means.

In conclusion, we believe that the emphasis in the future developments will shift to development of intelligent systems that could not only analyse the data but suggests strategies and interventions. This will be facilitated not only by technology and algorithms but by larger socially inclusive global networks that facilitate user group interaction and in turn disseminate both empirical and science-based knowledge. These fast penetrating networks will have self-structuring abilities and will be able to address the need for inclusiveness, social interaction and support. In our view, this is the best proof that the vision of Weiser back in 1988 was prophetic and the time when social and professional activities will be amalgamated by invisible and helpful technology is fast arriving. The great benefit for sport will be that knowledge and expertise in world class sport will trickle down to mass level that in turn will supply the elite with access to new talents and ideas.

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