Advances in Sports Informatics Research

Martin Sykora^, Paul W.H. Chung*, Jonathan P. Folland+, Benjamin J. Halkon#, Eran Edirisinghe*

^Centre for Information Management, School of Business and Economics
*Computer Science Department
+School of Sport, Exercise and Health Sciences
Wolfson School of Mechanical and Manufacturing Engineering
Loughborough University, LE11 3TU
(m.d.Sykora, p.w.h.chung, j.p.folland, b.j.halkon, E.A.Edirisinghe)@lboro.ac.uk

Abstract. With advances in hardware and software, computer science based technologies within sports sciences are becoming more pervasive. This paper presents the growing field of applied computer science often referred to as *"sports informatics"*, and considers some of the advancements that have been made by its relatively small, but growing research community. The review includes: feedback systems, team play analysis, image/motion analysis, exertion interfaces and virtual reality, and data mining and artificial intelligence.

Keywords: Sports Informatics, Team Play Analysis, Feedback Systems, Image Processing, Data mining

1 Introduction

A useful and thorough definition of sports informatics as a scientific discipline was proposed in [1]: *"Sport informatics is a set of multi- and interdisciplinary research programs including components of sport science and computer science. The material field is the application of tools, methods and paradigms from computer science on questions of sport science as well as the integration of sport scientific knowledge in computer science."* This definition highlights the two-way relationship between sport and computer science.

The broad scope of sports informatics research has applications in high performance sports, as well as the healthcare and entertainment sectors. Within elite sport the aim is typically to track, analyse and improve performance by providing feedback to athletes, coaches and/or sports scientists. With recent improvements in instrumentation (GPS, accelerometry, motion analysis) and data processing, contemporary work has focused on taking classical sports science research out of the laboratory and into more realistic field settings. For the wider population the primary aim of sports informatics, however, is to increase physical activity and exercise adherence in order to maintain/improve physical fitness. This has helped foster physical activity and human movement related entertainment applications of sports informatics such as exergaming.

Applications of computers in sport have been reported as early as the mid-1960's [2] although these were somewhat rudimentary. According to [3], the term *sports informatics* was first coined at a congress in 1975 in Graz, Austria, organised by the International Organisation for Sports Information. Supplying Information and Communications Technology (ICT) in competitions is one of the most challenging practical examples of the applied use of ICT in sports. At the 2004 Olympics in Athens, more than 10,000 computers, 4,000 printers attached to 900 servers, 300 routers, and 2,000 switches were supported by 300-400 computer professionals [4]. [5] describes a virtual environment for enhancing athlete preparation ahead of the 2002 Salt Lake City Olympics, an example of sports informatics research aiming at improving athletic performance at major sports events. A major driver for sports informatics research was the dramatic improvement in computer hardware, which has become faster and smaller. The miniaturization of hardware has made it possible to attach a wide range of sensors onto athletes and equipment in order to acquire data without affecting the athletes during training. The following sections provide a review of the various relevant research streams identified during this study.

2 Research Streams

The research streams in sports informatics is categorized by [2] into: data acquisition, databases and expert systems; modelling and simulation; multimedia, presentation; virtual reality; information and communication technologies; biomechanics and sports technology. Due to advances in ICT and video processing algorithms, classical biomechanics data collection suites have become increasingly mobile and easily deployable in real world, field environments e.g. the entire pitch area within a soccer stadium.

Advanced modelling and analysis software have been applied to a wide variety of sports related problems. Many of these software are based on Artificial Intelligence (AI) techniques. Effective presentation and visualization of data can improve cognitive understanding of complex data outputs and be beneficial to coaches and athletes.

Virtual reality and immersive environment applications also have an important place in sports, given their demonstrated effectiveness in preparing athletes for competition and training.

Many applications in sports informatics are essentially a type of feedback system so the next section will review feedback systems specifically. Our study of literature identified the following research themes in sports informatics: team play analysis, image / motion analysis, exertion interfaces / virtual reality, and data mining / AI These themes are the focus of the rest of the paper.

3 Feedback Systems

Feedback enables athletes to modify their movements and produce optimum performance. [9] identifies and provides examples of eight types of feedback systems: 1-video information feedback, 2-three-dimensional virtual environments feedback, 3-intrinsic feedback under vibration conditions, 4-temporal feedback, 5-feedback about team performance, 6-feedback in aiming sports, 7-force platforms / transducers based feedback, 8-eye tracking technology based feedback. He also points out that combinations of these feedback types are quite common. [10] discussed the various performance lifecycle elements typical for instrumented feedback systems: 1-measurement and data collection, 2-data capture and storage, 3-data analysis and feedback in real time, 4-feedback post-event, 5-information and review, 6-data archiving. Achieving each within a complete system, represents a significant area of research, since the various individual tasks involved are non-trivial.

[11] presents an exemplary swimming performance monitoring and feedback system which caters for all elements of the performance lifecycle, capable of tracking and providing feedback on elements of interest, such as technique and physiological capability. A lot of other currently accessible systems track various performance parameters in isolation without proper integration to provide for the needs of the athlete, coach and all supporting personnel (biomechanist, nutritionist, strength-conditioning coach etc.). [12] provides good examples of three rapid feedback systems: rowing - pulling forces and reaction forces in the foot stretcher on a stroke-by-stroke basis; table tennis- monitor the impact positions of the ball on the table and the time interval between impacts of the ball during service; biathlon shooting – the orientation of the muzzle immediately before shooting is monitored. The latter system, for instance, uses a single video-camera positioned diagonally several meters in the direction of the shot. Image analysis, based on a simple colour histogram model, is used to pick up the muzzle position in relation to the shot-target. The classical use of laser reflective plates can be worn out and damaged quickly and are considerably more expensive and involved to set-up. As the shooter is aiming, a video is recorded and provided on a screen to the athlete for review.

[13,14] point out that a clear trend in sports informatics is the use of small ubiquitous sensors. The sensors used in sports can be categorised as those that are attached to the athlete’s body (accelerometers, gyroscopes, GPS receivers, RFID tags, and a variety of physiological sensors), or mounted on parts of the sports equipment (i.e. equipment monitoring). They are used to measure physical quantities such as force, torque, pressure, acceleration / velocity / position (linear/angular) etc.

Feedback systems are not exclusive to high-performance sports. [15] presented a system called Mobile Motion Advisor (MMA), which is a mobile feedback system designed to support high school students by giving advice during physical exercises.

4 Team Play Analysis

The use of sports informatics relating to team sports is becoming popular in research [8, 16]. Previously, real-time player position and motion analysis in team sports was done using notation by hand or audio recording during a match, which was extremely time consuming particularly for the production of post-match analysis. [8] provides a review of observational analysis (for team sports in particular), and the technological advancements that have been progressively introduced into observational analysis. [17] presented one of the first computer-aided systems (goals/shots/specific plays were annotated with specific sections of video-action).

The most common contemporary approach in many sports, including soccer, rugby, ice-hockey or basketball, is to employ a system of multiple cameras (usually two to 12 strategically positioned cameras) around the playing field, and vision / image processing algorithms to track the players and the ball in a non-intrusive way [18]. For example, Prozone (http://www.prozonesports.com/) is a relatively well known commercial system. The problems of image processing associated with such systems include weather and lighting conditions and player occlusions. They are, therefore, typically semi-automated with a degree of manual verification [19, 20]. In football heuristics have been applied to automatically detect events such as simple ball-in / ball-out, ball contact, throw-ins, corner kicks, passes, possession, pass interceptions, shots on goal – derived solely on player and ball tracked data [21]. Using microwave-based player and ball tracking system can also provide coaches with player activity profiles, frequency distributions of tactical behaviour, and assess aspects of an opponent's tactical play [22]. This system employed AI techniques to classify the action into five layers: 1-position and motion; 2-action; 3-situation; 4-tactical and 5-tactical assessment – with each layer permitting an analysis at that level, and forming a basis for inferences at the next level.

Despite the drawbacks of visual camera based systems, advances in technology have enabled observational sports analysis to require less human intervention and to speed up the annotation process [8]. However, because of the need for manual verification with camera based systems a player tracking system based on sensors and microwaves tends to perform with far better accuracy [6]. Unfortunately, wearable sensors are not currently permitted during competition.

Analysis of team sports is also increasingly used to engage fans via television and web-based media. For example, the NHL'sonline Ice-Tracker system (http://www.nhl.com) shows live matches on a graphic visualisation of the rink, with the capability to query the graphic for events of certain players, specific time-intervals, or types of events (body checks, penalty minutes, number of shots, types of shots, most frequent shooting position to goal angles, etc.). This arguably enriches the NHL website visitor's experience of a match.

In summary, comprehensive intelligent analysis has the capacity to enhance in-match and post-match coaching practice and decision making. However at present both the automation and sensitivity of event detection during competition (with visual camera systems), and the extraction of tactical patterns, require considerable research and development.

5 Image / Motion Analysis

One common methodology in biomechanics is the kinematic assessment of human movement, that is typically done with high-precision camera systems and custom hardware and software to track placed markers automatically. These systems tend to be expensive and mostly restrict data collection to indoor environments. Advanced image processing devices that do not require markers (e.g. Microsoft Kinect) use algorithms and infrared point clouds to gain depth perception and detect body segments have begun to appear. At present, however, the Kinect system underperforms considerably in some aspects of accuracy, compared to a conventional marker tracking system (VICON). On the other hand, the Kinect was surprisingly accurate in tracking the mass, size and inertia of body segments [23].

Gaining depth perception and subsequently performing pose estimation and accurate motion tracking, purely from video sequences (i.e. without the use of point clouds, as in the Microsoft Kinect) is an ongoing research challenge. The use of video footage to achieve the data collection is naturally a preferred choice due to wide availability of such data, both current and historical sporting events are available on high-quality video.

There is insufficient space for a complete review of research in video-based image processing for pose and motion estimation that is relevant to sports informatics. The special double issue edited by Sigal and Black [24] is recommended. The following issues and challenges are highlighted [24]:

- Tracking of complex activities from monocular imagery (or with fewer than four cameras);
- Dealing with general loose clothing;
- Tracking multiple interacting people;
- Automatically recovering from failure;
- Automatically adapting to different body shapes;
- Dealing with moving cameras / backgrounds and strong / variable lighting;
- Tracking through non-trivial environmental conditions.

In relation to the first item, with the increasing wide availability of high-quality monocular cameras within smart-phones, rather interesting solutions have been proposed. For instance, [25] proposed a marker-less body and motion tracking approach based on a dynamic colour model from a monocular (smart-phone recorded) video-sequence. The aim was to track motion for postoperative kinematic analysis, which would have applications in health and exercise. Acceptable segmentation and tracking results (related to correct form during execution of post-operative physical exercises) were obtained. Joint angles, however, were not very accurately tracked. The authors suggest augmenting the system with human-body models to improve joint angle accuracies. Including more (low cost) cameras tends to generally improve performance significantly. It is also expected that development of relevant algorithms will further improve performance relating to challenges two to seven above. In order to assist in the evaluation and validation of image processing algorithms for pose estimation and tracking of human motion, ground truth datasets are necessary. [25] suggest for instance the HumanEva (http://vision.cs.brown.edu/humaneva/publications.html) datasets to be used to benchmark future research in this area. The dataset contains calibrated videos in which subjects perform common actions such as gesturing, walking, jogging, etc., for which the corresponding ground-truth was obtained from an industry-standard motion capture system.

Although underwater and on water-based sports have not been discussed specifically, these sports present further challenges of their own in biomechanics data collection [26, 27, 28].

6 Exertion Inferfaces and Virtual Reality (VR)

The aim of interactive sports via web-based media is not to replace existing sports but to provide participants with a comparable activity when they are geographically separated. It enables participants to interact and compete in a manner comparable to co-located sports, and can provide a shared experience and social interaction. It can be difficult to find local fellow participants with similar physical capabilities in order to ensure a mutually enjoyable or productive experience. Web-based exercise and sports expands the range of potential exercise partners [29]. These applications have emerged in part from the fusion of sports and computer technology within computer games. However to date, not much work has been done on enhancing social sports experiences. Many computer games support network play but have been criticized for encouraging social isolation of the players. This began to change with the advent of exertion interfaces, such as the Nintendo Wii and Microsoft Kinect [30]. Exertional games, or exer-games, are computer games where players use grossmotor movements of the body to interact with the gameplay, rather than micro-manipulation such as using fingers to press buttons [30].

The development of exertion interfaces has stimulated further work and has been facilitated by a number of open source development libraries (e.g. Pointcloud library (http://www.pointclouds.org) and Open NI (http://openni.org/)), which open up the commercial technologies to researchers. [31] investigated the uses of Nintendo Wii, as exertion interfaces for the elderly, while Bekker and Eggen [32] looked at their potential benefits in use with children. It can be argued that interaction with fitness video games generally does not significantly improve a player's skill in real life. For example, playing bowling in Wii Sports does not improve bowling skills. Therefore some researchers, such as Campbell et al. [33], presented work where a daily fitness activity, for which there is a fitness application to track exercise performance, is augmented with an interactive and fun element, also often referred to as "gamification" of a real world activity [34]. It has been argued that "gamification" of real world sports potentially adds an extra element of social engagement to an activity, and can be useful in breaking-up sizeable exercising tasks into more achievable sub-goals. [33] present an example of Nike + iPod running experience augmented by a fantasy game that tries to improve on Nike + iPod. Nike + iPod system uses a small sensor placed in a runner's shoe to track runs in support of multiplayer challenges on the Nike+ website;

however, the system is primarily focused on macro goals, and does not encourage frequent gratification associated with micro goals, but at the same time provides very limited social interaction within the online community. Kukini [33] is set in an imaginary world of elite class of swift runners of legend, known to undergo strenuous training as warriors, messengers, and foot racing athletes, with a significant social play element, integrated via communication layers throughout the game that support building relationships, forming teams, and interacting with other players both co-operatively and competitively. The game emphasizes micro goals by breaking up distances.

VR has been used effectively to help train astronauts, pilots, physicians, military personnel, and athletes [35]. In a 3D virtual environment, the coach may regulate important factors that influence perception, such as speed, orientation and directional changes, simply by operating a joystick or a keyboard. Training in this environment could enhance skill adaptation through progressive and repetitive practice in a systematic manner that is feasible in a highly controlled environment, but difficult to achieve in real environments. Skill may thereby result as a by-product of training in controlled simulated 3D environments. VR systems also have the potential to provide enhanced, immediate and direct feedback to participants [9]. Examples include a bobsleigh simulator for training the US bobsleigh team [36], a speedskating virtual environment for enhancing athlete visualisation and preparation for the 2002 Salt Lake City Olympics [5], and an archery system based on haptic feedback, motion tracking and custom graphical avatars [37]. There is some indication that various elements from VR and exertion interfaces are coming together in one solution [38]. The authors implement a martial arts game, based on an exertion interface, motivating training through a playful VR environment, and subsequent evaluation their system on 46 martial arts practitioners with encouraging results.

7 Artificial Intelligence (AI) and Data Mining

AI techniques are receiving attention in sports informatics literature. For example, sensor based feedback systems [39], team-play analysis systems [40], or many of the pose recognition applications [41] have benefited from AI classification algorithms. Baca et al. [6] point out that there is an increasing need for smart and intelligent systems and that research effort emphasis should shift from fundamental technologies to intelligent systems. The authors point out the need for applications of AI in coaching / training systems and especially the use of decision systems, which leverage machine learning and methods from AI. Such systems, it is argued, will help take the load off from coaching staff by semi-automatically discovering valuable insights and patterns in the datasets. [7] provides an introduction into AI / soft-computing modeling within sports informatics. A lot of classical sports science experiments and analysis of data could benefit from these techniques and the field of data mining [13]. Much historical performance data from different sports is readily available; however, the data mining and pattern discovery within these has been limited. For example an application of genetic algorithms was used to optimize alpine ski paths, given some constraints and fitness level parameters [7]. Erdogan et al. [42] provide a useful review of previous uses of Artificial Neural Networks in sports science related problems.

The increase in ubiquitous sensors has also facilitated the use of embedded intelligence in sports-related feedback systems. For example Neural Networks and Hidden Markov models have been used to recognise different movement patterns, based on force data [43]. There are numerous other potential applications in sports, healthcare, entertainment and leisure.

8 Conclusions

Feedback systems are not necessarily only applied in high-performance sports, although this has been often a common application area. Given current nationwide issues and health care costs associated with obesity, applications of such systems present a research area for future work. Non-intrusive or sensor based player tracking systems are highly sought after and receiving extensive research and development attention. The use of this information is also encouraging the development of intelligent decision support systems that may ultimately provide real-time guidance to coaches during match play. Image recognition is traditionally a significant research area in computer science. The application of image / video processing algorithms to sports, health and exercise applications, presents an interesting set of problems in constrained environment. Exertion interfaces, virtual reality, and AI / machine learning are all highly relevant to sports informatics and hold much promise. The integration of different technologies to cover the whole sports requirements also need to be considered. However, one must consider the criticism that technology and informatics use in professional sports can sometime be seen as unethical and inappropriate by some [44].

9 References

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