



Pervasive Computing in Sports Technologies

Sport is an extremely exciting field in which to apply our craft. Results over the last decade of research on applying ubiquitous computing technologies to enhance sports are indeed encouraging.

Researchers have learned a great deal about sensors and how to embed them in everyday objects. For example, accelerometers, gyroscopes, microphones, and cameras all lend themselves nicely to a range of sports applications. Computer vision algorithms are enabling researchers to analyze not only a single player's motions but also the patterns of a group of players simultaneously.

Our goals in organizing this issue are to encourage and highlight new research in this emerging area and to pique everyone's

interest in understanding how technology can be applied to sports. Indeed, other efforts to do this exist. For example, in September, a pioneering workshop at the UbiComp '05 conference (<http://ubicomputing.org/ubicomputing2005/calls/callworkshops.shtml>), organized by Intel researchers Elizabeth Goodman, Brooke Foucault, and Sunny Consolvo, will examine various issues of applying technology in sports. This workshop is certainly timely, coinciding nicely with this special issue.

The growing interest in and demand for better sports technologies have spawned a wide variety of new research.

Important trends and implications

Pervasive computing researchers are studying three areas of sports technologies: athletic performance, leisure and entertainment, and how technology could affect the rules of the game.

Improving sports performance and learning

The history of sports performance studies is littered with success stories. For example, instruments have been built into golf clubs to offer golfers a computer analysis of their swing,¹ and runners use heart rate monitors to track their training progress. Researchers continue to innovate, creating new ways to understand human performance in sports. For example, Joan Vickers has been examining neuromotor psychology by studying the gaze of athletes while they perform specific sport skills using helmet-mounted eyetrackers.²

Sports technology, of course, isn't limited to enhancing performance; it potentially extends into rehabilitation and injury prevention. For example, in a recent *IEEE Spectrum* article, high-tech prostheses enabled double-leg amputee Oscar Pistorius to run nearly as fast as able-bodied athletes, raising the question regarding whether the Olympics

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will allow athletes with running prostheses to compete.³

Almost any sport could benefit from equipment enhancements as well as novel measurement and analysis of athletes' performance. From popular sports such as golf, baseball, and basketball to extreme sports such as snowboarding, motocross racing, and rock climbing, athletes can all gain from a better understanding of their muscle movements, orientation, and heart rate response. The research question here isn't to instrument everything on the human body but rather to understand what the most appropriate sensors are and how they should be used. Being "appropriate" here means enhancing players so that they want to use sensors in their training, enabling unobtrusive instrumentation so that coaches can analyze the best data available, and cooperating with judges so that they make good, socially acceptable calls on the field.

Leisure and entertainment

Sports are also closely tied to the availability of leisure time and the desire for entertainment. Using technology in sports entertainment offers two possibilities. The first is in participatory games. For example, game arcades have already incorporated various technologies into soccer balls, golf clubs, baseball bats, motorcycles, and boxing gloves to make sports games more entertaining. Companies such as Laser Quest are creating innovative new games with laser tag equipment, such as the team mission game of protecting the queen bee (www.laserquest.com/pages/about/LQ_About.html?index=about). Laser tag games can be every bit as exhausting as professional sports. As another example, fitness clubs have started to incorporate video games in their exercise equipment. For example, in the mid-1990s, Life Fitness connected its Lifecycle to a Super Nintendo (www.gamersgraveyard.com/repository/snes/peripherals/exertainment.html). The faster you pedaled, the faster your counterpart on the video game screen went. This kind of equipment encourages users to exercise harder.

The second possibility is to use technology to enhance spectators' enjoyment. Major tennis tournaments now measure the speed of serves, for example, to satisfy spectators' curiosity about what it might be like to receive such serves. On the other hand, TV viewers rejected the use of highlighted trails of hockey pucks during live broadcasts of National Hockey League games (www.embedded.com/97/inc9603.htm). The pucks were instrumented with 20

disk wheels in cycling events after some wrangling in 1984.) Other controversial technologies include the Cyclops tennis line-calling system (discussed in this issue in Ed Chi's article). In most cases, sports' governing bodies are reluctant to adopt new equipment technologies and standards. Indeed, in many cases, the rules themselves must be changed to accommodate new technology.

Occasionally, however, governing bodies can themselves be the catalyst for

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infrared emitters, and sensors around the rink picked up the infrared signals to track them. Fans hated the trails, so TV broadcasters eventually pulled the trails out of their live coverage of the games. How to design technology for spectator enjoyment has been less than clear. The key appears to be balancing tradition, distraction, and satisfaction of spectator curiosity. Spectators enjoy total immersion in watching live sports, so the technologies we introduce must assist in this immersion rather than disrupt it.

Interaction with sports authorities

A technology's acceptance not only involves spectators but also the sports' governing bodies. The US Golf Association heavily regulates the modification of golf balls, clubs, and other equipment. The so-called "dimple wars" in the 1970s ignited quite a controversy about such equipment; people even feared that "old" golf courses would become obsolete because balls were traveling much further than before due to new ball design.¹ As another example from the past, bicycle design modifications have been severely restricted, with several newer, fast recumbent-type designs rejected for international competition.⁴ (Cycling federation officials did allow

change. In a rule change in May, for example, the World Taekwondo Federation reduced the number of scoring judges required around the competition ring from four to two when the competition includes the new force-sensing electronic chest protectors. Interestingly, these new chest protectors aren't even on the market yet, so the governing organization is one step ahead of the technologists. (See Chi's related article in this issue.)

In this issue

We've chosen four articles for this issue. First, Gertjan Wijnalda, Steffen Pauws, Fabio Vignoli, and Heiner Stuckenschmidt present a research product for personalizing music selections based on heart rate monitors and MP3 players. The idea is both simple and elegant. By monitoring runners' heart rates before, during, and after exercise, the IM4Sports system can construct unique personal training programs automatically. The device helps users select songs that fit their training programs and can dynamically change playback to guide the runners. During training, it can modify the tempo to suit the runner's speed. This research has immediate marketplace appeal by making training programs not only more enjoyable but also more effective.

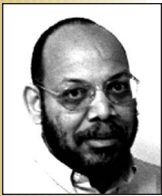
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ond article, Michael Beetz, Bernhard Kirchlechner, and Martin Lames present a novel system developed at Fraunhofer Institute for Integrated Circuits for tracking not only the soccer ball on the field but also the players.⁵ Coin-sized microwave transmitters that are embedded in the ball and players' shin guards broadcast signals to receivers placed on floodlight masts and sidelines. A central computer calculates the exact location from these pulsed signals, much like how global positioning systems work. By analyzing game data and patterns, the authors hope to enhance coaching, spectators' enjoyment, and everyone's understanding of game strategy. With balls and players

instrumented, spectators and coaches will be able to know a shot's speed, whether the ball passed the goal line, and who ran the fastest.

The last two articles present wearable devices. Florian Michahelles and Bernt Schiele apply wearable sensors to downhill skiing. By embedding various sensors on clothing and ski boots, the system reveals information about the athlete's motions, including forces, rotations, and accelerations. This is a huge improvement over the quality of data that previously could only be partially obtained from video analysis. By working with trainers and former World Cup coaches, the authors are developing data visual-

ization software that presents measured sensor data alongside the reference video.

Finally, guest editor Ed Chi, a Taekwondo black belt and referee, analyzes the criteria for the social acceptance of sports technology by players, coaches, and sports organizations. Working with the Stanford Taekwondo Program and the Silicon Valley startup company Impact Measurements, he developed a prototype system in which sensors were embedded into wearable chest protectors for sparring matches. The article discusses the technical challenges involved and how the system affects the judging of the match. In applying an evaluation framework for ubiquitous computing technology developed by Jean Scholtz and Sunny Consolvo, he notes that several evaluation metrics are important, including the technology's accuracy and predictability; players', coaches', and judges' awareness of the system's technical capabilities; the amount of behavior changes and distraction to the players; and the amount of social resistance to changes in the game's rules or structure.

As these articles show, these technologies have enormous implications. They will increasingly help runners train more efficiently, soccer coaches better understand their athletes' performance, ski trainers design better programs for learning precise muscle movements, and judges score Taekwondo matches more accurately.

As research and discussion carry forward, more and more novel pervasive technologies will be introduced. New uses for embedded sensors will expand our understanding of how to use them in different situations while gaining social acceptance.

One of our hopes is that technology will make sports more entertaining for players and encourage the general pub-

lic to exercise more. As one example, the interactive video game “Dance Dance Revolution” involves players actually dancing on a game mat, so it clearly burns more calories than a typical, sedentary game.

In extreme cases, some players believe changes to sports equipment might actually alter the ideal body type for a sport. We must understand how a particular technology affects the game and whether it enhances athlete performance at the expense of creative expression. Indeed, in introducing new technology into a sport, there’s a fine balance between completely eliminating the human factor in competition and enhancing the expression of fitness and technique. ■

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