Sensors and ubiquitous computing technologies in sports

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**Abstract**

Sensors and other ubiquitous computing technologies have slowly penetrated the arena of sports. As a field, ubiquitous computing has learned a great deal about sensors and how to embed them in everyday objects. Accelerometers, gyroscopes, microphones and cameras all lend themselves nicely to various applications in sports. Here we examine some examples of pervasive technology in sports and points to future directions. This article consists of two parts. First, we outline trends and implications of utilizing sensors in sports. Second, we examine technological challenges in introducing sensors in various sports, in particular paying attention to our own research case study on introducing force sensors into a martial art competition.

**Keywords**: sensors, ubiquitous computing, wearable computing, user interfaces, ergonomics, wireless computing, extreme sports, taekwondo, usability of wearable wireless systems

**1 Introduction**

The development of sports throughout history has been essential to our health and is keeping us strong physically, mentally and spiritually. Sports not only enhance our mind, body and spirit, but as a social activity, also helps us feel connected to the rest of the community. In its manifestation in the spirit of the Olympics Games, it promotes peace and increases contact between different cultures and people. The benefit and importance of sports cannot be overemphasized.

Here we focus on the application of sensors and ubiquitous computing technology to enhance sports. Recent results are quite encouraging. As a field, ubiquitous computing has learned a great deal about sensors and how to embed them in everyday objects. Accelerometers, gyroscopes, microphones and cameras all lend themselves nicely to various applications in sports. For example, accelerometers can be used to detect activities that generate unique motions, while gyroscopes can be used to measure changes in orientation. New computer vision algorithms
are enabling researchers to not only analyse the motions of a single player, but also analyse the patterns of a group of players simultaneously. For example, Stephen Intille at MIT has explored the use of contextual information to track multiple football players in video clips of plays. Knowledge about the rules of football enables the disambiguation of colliding players.

One of our hopes is that technology will make sports more entertaining for players and encourage the general public to exercise more than they do currently. Certainly, the video game ‘Dance Dance Revolution’ must have had an effect on the amount of calories burned during gaming, especially since gaming is otherwise a rather sedentary activity. Indeed, if we can make couch potatoes exercise while playing video games, we might very well be creating a new research endeavour to solve obesity problems in the world.

These new results and a growing interest and demand for better technology for supporting sports activities have spawned a wide variety of new research areas. For example, a pioneering workshop at the UbiComp 2005 conference organized by Intel researchers Elizabeth Goodman, Brooke Foucault and Sunny Consolvo examined various issues of applying technology in sports.

These new technologies can deal with the possibilities of enhancing the experiences for players, spectators or judges in sports in several different ways:

1. We need research that helps us understand how ubiquitous computing techniques could be used to change the game for the better, sense and monitor practices or matches, assist in training and enhance the experience for spectators.
2. Technologies could be developed for a wide range of areas in sports, including single-player, multiplayer and large team sports as well as activities ranging from track and field to indoor team sports.
3. Research and technological explorations could be conducted in a wide range of aspects in introducing pervasive technology into a sport, including reports on the challenges of integration, deployment and usage experience.

What is needed to move this forward is solid research presenting case studies and lessons learned, so that other technologists interested in this area could learn from both successes and mistakes made by other pioneers in this area.

This article consists of two parts. First, we outline trends and implications of utilizing sensors in sports. Second, we examine technological challenges in introducing sensors in various sports, in particular paying attention to our own research case study on introducing force sensors into martial art competitions.

2 Trends and implications of utilizing sensors in sports

First, we review and outline some of the trends and implications of utilizing sensors in sports [1]. Our goal is to encourage and highlight new research in this new emerging area, and to spike everyone’s interest in understanding how technology can be applied to sports.
2.1 Improving sports performance and learning

The history of sensors in sports performance studies is actually littered with success stories in the recent past. Golf clubs have been instrumental in offering a computer analysis of one’s swing for example [2]. Runners have been using heart rate monitors to keep track of their training progress.

Wijnalda et al [3] at Philips Research in the Netherlands present a research product for personalizing music selections based on heart rate monitors and the ubiquitous MP3 players. The idea is both simple and elegant. By monitoring runners’ heart rate before, during, and after exercise, a unique personal training program can be constructed automatically. The IM4Sports system helps users in selecting songs that fit a training program, and can dynamically change playback to guide the runner. During training, the tempo of the songs can be modified to suit the speed of the runner. It is obvious that this research has an immediate appeal in the market by making training programs not only more enjoyable but also more effective.

Researchers in this area continue to innovate on new ways to understand human performance in sports. For example, Dr. Joan Vickers at the University of Calgary have been examining neuro-motor psychology by understanding the gaze of the athletes while they perform specific sports skills using a helmet-mounted eyetracker [4].

There is also research into wearable sensor devices that enhance sport performance and training. Michahelles and Schiele [5] present the application of wearable sensors to downhill skiing. By embedding various sensors on the clothing and ski boots, the system reveals information about the athlete’s motions, such as forces, rotations or accelerations. This presents a huge improvement in the quality of data that could only be partially obtained from video analysis previously. By working with trainers and former World Cup coaches, they are developing data visualization software that presents measured sensor data alongside reference videos.

Sports technology, of course, is not limited to enhancing performance, but potentially also to rehabilitation and prevention of injury. For example, in a recent article in IEEE Spectrum, high-tech prosthetics enabled double-leg amputee Oscar Pistorius to run nearly as fast as able-bodied athletes, raising the question regarding whether the Olympic Games will allow athletes with running prostheses to compete in the future [6].

It is not hard to imagine that almost any sport can benefit from both equipment enhancements and novel measurement and analysis of athletes’ performance. From popular sports such as golf, baseball and basketball to extreme sports such as snowboarding, motorcross racing and rock climbing, athletes could all benefit from better understanding of their muscle movements, orientation and heart rate response.

The research question here is not to instrument everything on the human body, but rather the understanding of what are the most appropriate sensors and how they should be used. ‘Appropriate’ here means how to enhance players so that they want to use sensors for their own training, enable unobtrusive
instrumentation so that coaches can analyse the best data available, and cooperate with judges to make good calls on the field with social acceptance.

2.2 Leisure and entertainment

In addition to enhancing performance and learning, the field of sports is closely tied to the availability of leisure time and desire for entertainment. There are two possibilities for technology in sports entertainment. First is the use of sports technology 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 sport games more entertaining. There are also companies such as Laser Quest [7] who are creating innovative new games from laser tag equipment, such as the team mission game of protecting the queen bee. Laser tag games can be every bit as exhausting as professional sports. Fitness clubs have started to incorporate video games into their exercise equipments. For example, Life Fitness’ Lifecycle had been connected to a Super Nintendo. The faster you pedal, the faster the counterpart on the video game screen goes [8]. Here the user is encouraged by the game to pedal harder.

The second possibility is to use technology to enhance spectators’ enjoyment of sports. Major tournaments now measure the speed of tennis serves, for example, to satisfy spectator’s curiosity of what it might be like to receive such serves. Beetz et al present a novel system built by Cairo Technologies and Fraunhofer IIS in Germany for tracking not only the soccer ball on the field, but also the players [9, 10]. By embedding microwave transmitters into the ball and shin guards of footballers, they are analysing game data and patterns to enhance understanding of game strategy, coaching of players and entertaining of spectators. The coin-sized transmitters broadcast signals to receivers placed on floodlight masts and sidelines. A central computer calculates the exact location from these pulsed signals, much like the way the Global Positioning Systems work. With balls and players instrumented, spectators and coaches will be able to know the speed of a shot, whether the ball passed the goal line, or who ran the fastest.

On the other hand, TV viewers rejected the use of the highlighted trails of hockey pucks during live broadcasts of National Hockey League games. These pucks were instrumented with 20 infrared emitters, and sensors around the rink picked up the infrared signals to track the puck [11]. Fans hated the trails and the pucks were eventually pulled. It has been less than clear how to design technology for spectator enjoyment. The key appears to be balancing the tradition, distraction, and satisfying spectator curiosity. Spectators enjoy the total immersion in watching live sports. Technologies should be introduced to assist in this immersion rather than to break it.

2.3 Interaction with sports authorities

Indeed, the acceptance of a technology interacts not only with spectators but also with sports governing bodies. Modifications to golf balls, clubs and other equipments are now heavily regulated by the United States Golf Association.
The so-called ‘dimple wars’ in the 1970s ignited such controversy that, for a while, people were afraid ‘old’ golf courses would become obsolete. As another example, modifications to bicycle design have been severely restricted with several new fast recumbent-type designs rejected for international competition [12]. However, after some wrangling in 1984, cycling federation officials allowed disk wheels to be used in cycling events. Other controversial technologies include the Cyclop tennis line-calling system and its acceptance by players. In most cases, sports governing bodies are reluctant to adopt new standards for equipments and new technologies. Indeed, in many cases, the rules themselves need to be changed to accommodate the new technology.

Occasionally, however, governing bodies can themselves be the catalyst for change. For example, in a recent rule change, the World Taekwondo Federation states that the number of scoring judges around the competition ring shall be reduced to two from four when the competition includes the use of new forcesensing electronic chest protectors. Interestingly enough, these new chest protectors are not yet even available on the market, so the governing organization has been one step ahead of the technologists.

As a unique challenge of working with sports technology, developers of new ubiquitous computing devices for sports would do well to learn from others who have tried to transfer new technology into sports. In extreme cases, changes to the sport equipments can actually alter the ideal body type for a sport. We need to 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 is a fine balance between completely eliminating the human factor in competition vs. enhancing the expression of fitness and technique.

3 Technological challenges in introducing sensors in sports

As the above researches show, there will be enormous implications if these sensor technologies are adopted in sports in the future. It can help runners train better, allow coaches to understand their athletes’ performance on the football field, enable ski trainers to design better programs for learning precise muscle movements and help judges score more accurately in a Taekwondo match.

Dario Salvucci of Drexel University suggested to the author that Jean Scholtz and Sunny Consolvo’s recent work on an evaluation framework for ubiquitous computing applications [13] might be fruitful for analysing the sensors and ubiquitous computing technologies in sports. Scholtz and Consolvo’s paper suggests nine evaluation areas that are worth examining in understanding a ubiquitous computing area: attention, adoption, trust, conceptual models, interaction, invisibility, impact, appeal and application robustness.

For each of these areas, they also suggested a set of metrics for understanding how these areas might be evaluated. There are a total of 34 different metrics under these nine areas. Here we take a subset of these metrics and apply them to a variety of sports technology. We chose a subset of these metrics that are the most appropriate for sports technology. While other metrics would have been
interesting to examine, space constraints in this paper would prohibit a meaningful analysis of all 34 metrics. Salvucci applied these metrics to these sports and made rough guesses at these measures, which we report there with more detail. These metrics and measurement serve as a guide rather than a conclusive evaluation of these systems.

3.1 Bowling foul-line detector

In the game of bowling, a simple foul line system has been used for detecting when a player steps over the line, which results in a beep (see Figure 1). Moreover, the system also automatically counts the pins and scores the game. An interesting bit of trivia is that, as a new start-up in Silicon Valley, Hewlett Packard tried to sell a bowling foul-line indicator as far back as 1938.

This technology is a poster child for excellent adoption of a sensor system into a sport. The systems are everywhere, and they are extremely accurate. Players understand how they work and can easily predict its behaviour. Because the beep occurs after the players have already released their ball, they require no behavioural changes and they are not distracting. Socially, they are as much part of the sport as any other part of the bowling alley. Table 1 summarizes its advantages when evaluated using the simplified framework.

3.2 Cyclops auto serve line detector for tennis

A system with very similar functionality called Cyclops has been in use at major tournaments since the 1990s. Cyclops detects whether serves are ‘in’ or ‘long’ (see Figure 2). They are not used for the detection of ‘wide’ serves, and are
Table 1: Three sports technologies evaluated using the framework proposed by Scholtz and Consolvo.

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<td>Aware of capability</td>
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<td>Distraction</td>
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<tr>
<td>Behavior changes</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
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<tr>
<td>Social acceptance</td>
<td>✓</td>
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<td>X</td>
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Adopted from Salvucci’s discussion slides [14].

Figure 2: The tennis Cyclops system is used to call ‘in’ or ‘long’ during service for only one line on the whole court. (http://newsimg.bbc.co.uk/media/images/39180000/gif/_39180948_cyclops_298.gif)
only used for serves, and can be overruled by the umpire. Its use has created quite a stir when it was first introduced, but eventually won reluctant acceptance.

Cyclops systems are quite accurate and consistent in its detections, and it is easy to understand how it is used. Despite having these characteristics similar to those of the bowling foul-line detector, Cyclops has won only limited adoption. While the system does not directly change players’ serves or the strategies of the receiving players, the problem is that it is distracting. The beep occurs just before the receiving player is about to strike the ball. This breaks both players’ concentration and focus and, therefore, has won limited social acceptance. Table 1 above summarizes these points.

More ergonomic studies of the beep and its effect on players are needed, and we might yet have to find a more optimal timing for the beep. For example, ensuring the beep occurs after the receiving player has returned the ball might minimize the distraction effect.

3.3 QuesTec system for video analysis of balls/strikes in baseball

A huge dispute over the QuesTec system for video analysis of balls/strikes was at the centre of the labour negotiations between Major League Baseball and its umpires (see Figure 3). This dispute was not settled until recently [15], and is still subject to ratification. It has been installed at 10 of the 30 major league stadiums, and baseball officials have used the system to grade the performance of umpires. “If an umpire’s calls disagree with the computer’s more than 10 percent of the time, his performance will be considered substandard and possibly held against him in future promotion considerations and when lucrative post-season assignments are made. The umpires are, naturally, freaked out by QuesTec…” [16].

Players are just as unhappy about the system. Arizona Diamondbacks ace Curt Schilling was fined for smashing a QuesTec camera after being told umpires are “changing their strike zones to match the machine” [17]. Atlanta reliever Darren Holmes was quoted as saying that “this system is one of the worst things that has happened in baseball” [17].

Despite the fact that players and umpires understand how the system works, it has proven to be a major distraction for hitters and pitchers alike.

The reason is because QuesTec forced definitive behavioural changes. First, umpires changed their strike zones in order to conform to QuesTec’s zones. Second, the pitchers, therefore, had to deliver pitches to the new zones and modify their mix of pitches. Third, the hitters must also adjust to the new strike zones and new styles of pitching. These chain effects resulted in extremely poor social acceptance of the technology.

Despite being proven as being fairly accurate and consistent, the system is only installed in some parks, and not others, resulting in further inconsistencies across the league.

We analysed the criteria for the social acceptance of sports technology by players, coaches and international sports organizations. In applying an evaluation framework for ubiquitous computing technology developed by Scholtz and
Consolvo, we note that several evaluation metrics are important, including accuracy and predictability of the technology; awareness of the technical capabilities by players, coaches and judges; the amount of behaviour changes and distraction to the players and the amount of social resistance to changes in rules or structure of the game.

Table 1 above summarizes these points.

4 Case study on force sensors in martial art competitions

Recently, we examined how force sensors could be embedded into wearable chest protectors for martial arts matches (see Figure 4). As a black belt and referee in Taekwondo myself, working with the Stanford Taekwondo Program and a Silicon Valley start-up company called Impact Measurements, we presented technical challenges in both developing the prototypes and understanding how it affects the judging of the match [18].

Figure 3: QuesTec video analysis system for calling balls/strikes in baseball is controversial. (http://www.isa.org/Images/InTech/2003/July/20030761.gif)
Our system, called SensorHogu, uses piezoelectric force sensors on body protectors to help Taekwondo judges and referees score real tournament matches [19]. The objective is to support the judges in scoring the sparring matches accurately, while preserving the goal of merging and blending into the background of the activity.

Based on this experience, we discuss issues and roadblocks we have encountered in introducing the SensorHogu to tournament players and judges:

- First, there is the challenge of making the system work technologically without affecting the play of the game significantly.
- Second, player acceptance hinges on their perception of fairness and unobtrusiveness of the technology.
- Third, judges must be comfortable in converting to a new system of scoring.
- Lastly, rule changes are required to accommodate the use of the electronic scoring equipment. We must work with the World Taekwondo Federation (WTF) and United States Taekwondo Union (USTU) to validate and certify the equipment for tournament adoption.

Here we chronicle our experience, and then compare our experience with adoption issues that have arisen in other sports.

4.1 SensorHogu design

First, we introduce our SensorHogu design. Inducted as an official Olympic sport in 2000 Sydney Games, taekwondo has enjoyed enormous popularity in the...
last several decades. Because of this popularity, there has been increasing pressure to ensure fairness in judging and to make the sport more spectator-friendly.

This pressure has directly caused several changes in the rules [20], and the desire to utilize technology to ameliorate some problems inherent in judging a match. The utmost problem in achieving accurate scoring is the subjective judgment of what constitutes a valid scoring kick to the body. As defined in the rules in 2003, a scoring kick must be delivered “accurately and powerfully to the legal scoring of the body [20].” The subjective nature of this judging criterion has been a major impediment to the development of the sport, sometimes resulting in accusations of biased judges favouring players from certain countries (see, e.g. news stories at http://www.indiavarta.com/olympics/newHeadlines.asp?cat=Taekwondo: ‘Never-ending protests against taekwondo judges’, ‘More complaints about taekwondo bias towards home team’ and ‘Another day of disputes in Olympic taekwondo’).

As shown in Figure 5, the competition sport of taekwondo sparring is conducted on a square padded mat 12 metre wide on each side. The competitors,
one wearing a blue body protector and the other red, face off against each other in a controlled environment. The competitors are moving rapidly on a large mat. There are three judges and one referee. The referee is responsible for conducting the match, while the judges are responsible for actually scoring the techniques. The judges are placed around the mat in a triangular shape, as shown in Figure 2. Existing scoring systems use wired handsets for the judges to score the points. According to existing rules for electronic scoring, a point is only awarded when at least two judges confirm it within a one-second window.

Figure 6 represents the relationships of the devices in the entire system. The system consists of a single base station that is connected to a laptop, three judges’ scoring handsets and two TrueScore™ Sensor Hogu wireless body protectors.
SensorHogu uses piezoelectric sensors to sense the amount of force that has been delivered to a competitor’s body protector, and wirelessly transmits this signal to a computer that scores and displays the point. Our hope is that the force sensors will help judges achieve greater accuracy and help eliminate controversy.

Figure 7 shows the body protector with its wireless transmitter on the upper left shoulder. For the force sensor, we needed something that is low-cost, low-powered and rugged. We did not consider employing accelerometers because of our desire to directly measure the impacting force. The most common dynamic force detector is the piezoelectric sensor. Piezo sensors’ stiffness and strength make them particularly suitable in a harsh environment like a protective suit. In our application, a single long piece of piezoelectric sensor is mounted onto a plastic backing and inserted into the middle of a World Taekwondo Federation (WTF)-approved body protector. We did not instrument the facial and head area because a facial mask would obscure the player’s vision, and attacks to the face are easy for the judges to score.

We developed the handset system to go along with the SensorHogus so that they all work wirelessly to the same base station. There are two handsets for each judge, one for scoring the red player on the left hand, and one for scoring the blue player on the right hand. Figure 8 shows the judge’s red handset held in the left hand. As shown, there are two buttons on the handset. A trigger button scores a point for the body, and a side button scores two points for a head blow.
Complicating the design of the system, the events from the protector must coordinate with the scoring handsets. At least two judges must press the same button on their handsets within a one second window for the point to score.

There were numerous design goals for the SensorHogu system: easy to use, accurate, robust, secure, modular, low-cost and low-powered.

First, the system is completely wireless. In comparison, the standard foil fencing scoring system that has existed for several decades has competitors tethered [21]. The fencing system is based on electrical switches that complete a circuit when the switches touch a metal vest. The tethered set-up has limited the sport to linear forms of fencing, thus restricting the natural development of the sport. The human activity has been modified to suit the technology that was available. In comparison, SensorHogu must not only transmit contact wirelessly, but must also measure the amount of force applied.

Second, it must functions flawlessly in real time. Multiple signals from each body protector are transmitted around the same time, and the system must interpret these signals according to the rules.

Third, the whole system is designed with several criteria of robustness in mind. The devices can withstand an extremely hostile environment. It is small and secure, and can resist physical abuse and potential radio interference.

Figure 8: Judge’s handsets are ergonomically designed to eliminate hand fatigue, because competitions often run for an entire day.
Lastly, the system is modular, low-cost and low-powered. Each device can run on two AAA-sized batteries for three or four days of competition. For modularity, each device can be individually replaced. For example, the hogu and the transmitter unit in the pouch can be replaced separately.

In summary, the SensorHogu is a novel wearable system that supports an extreme human activity. The natural next step is to test how well it works in practice and how players and judges respond to the new technology.

4.2 Players and judges trust and comfort

We believe there are two different ways to gain the trust of players and judges. First, we conducted real user testing of the system and published the results for examination [19]. Second, we performed live demonstrations at major tournaments.

The difficulty with both of these strategies is that there is a wide variety of different factors in the judgment of whether a hit is a scoring point or not. Depending on the weight division, gender and type of kicking technique used, judges modify their criterion for a point accordingly. As mentioned before, the subjective nature of the judgment of a point is one of the major reasons for the development of the SensorHogu.

For real user testing, we obtained an anatomically correct anthropomorphic dummy of a male upper torso. We outfitted the torso with the SensorHogu and asked a wide variety of taekwondo players to attack the dummy. The data were recorded and analysed for reasonable settings for the scoring threshold. The data were published in a conference paper [19]. At the same conference, we also published live footages of the system used in action, where independent judges analysed the videotapes in slow motion. For example, the analysis in Figure 9 showed that very fast kicks may falsely appear to be blocked by the arm, and the system helped in scoring these cases accurately.

For the judges’ scoring handsets, we demonstrated the use of the system at a number of local tournaments first, and then gradually the system was accepted locally, nationally and internationally. Recent tournaments that used our wireless scoring handsets included US Taekwondo Union National Championships, US Junior Olympics and World University Championships. We have also demonstrated the SensorHogu scoring system at the Stanford Open 2004 tournament.

In our experience, for systems with such potentially controversial roles in determining the outcome of the matches, we must demonstrate to the players and judges the validity of the system in a wide variety of ways. Even in the large community of taekwondo practitioners, words-of-mouth reputation is extremely important for gaining the trust of players and judges.

Some details of the design played crucial roles in forming the community’s opinion. For example, the handset grip is modified from industrially designed joystick grips that reduce fatigue during prolonged use. Judges really appreciated these details, as some of the earlier electronic scoring systems used cylindrical plastic handles. Players appreciated the fact that the look-and-feel of the new...
chest protectors is exactly the same as their normal gear with little modification. We also made sure that the beep made by the system when a player scores is not distracting to the players.

Lastly, to allow the use of the SensorHogu, rule changes are necessary to use the system in tournament matches. To achieve this, we have demonstrated this technology to taekwondo officials. However, organizational changes are extremely difficult to push forward, particularly rule changes required to allow electronic scoring equipment. Fortunately, there is pressure from the Olympic committee to introduce new scoring technology in taekwondo, and we hope to introduce the system in the 2012 Olympics.

4.3 Evaluating SensorHogu technology using the framework

We were naturally concerned after understanding what happened to QuesTec systems, because like QuesTec we are trying to introduce a technology that would set the standard of the threshold the players must perform to earn a score in taekwondo. The original standard for a hit was inconsistent and poorly understood, but it was used for a long period of time and a culture of understanding had been built around the rule. Players and judges adjusted based on their own

Figure 9: Screenshots from the videotape of the sparring test study showing a kick to the body that would have been difficult for the judges to see clearly because of the speed.
personal interpretation of the rules and the situation of the match. The inconsist-
sencies had become part of the game. Like the QuesTec system, winning their
acceptance required not only sports officials’ buy-in, but also their beliefs in its
accuracy and fairness. Moreover, it was important that the system does not force
any unwanted behavioural changes on the part of the player or the judges. Our
design mantra was ‘every design is for the benefit of the players and the fairness
of the game’.

At this point in the introduction of the technology, we do not know what the
adoption rate will be, since it is still too early to tell. Our published data suggest
that the system is consistent and fairly predictable to the judges and players, and
the sensors are reliable enough to be used for fair play. Its capability is easy to
understand for both players and judges. In our test matches, players performed as
if the system was not there, and they have thus far not modified their behaviours
or strategies while wearing the system. At this point in time, before its official
introduction and sanctioning, players and judges seem to enjoy using the tech-
nology and appreciate its added value to the game. Many of these early opinions
are based on reputation and inherent reliability of the system, but could change
if there were to be a high-profile failure of the system. Our work is to prevent
failures of this kind. Table 2 summarizes our initial evaluation of the SensorHogu
system.

Interestingly enough, the audience is the third party with an indirect stake
in this issue. We believe there might be value in displaying how hard someone’s
Hogu was hit during each encounter. This could add to the entertainment value
of the system. The opaque culture of understanding on scoring thresholds would
become more transparent, and easily verified.

Another interesting issue is that given that the system has no way of knowing
what type of kick was used, we do not know how the system might change the
kick distribution. Currently, it is not known whether judges tend to score kicks
with higher degree of difficulty, even if they do not generate as much power. This
is a potential area of behavioural change.

Table 2: SensorHogu evaluated against the same evaluation framework pro-
posed by Scholtz and Consolvo. Adopted from Salvucci’s discussion
slides [14].

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<th>Adoption rate/value</th>
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<td>Accuracy</td>
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<tr>
<td>Behavior changes</td>
<td>✔</td>
<td>– Doesn’t seem to affect play</td>
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<tr>
<td>Social acceptance</td>
<td>✔</td>
<td>– Players/judges seem to enjoy it</td>
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5 Summary

As further research and discussion carry forward, more and more novel sensor technology will be introduced in different sports. As technologists, we can already see that sport is an extremely exciting field to apply our craft. Novel uses for various sensors here will further our understanding of how to embed sensors in different situations while gaining social acceptance. The benefits to players, coaches and spectators are often clear.

As our exploration with the evaluation framework above shows, there are many technological issues in adopting sensor technology in sports. Indeed, the general issue of how technology has changed the face of sports have arisen in the past, including corked baseball bats, novel special tennis rackets, special long flight golf balls and swimsuits made with low-drag material. The adoption of sensor technology is in line with prior experience with technology in general.

The broader issue is how do we want technology to augment sports and help referee sports. There are many possibilities for sensors to change various sports, such as augmenting hockey pucks with sensors and detecting pucks going over goal lines, or augmenting golf balls to better track their trajectory or augmenting footballs to better sense the last point of forward momentum. Is there a way for us to systematically understand when it works well or when it does not work too well? As the QuesTec system demonstrated, do we understand when a technology starts to ‘ruin’ the spirit of sports?

Researchers have envisioned a wide variety of application areas for sensors, including everyday environments such as the home or the office. Evaluators have studied the adoption of technology in these application areas, but none so far in sports. Indeed, the adoption of sensor technology in sports appears to operate on a similar set of evaluation factors when compared with other areas of ubiquitous computing. We hope this article points to future work necessary in understanding when a ubiquitous computing application has the potential for being a ‘killer app’.

Besides, who can resist helping everyone be just a little healthier and better looking?

References


