TeamAwear:

User-Centred Design and Evaluation of a Wearable Display for Team Sports

By

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Abstract

A novel wearable display system for the team sports context is presented, termed *TeamAwear*. Wearable displays are a class of display that is worn on the body, and used to communicate information about the wearer to the surrounding public. The TeamAwear system aims to actively enhance the awareness and understanding of a team sport for its stakeholders, including athletes, referees, coaches and spectators, without negatively disturbing its game-play. Designed specifically for basketball, TeamAwear consists of four basketball jerseys that are equipped with electronic displays and small computational devices. Each jersey can be wirelessly controlled to represent game-related information sources in real-time, such as the amount of individual fouls, scores and time alerts.

A user-centred approach, including ethnographic and participative design studies, is applied to significantly guide the design process towards a more meaningful, ethically and ergonomically valid prototype design.

A final case study evaluation demonstrates the system's perceived usefulness during typical basketball situations, particularly for non-players such as the spectators, referee and coach. The results of the evaluation further provide the basis for several design guidelines, for the application of awareness increasing devices in team sports.

Acknowledgements

This research lies within the context of team sports, which by nature are activities that require the collaborative involvement of multiple participants. Similarly, this research has been achieved only as a result of the combined efforts of multiple people, other than myself, whom I would like to take this page to recognize.

Firstly, I would like to thank my supervisor Dr Andrew Vande Moere for his constant feedback and direction throughout the year. Many thanks also to staff and students within Key Centre of Design Computing at the University of Sydney, specifically Dr Rob Saunders and Justin James Clayden for offering their technical expertise, and fellow students Andrea Lau and Daniel Holmes for generously providing feedback throughout the writing of this thesis.

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1 Introduction

It is sometimes said that sport is perhaps the most dominant cultural influence in the world today (O'Mahony and Braddock, 2002). Team sports are a particular class of sport which require the collaborative involvement of multiple participants simultaneously, and consist of a period known as *game-play* occurring between when a team sports game begins and ends. This period involves a multitude of *game-related data*, that is the information sources and datasets that directly result from or affect game-play. Technological developments which allow game-play to be improved in some way have been regularly introduced over time. Two fields in particular have been at the forefront of these developments: *visualization*, and more recently *wearable computing*. Applications of these two fields within team sports have been utilized regularly to enhance game-play, not just for athletes, but for all stakeholders, including: coaches, referees, and spectators.

Visualization is often described as the abstract representation of data, allowing users to perceive the most important aspects of relevant datasets quickly (Thomas and Cook, 2005). Its conceptual use within team sports can be broadly interpreted, with applications that range from the *scientific visualization* of physical phenomena such as a balls trajectory; to *information visualization* for representing and interpreting complex sports information sources; to *information graphics* such as maps, charts and cartograms used for representing periodic game data. Visualization has played a major role since the earliest modern team sports (Page and Vande Moere, 2006). For instance, colours and numbers have allowed athletes and teams to be identified, field lines and markings have enabled rules to be followed, while more recently advanced computer generated graphics allow even the most complex sports data to be easily understood by a wide range of non-expert viewers.

Wearable computing refers to the use of small body-worn computers which are always on and always ready and accessible (Mann, 1998). The recent introduction of these technologies has shown promise for use within team sports, as they can be integrated within game-play easily and without significant change or distraction (Chi et al., 2005). They have provided the ability to track, record, and even display various game-related data that has previously been unreachable. This has broadened the range of information available and presents a flexible new medium for team sports development.

The latest trend of incorporating these wearable technologies within clothing has resulted in the development of devices known as *wearable displays*. A wearable display is a class of display that is worn on the body, and is used to communicate information about the wearer to surrounding viewers. These devices effectively combine the aforementioned fields of wearable computing and visualization, to create a new wearable medium for representing context specific information in non-distracting ways. This approach is similar to that of *ambient display*, which supports the non-distracting monitoring of information in an aesthetical way (Mankoff et al., 2003). Although the successful application of wearable display technology has so far been largely restricted to a social setting, it is expected the introduction within a team sports environment will provide a means to enhance the current nature of game-play.

The role of this thesis will be to report on the implementation of a wearable display system that is capable of visualizing game-related data during competitive team sports game-play. This system, termed *TeamAwear,* will focus on one team sport in particular: basketball. Implementation will be introduced via a number of stages, including: the design process (ethnography and user studies), physical development (software and hardware production), and finally evaluation (functionality and user testing).

1.1 Motivation

Within present team sports, there are vast amounts of game-related data which are brought in and out of existence throughout game-play. For instance during a basketball game, this data includes: goals, points, times, fouls, assists, steals, rebounds and many more. For a single stakeholder, whether they are an athlete, referee, coach or spectator, it is virtually impossible to monitor and recall all of this data single-handedly. Instead, team sports stakeholders currently rely on scoreboards, television or radio broadcasts, internet websites, and newspapers to convey this data to them. For this reason, knowledge of game-related data - which is often critical to understanding a team sports game - is only constantly available to a small portion of stakeholders, namely those viewing remotely such as remote spectators and officials (Page and Vande Moere, 2006). In addition, a large majority of this game-related data are *only* available to the remote stakeholders during game-play, such as statistics and historical activity. This is a significant problem in team sports, yet one which has always existed.

Team sports such as basketball continue to become more complex over time, typically as a result of the regular and manifold introduction or modification of game rules and regulations (Deltow et al., 1984). These rules and regulations are often based on, or even introduce *new* information sources into game-play. Presently, team sports are still able to function with the often overwhelming amount of information and rules, yet there exists a need to improve awareness of these items. It is increasingly apparent that methods are required to provide game-related data to team sports stakeholders during game-play. This research will demonstrate that this can be achieved through the introduction of a wearable display system.

Wearable displays, which will be worn by athletes, publicly portray externalised visualizations of game-related data within the immediate vicinity of game-play. The information encoded within these visualizations is then viewed, extracted and utilized by team sports stakeholders. Using a wearable display in this manner is intended to increase stakeholder awareness of game-related data in a way that is not achieved with current technologies. This research will investigate if this increased awareness can actually influence the current state of team sports game-play, and whether this leads to a more enhanced stakeholder experience during such events.

1.2 Aims and Objectives

The aim of this research is to evaluate whether wearable displays of information can be used within a team sports context to enhance the experience of game-play for immediate stakeholders. These key immediate stakeholders of team sports are: athletes, coaches, referees, and spectators. The term ‘enhance’ refers to influencing or changing the nature of game-play in some positive way, which varies for each stakeholder type:

- For an **athlete and coach**, this corresponds to increased motivation and improved decision making
- For a **referee** this translates to an ability to make more accurate judgment calls and to make these calls more easily
- For a **spectator** this refers to a more enjoyable viewing experience, and increased understanding of game-play

Three stages will be completed during the implementation of this research. The objectives to be achieved are therefore as follows:

- **User-centred design** will play a major role in the implementation process of a team sports wearable display, through identifying the design requirements and user needs that the system will possess. A focused ethnographic study will be carried out to observe, gain insight, and collect concrete information about team sports stakeholders in their context of work. This will be followed by a number of user-centred participative design studies. These will be conducted with a select number of each stakeholder, and will involve open-ended discussion, interviews, ‘talk-aloud’ sessions, and design critique.
- **Technical development** will involve the construction of the wearable display system. A preliminary review will be completed to firstly identify the possible materials (software and hardware) from which the system can be built. When suitable materials have been selected,

a number of early prototypes will be assembled to test and refine various aspects of the system. This will be followed closely with the assembly of a final prototype that will meet all the design requirements and needs of the team sports stakeholders as identified during the user-centred design stage. This final prototype will then be suitable for evaluation.

- **User evaluations** will be carried out to determine the success of the completed wearable display system within the intended team sports context of use. The final prototype will be utilised during a number of controlled 'trial' and 'competitive' team sports (basketball) games involving end-users. During the games, users will experience first-hand the way in which the system affects game-play. Finally, questionnaire and 'think-aloud' evaluation methods will be used at the conclusion of these games to assess both the overall functionality and workability of the TeamAwear system.

1.3 Significance

This research contributes to the fields of wearable computing and sports technology in three ways: a custom-made team sports wearable display device that is capable of visualizing game-related data; a user-centred method for developing this device involving ethnographic observances and user design studies; and most importantly, an evaluation of the device by intended users within a team sports environment.

Wearable display systems have been shown to be successful within social applications (see Chapter 2: Related Work), but have not yet been witnessed within a team sports context. The development and evaluation of a wearable display for basketball is therefore a first step in bringing forward the application of this technology within the team sports community. Unlike existing sports-information-display- systems, such as those which appear on television during live broadcasts, a wearable display system keeps the information where the action is, at the centre of game-play. Here it can be viewed, understood, and acted upon by all stakeholders.

The team sports community at large is a major beneficiary from the implementation of this research. The application of a wearable display system within basketball reveals the possibility for applications within a wide range of other team sports. Given that competitive team sports are an extremely popular constituent of most modern societies (Wenner, 1989), successful applications of this technology may later be reflected on a global scale. This could one day lead to team sports in general becoming more enjoyable, fair, and stimulating.

Existing team sports have a variety of rules and tradition that may prevent the use of a wearable display device immediately. It is nonetheless appropriate for a full spectrum of other team-based activities. This technology is particularly suited as a training system for novice athletes to fine tune their skills by receiving constant visual feedback regarding their performance. Similarly, disabled or impaired athletes that do not meet the demanding physical requirements of many team sports, can receive information that may have previously been inaccessible, allowing them to enhance their game-play beyond the permitted scope. Additionally, other suitable team-based activities which stand to gain from this research may include physical education, endurance testing, social games, and even non-athletic team activities, such as: contests, debating, musical orchestras and groups, quiz programs, and more.

Sports manufacturers may seize the commercialization potential of this technology. Using the results of this research, they may begin to mass manufacture similar clothing integrated display devices for team sports. Even by removing it from its competitive sports context, manufactures can incorporate similar wearable display devices within their sports clothing lines. This may not only pioneer awareness of wearable display technology as an information communication medium for the wider community, but also as a fashion statement.

The application of user-centred design and evaluation methods within this research provides a suitable framework to conduct further or quite similar research in this area, by covering: required volunteer types, the design process, and various methods of testing. Although the TeamAwear system will be specifically tailored for application within basketball, the users and the team sport in question can be easily augmented. A similar user-centred design and evaluation process could therefore be applied to the development of different kinds of wearable sports systems, for literally any team sport.

Institutions affiliated with team sports development will be made more aware of the advantages wearable display technology can provide in the context of team sports. Additionally, researchers in the fields of visualization and wearable computing - where increasingly sports affiliated applications are beginning to emerge - will also observe the benefits of this technology within their particular area. This may ultimately lead to an increased research interest regarding the use and practice of wearable displays within team sports.

2 Related Work

This chapter concentrates on the background and related works which surround the implementation of this research. The works considered here have been grouped into the following categories: visualization and wearable computing. Throughout each category, a selection of social and sport-related applications is addressed that are related to factors concerning the development of a wearable display system, its application within a team sports context, or both.

2.1 Visualization

Visualization is a field associated with different meanings in different contexts. For instance: scientific visualization incorporates visual images to increase understanding of complex scientific concepts (Bryson, 1996); information visualization is the visual abstract data to amplify cognition (Card et al., 1999); and so-called non-visual visualization makes use of human senses other than sight to convey data (Wall and Brewster, 2005). Additionally, visualization can include: information graphics such as maps and cartograms used to represent data (Harris, 1999); as well as information design for efficient communication of information for use through visual narratives within an illustrated context (Horn, 1999). Put simply, the field of visualization is concerned with the representation of data in an insightful manner.

In terms of this research, two specific application areas of this field are considered: visualization in sports, and ambient display. The visualization work being done in the sports community firstly presents an obvious need for current and future developments in this area. Ambient display on the other hand is an effort that sees visualization removed from a screen and placed throughout the physical environment, which is closely linked to wearable display research.

2.1.1 VISUALIZATION IN SPORTS

Visualization is used within sports to improve the participation and understanding of a variety of sporting events. This is achieved by presenting stakeholders with meaningful representations of sport-specific information and statistics. Visualization is regularly applied within team sports in particular, to provide the stakeholders with a synchronous understanding of game-play. This has resulted in team sport games that are easier to play, judge and watch. Its application is quite broad, ranging from uniform colours and graphics that act as an identification system (O'Mahony and Braddock, 2002); to field lines and patterns which specify rules; to complex on-screen graphics during broadcasts revealing athlete performance (see Figure 2.1); to non-visual forms such as the Cyclops Auto Serve Line Detector that uses sound tones to convey information

(Hibbert, 1999). Many of the visualization systems currently in place within sport are restricted to the media. For instance, within a newspaper sports section, on internet sports networks, or on television, such as the virtual world record line which represents the existing record for particular racing events (Orad, 2005). However, research works has also been completed to provide stakeholders with improved methods of experiencing sports events through the application of visualization, some of which are discussed below.

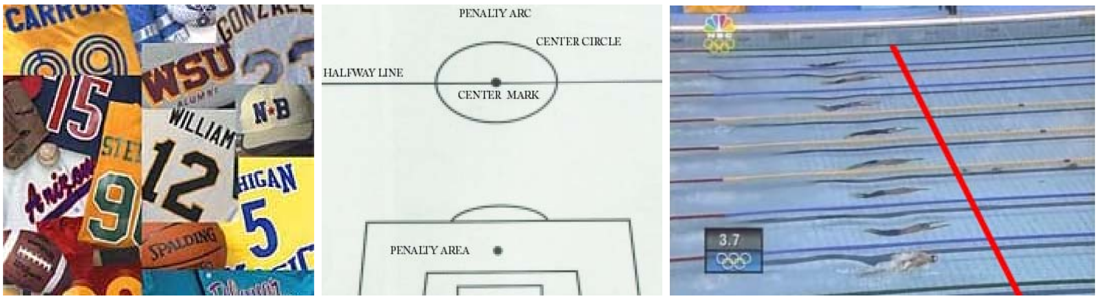

Figure 2.1. Left to Right: Uniforms (TeamSportswear.com, 2006), playing fields (United States Soccer Federation Inc, 2005), and television broadcasts (Orad, 2005), represent visualization used in sports.

Graphical Basketball Game Presentation: An early research application of visualization in team sport was to provide real-time graphical summaries of the scoring activity of basketball games (Westfall, 1990). Game-related data is constantly changing throughout a team sports event, especially for a fast paced sport such as basketball. For this reason, it is often difficult for stakeholders to remain knowledgeable of the actions during game-play. This work concentrated on allowing spectators to be aware of the essential data at any time via simple graph like visualizations. The graphs generated are essentially information graphics that intend to summarize and highlight important basketball game datasets such as: points, score, athlete fouls, lead changes, and the winning/losing team (see Figure 2.2, left). Although this visualization is specifically intended for the spectators of a basketball match, it can be equally used by coaches and athletes after a match to identify and analyse game-play aspects.

These types of graphics are now common place within the sporting world. They are regularly displayed on television screens and websites during sporting events. These allow stakeholders, primarily spectators, to discern game-related data that is previously ‘unseen’. However, such graphics which show large amounts of data, such as this work, can be difficult to comprehend in a short amount of time. Although this is appropriate for spectators, if an athlete or coach were to be presented with this kind of visualization during game-play they may be overwhelmed. This research will extend on this work, using visualization to highlight game-related data in a way that is accessible to all stakeholders. This will be done in an intuitive rather than complex manner, that will allow stakeholders to retrieve the relevant data quickly and easily, allowing game-play to continue unimpeded.

TennisViewer: Due to the complexity of many sports, they are often difficult to follow and understand. The *TennisViewer* system was developed to address this problem for the sport of tennis. TennisViewer allows sports stakeholders, specifically spectators, to explore and understand the vast amounts of data occurring during a tennis match (Jin and Banks, 1996). For instance, a novice watching a game for the first time will be able to visually see the importance of tennis data and relate this to what they are witnessing on the playing field. This system is also intended for a coach or athlete, to examine and extract the critical moments of game-play for further analysis. TennisViewer compiles tennis data into an intuitive tree-structured visualization which can be analysed, reviewed, and browsed by users (see Figure 2.2, right). The visualization dynamically updates throughout a match, allowing stakeholders to follow the data in real-time.

This work exemplifies an effective use of visualization in sports, by representing complex game-play data in a way that can be easily explored and understood by stakeholders. Similarly, this research will better equip team sports spectators with information that will enhance their awareness of game-play. The TeamAwear system can allow spectators to see why an athlete made a particular decision, or why a referee has disqualified an athlete, or which team is winning a game. This may potentially create a more understandable and enjoyable game-play experience.

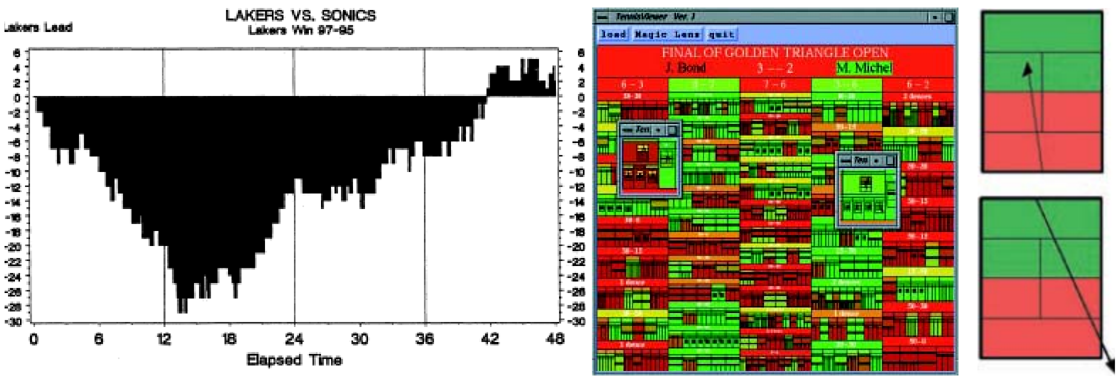

Figure 2.2. Information graphic type visualization of a basketball game (Westfall, 1990) (left); tree-structured visualization of a tennis match (Jin and Banks, 1996) (right).

These works highlight the efforts of visualization in sports. They describe how this field can be used to enhance the experience of sporting events by representing the large and often complicated information which make up the various games. However, one problem which is clearly evident from the current state of these works is that they are primarily intended for spectators only. In this way, the information they provide only becomes accessible to other stakeholders - such as coaches and athletes - after a sporting event has occurred. This research will differ considerably in this respect. The TeamAwear system, essentially a wearable visualization of game information, will be immediately accessible to *all* stakeholders throughout game-play, not just spectators. This will allow these stakeholders to become more aware of what is actually taking place and react to it appropriately.

2.1.2 AMBIENT DISPLAY

Ambient displays are aesthetically pleasing displays of information which sit on the periphery of a user's attention (Mankoff et al., 2003). The common objective of these devices is to allow the monitoring of non-critical information. They make use of both physical objects and environments to present this information, so that the display can take the form of an artefact, an architectural space, or even a handheld or wearable device. They effectively allow a person to be aware of information while attending to some other primary task or activity (Matthews et al., 2004). In this way, users can be informed without being distracted and overburdened, which are required aspects for this research (see Figure 2.3).

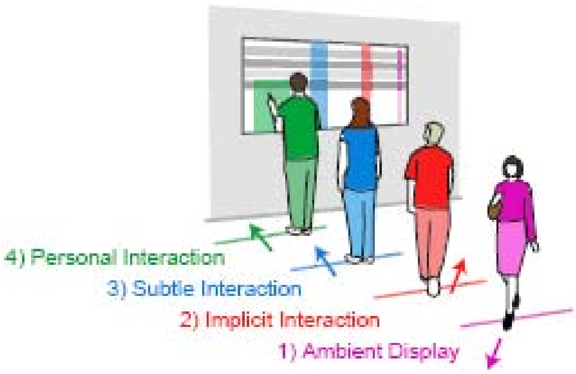

Figure 2.3. Ambient displays allow users to monitor information subtly (Vogel and Balakrishnan, 2004).

The Power-Aware Cord: One popular application for ambient display systems is to empower an everyday object with information. The *Power-Aware Cord* uses a standard electrical power cord which has been augmented to visualize the electricity being used (Gustafsson and Gyllensward, 2005). A dynamic visualization consists of glowing pulses, flow, and intensity of light inside the cord, which is able to inform users of the electrical current passing to electrical appliances (see Figure 2.4, left). This work included a series of observations to test the perception of the device, and to obtain user feedback regarding the visualization. User feedback revealed the use of light was more natural and intuitive way of symbolizing electrical energy than showing Watts on a numerical display. Ultimately the display provided users with an increased awareness of the electrical consumption in their local environment. This may eventually lead people to be more mindful of their electrical usage behaviours.

An ambient display is capable of making abstract information qualities concrete in a way. Information which does not have any inherent form or inherent perceivable qualities can therefore become viewed and understood. This work reveals how this is done for electricity, while a number of comparable works represent other abstract quantities such as tap water heat (Bonanni, 2005) and time of day (Kientz et al., 2002). Similarly, this research will be used to visualize abstract game-related data which has no physical form, such as athlete performance and time. Using an athlete's jersey to carry this visualization is also favoured according to this work, by increasing people's awareness of the athlete and their local environment via an intuitive display.

Breakaway: Ambient displays can be an effective tool for encouraging changes in people's behaviour. This is evident from *Breakaway*, an ambient display in the form of a small office sculpture which reminds office workers to take 'breaks' (Jafarinaimi et al., 2005). The sculpture uses a pressure sensor in the office workers chairs to measure how long they have been sitting for. This information is then reflected by the ambient display sculpture through subtle movements (see Figure 2.4, middle and right). The display is also clearly non-intrusive, it does not interfere with the office workers day to day activities, yet it is still peripherally accessible to them at all times. An evaluation of this work revealed correlations between movement of the sculpture and when people took breaks. This suggests that ambient displays are an effective means of motivating users via increased awareness.

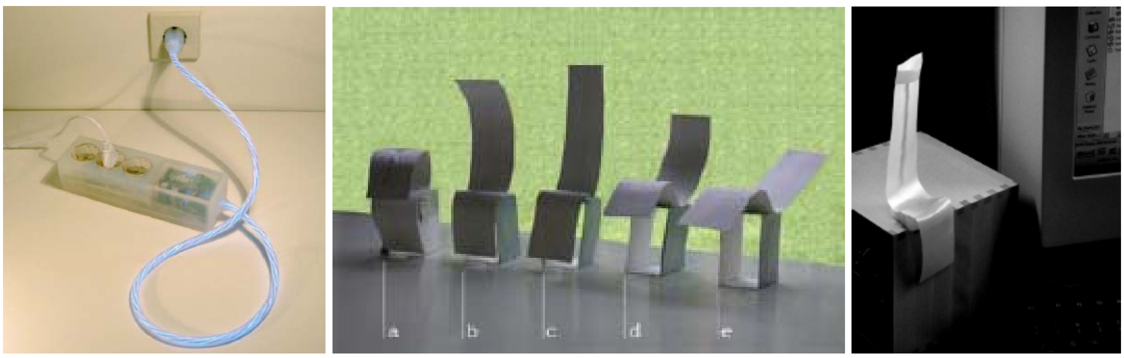

Figure 2.4. The power-aware cord during use (Gustafsson and Gyllensward, 2005) (left); the Breakaway ambient display revealing information via movement (Jafarinaimi et al., 2005) (middle, right).

This work represents two important aspects for this research. Firstly, the non-distractive nature of Breakaway allows users to carry on with their activities. This aspect is crucial for a team sports context, in which athletes especially must remained focus on the primary athletic task. Additionally, evaluations revealed this work to noticeably change human behaviour by delivering users with relevant information. This research will evaluate whether the display game-related data in a similar way can encourage changes in the ordinary behaviour of stakeholders in team sports.

Ambient display systems introduce forms of visualization into the physical environment in a way that complements it. This can allow for the application of such systems within almost any context, including team sports. By restricting the display to non-critical information only, ensures that users are not forced to rely on these systems to make vital or potentially damaging decisions. More important is the implicit nature of ambient displays, which gives surrounding users the option to either embrace or ignore the information displayed. In the same way, this research is not intended to overwhelm users nor demand their undivided attention. Instead it will provide a means to convey game-related data in a way that does not immediately invoke action, but rather encourages action through increasing awareness.

2.2 Wearable Computing

The field of wearable computing is tied into ubiquitous computing, which envisions computers as invisible and omnipresent, moving away from the desktop and becoming seamlessly integrated within the physical environments in which we work and live (Weiser, 1993). Wearable computing suggests that instead of embedding computers around us, they are embedded *on* us. This negates the need for any environment infrastructure, as all devices are carried or worn on the wearable user's body. However, most modern wearable systems consist of an appropriate mix of features from both of these fields (Rhodes et al., 1999).These devices usually focus on providing information to, or collecting information about, the wearer.

Current wearable technologies, such as sensors and microprocessors, have become small enough that they can be integrated into clothing and fashion items seamlessly (see Figure 2.5). They are able to be worn almost anywhere on the body, while still allowing the wearer to move about and interact freely. This has allowed for a diverse range of applications in a variety of contexts. The following section will consider two specific applications of wearable computing as related to this research, sport and wearable display. The former will discuss the current state of wearable computing as used within sport activities. The latter describes a fairly new application of wearable computing which concerns information about wearers being communicated to surrounding viewers.

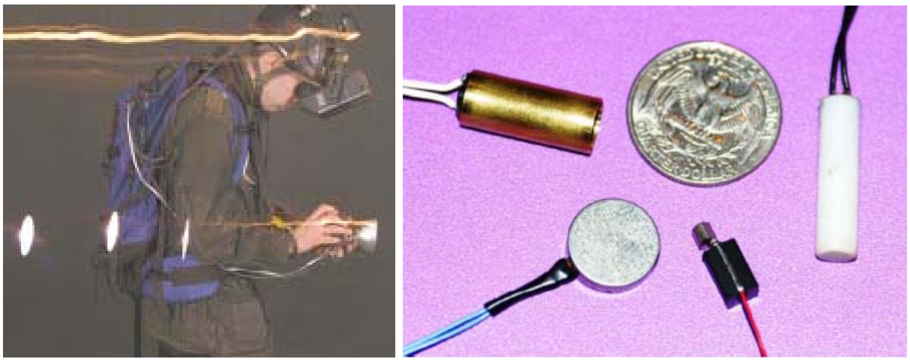

Figure 2.5. Wearable computing past and present (Mann, 1997), (Jones et al., 2004).

2.2.1 WEARABLE COMPUTING IN SPORTS

While wearable electronics such as heart rate monitors have been used to enhance sport and fitness for some time, the use of this kind of computing technology in sport is a relatively recent phenomenon (Barkhuus, 2005). Because ubiquitous technologies are hidden, or almost invisible, they can be incorporated into a wide range of sports with virtually no change to rules or regulations. Although a great number of such devices currently exist, this section will take into account only those that facilitate in the exchange of sport data in some way or other, so as to remain closely tied to this research. Both team and individual sports will be considered throughout the following cases.

SensorHogu: The *SensorHogu* system incorporates wearable force sensors into the sport of Tae Kwan Do (Chi, 2005). The sensors are seamlessly integrated within standard issue protective padding, and so have been implemented within the sport with little to no change (see Figure 2.6, left and middle). During a Tae Kwan Do match, points are awarded based on whether one athlete hits another. SensorHogu is able to measure the amount of force delivered to an athlete. This data is then transmitted to sport judges, who are then able to make an accurately informed decision. This work also included a vigorous testing regime and end-user study to examine the effectiveness of the system as well and its acceptance by users. As a result, this system has been implemented within actual sports competitions where it has been shown to drastically improve the judging of the sport. This work has successfully changed and improved the very nature of Tae Kwan Do, where as previously four judges would make a majority vote decision, now only two judges are required to monitor the sensor data. This research will in a similar way aim to change the nature of team sports game-play, via the implementation of the TeamAwear system.

SensorHogu only presents data to judgement officials, rather than display this to surrounding spectators. In this way its usage is restricted as simply a judgement tool, when it could be used to increase spectator or even athlete awareness. This research will differ in this respect by presenting game-related data to all surrounding viewers, while still allowing judges to make accurate decisions. The seamless integration with already existing sports wearables (the protective padding) presented by this work is closely linked to this research. The TeamAwear system will make use of existing team sports clothing items to prevent significant equipment changes. Lastly, the most crucial aspect of the SensorHogu work in terms of this research is the critical evaluation of the system shown by testing and user studies. Rigorous testing will be carried out during the final stage of this research to similarly evaluate the TeamAwear system in terms of its end-users.

GPS: Recently, Global Positional System (GPS) technology has found its way onto the playing field within a number of sports. These devices have in fact been integrated into team sports game-play including Hockey and Australian Football. In the Australian Football League (AFL), GPS has been introduced to monitor athlete performances in training and during game-play. It has allowed full game movement data, along with player and positional demands to be obtained, visualized and assessed (Wisbey and Montgomery, 2005). The device consists of a small GPS unit that is affixed to the upper back of an athlete's body using a purpose built supportive harness underneath their jersey (see Figure 2.6, right). During game-play, the devices are able to capture individual data such as speed, altitude, longitude and latitude. This is later combined with game-related data such as goals, score, kicks, and time, allowing researchers to accurately analyze athlete performance and identify areas for improvement.

Figure 2.6. Force sensors integrated into Tae Kwan Do protective padding (Chi et al., 2004) (left); wearable GPS technology fitted to AFL athletes (White, 2005) (right).

Female hockey athletes are currently using wearable GPS tracking systems to capture and analyze their game-play activities (Petersen et al., 2005). In doing so, researchers are able to identify the patterns and physiological demands which these athletes are faced with during game-play. An athlete-tracking GPS device placed within a custom harness positioned unobtrusively between an athlete's shoulder blades captures game-related datasets such as speed, distances covered, and times. Using this information, coaches are able to develop more efficient training and conditioning programs that can allow athletes to achieve top individual performance.

Wearable GPS systems for team sports are specially designed to be as unobtrusive as possible, allowing them to be worn during game-play almost unnoticed. This research will consider similar non-obtrusive means of body-attachment for the TeamAwear system which can be achieved by using a specially made harness. These works also discuss the design of the wearable sports devices, yet they do not consider how they arrived at particular design decisions, which are a critical aspect of their implementation. In contrast, this research will take into account the design needs and requirements of the intended team sports users prior to any design decisions.

Wearable Sensors: Sensor-based technologies allow athlete performance data to be measured and recorded, particularly within dangerous or extreme sporting activities. Cross country skiing is a sport that is seldom able to be enjoyed by spectators due to the harsh and remote environments in which events occur. Recent work is changing this by equipping athletes with internet-enabled sensor technology that allows a variety of data to be obtained, creating an enriched spectator experience (Hallberg et al., 2004). The sensors measure aspects important for spectators, such as athlete vitals and location. This data is then transmitted wirelessly and converted into a suitable visualization which allows spectators to track and monitor athlete performance over the internet. The particular consideration of spectators here is especially related to this research. In order to enhance the spectator experience of team sports game-play, spectator-specific datasets must be taken into account. The discovery of these datasets will become a necessary part of the development stage of the TeamAwear system.

Sport training is another area where sensing technologies have been implemented, as they are able to deliver performance data more accurately than any other currently available system. They are especially useful for training that occurs over difficult terrain, such as downhill skiing. In downhill skiing athletes must constantly train to optimize their body movements for maximum performance. This is often the purpose of an athletes coach or trainer. Recent work by Michahelles and Schiele (2005) utilises wearable sensors to describe vital movement technique data in order to improve the athlete-trainer relationship (see Figure 2.7, left). This technology is now superseding the previous data collection method of video recoding, which could only replicate an athlete's motions visually. Wearable sensors communicate data to accurately visualize an athlete's movement, allowing the athlete and coach to achieve consensus regarding performance improvement. Although this research will not involve the sensing of athletes motions specifically, it is important that the TeamAwear system does in fact improve the understanding of the coach through communicating individual athlete data. This work demonstrates how this can occur through careful consideration of coach needs during design.

Field Lab: The use of measurement sensors has recently been introduced within Football training, representing the successful use of wearable computing within competitive team sports. *Field Lab* is a project that is directed at improving athlete performance and coaching methods during training (TNO, 2006). The system raises the insight of the coach, trainer and athlete alike, by providing data relating to athlete actions, tactics and technique, as well as by monitoring vitals and physical strain. The system consists of a custom vest which is fitted with sensors for obtaining an athlete's position, speed, acceleration, and heart activity (see Figure 2.7, middle and right). This information is then captured by field based measuring terminals, which is then very accurately visualized in real-time using custom software. This allows coaches to get immediate feedback on the performance information of individual players, or of the team as a whole. This information can later be accessed by the athletes themselves, allowing them to contribute to better training supervision and match preparation.

This work reveals the benefits of measuring game-related data such as improving athlete performance. However, these benefits only become available after the data has been collected and analysed. The data is kept 'hidden' from players till after game-play, and so are only suitable for training purposes. In contrast, this research will display rather than hide such data, so that athletes and surrounding viewers can make decisions that could be vital to improving performance.

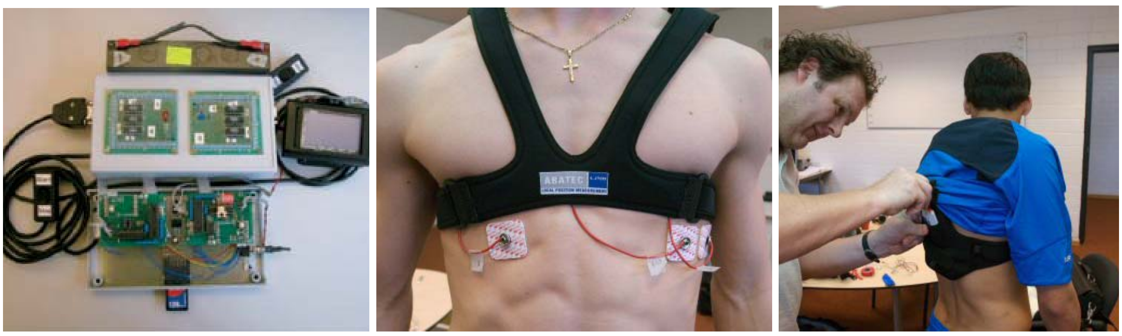

Figure 2.7. Wearable sensors for downhill skiing (left) (Michahelles and Schiele, 2005); wearable vest based sensors for monitoring football athletes (middle, right) (TNO, 2006).

Houston Mobile Application: Outside of a competitive sports context, the use of wearable computing can be used to effectively change human behaviour, by increasing awareness of ones own physical activity. *Houston* is a wearable mobile application which displays the wearer's step-count, and shares this information with other wearers to encourage exercise (see Figure 2.8). This work is an effort to address the problem of obesity, and encourage physical activity into people's normal everyday lives. During a user study, it was found that after using the Houston wearable application for several weeks, users were actively planning increased physical activity (Consolvo et al., 2006). These results revealed several design requirements for the development of devices that encourage physical activity, such as providing increased personal awareness and acknowledging ones own performance.

Unlike many of the other wearable sports devices discussed in this section, this work concentrates on encouraging participation in physical activity rather than measuring or improving the activity itself. However, this identifies that an increased awareness of relevant information in a physical activity context (i.e. sports), can provoke a positive change in human behaviour. The TeamAwear system will similarly encourage a change in the normal behaviour of stakeholders during a team sports match. If an awareness of one's step-count can be shown to encourage exercise, an increased awareness of relevant game-related information sources in team sports may likewise encourage changes in game-play. Additionally, the implementation of the TeamAwear system is expected to reveal similar design guidelines, in terms of awareness increasing devices in team sports.

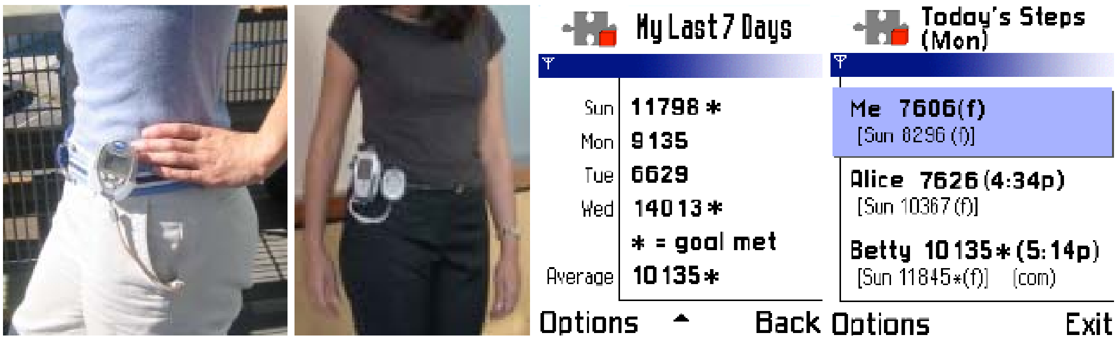

Figure 2.8. A wearable mobile application encourages users to exercise by increasing awareness of personal physical activity, and sharing this information with other users (Consolvo et al., 2006).

The wearable computing systems described above reflect the current state of this field in sports, and offers insight into how, and most importantly why such technologies are introduced. These works have shown how wearable computing can offer support to athletes or teams in the form of increased awareness, often leading to improved performance. They also reveal a mutual need for improvement, which has led to the acceptance and application of wearable systems in a sports context.

2.2.2 WEARABLE DISPLAY

Wearable display is a kind of wearable computer that is used to convey information about the wearer via an integrated display material. The primary interaction with such devices is shifted from the wearer to the viewer. They are designed to be viewed by the surrounding public, allowing them to understand information about and therefore make decisions about the wearer. This is in contrast to common wearable devices such as heart rate monitors, personal digital assistants (PDA's), and mobile phones, which are solely designed for viewing by the wearer.

The type of display materials used within a wearable display can be visual or non-visual. Examples include, LCD displays, light-emitting panels, sound emitting devices, and also tactile vibrational surfaces that communicate to a user through the sense of touch (Tan and Pentland, 1997). This section will largely concentrate on those current works that use visual displays, which are more closely related to this research. These works can be classified within two categories: those which are *badge-based,* and those which are *integrated within clothing*.

2.2.2.1 Badge-Based Wearable Display

Works from this category are ultimately externalised displays, which like a common name-tag or brooch, are worn on the outside of ones clothing and usually reside close to ones face. They are primarily used as a means to communicate personal information about a wearer to attract interest from surrounding viewers. The following cases reveal works from recent badge-based wearable display research.

Thinking Tags: One of the earliest examples of a wearable display system is found in *Thinking Tags*. These tags are worn within a socio-academic environment, with the purpose of 'telling' wearers how much they have in common with each other (Borovoy et al., 1996). Each tag contains a number of LED's, and when two wearers encounter one another, their tags exchange data and visually convey the results using the LED interface (see Figure 2.9, left). They augment the notion of the name tag by providing more useful information about the wearer such as personal traits, therefore sparking social interaction among strangers and providing a sort of 'entertainment value' for those already acquainted.

The TeamAwear system will similarly encourage interaction between wearers by visually providing relevant information about one another. Like Thinking Tags, this information presentation should occur passively without the need for user intervention. The use of an undemanding display medium is especially relevant to this research. The use of subtle variations in light and colour, particularly in team sports, is more accessible via ones peripheral attention than a complicated or text based display. The 'entertainment value' of Thinking Tags is an important part of their implementation, and this aspect will be shared by the TeamAwear system. For in cases where users are already aware of the information shown on the displays, its presentation in a new and interesting way provides a quite enjoyable viewing experience.

BubbleBadge and WearBoy: These works explore the use of early wearable display systems to present personal information publicly rather than kept privately. The *BubbleBadge* explores viewer interaction with wearable information devices, which are commonly highly private and controlled only by the wearer (Falk and Bjork, 1999). It uses a small wearable display in the form of a brooch that is capable of displaying dynamic information (see Figure 2.9, middle). The display capitalised on a brooch based design because such objects afford viewing by people other than the wearer. While being worn, the devices constantly request information from surrounding devices including other BubbleBadges, displaying information such as: emails, personal interests, and local activities. The broach-like display is worn close to the face, and so encourages and augments face-to-face communication between wearers and viewers by delivering supplementary information. It was shown that the display did not necessarily interrupt conversation, revealing how such devices can be informative while also remaining unobtrusive.

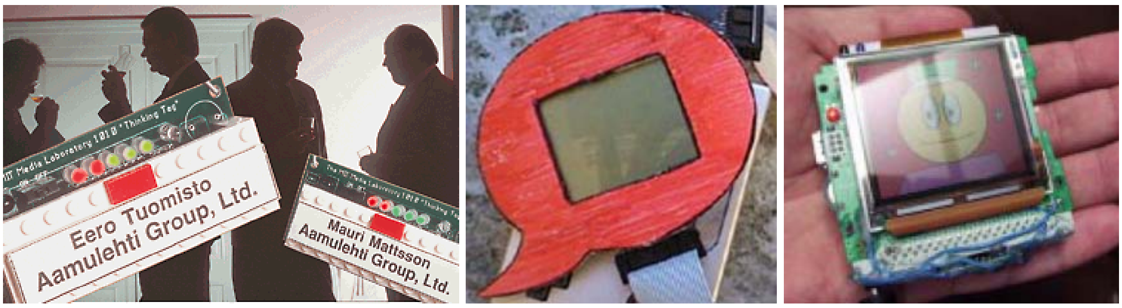

Figure 2.9. Thinking Tags in use at a social event (Gessler, 2001) (left); the BubbleBadge (Falk and Bjork, 2001) (middle); the WearBoy (Ljungstrand et al., 1999) (right).

The *WearBoy* similarly supports and enriches social interaction between people where the primary user of the system is not the wearer but the viewers of the device (Ljungstrand et al., 1999). As well as being able to explicitly portray personal information to the public like the BubbleBadge, the WearBoy makes use of dynamic graphical art representations to display information (see Figure 2.9, right). The constantly evolving aesthetic patterns of information displayed are an effective means to attract attention from surrounding viewers, who can then gain an understanding about the wearer. The display used for this research will be closely related to the simple graphical patterns drawn on by the WearBoy, which are more easily perceived than non-graphical displays.

Both the BubbleBadge and the WearBoy challenge the notion of a personal device, by using such a device to make private information public. However, the presentation of this kind of information is only permissible in cases where the participating users consent. On the contrary, the TeamAwear system will reveal only publicly accessible information about the team sport users, avoiding any privacy issues. The location of the displays is quite important in this work, as it allows the information to also be detected by the wearer. The TeamAwear system will similarly be viewable by the wearer, so that they too may use the information for understanding and decision making. Lastly, the unobtrusive nature of these devices is of particularly relevant here. This research will provide information in a similar way to allow detection on the periphery of ones attention, so that the act of game-play can be preserved without interruption.

Hotspot Bloom: This work is used to communicate information not about the wearer specifically, but of the wearer's location in their environment. *Hotspot Bloom* is a robotic flower that 'grows' when the wearer is within regions of strong wireless network connectivity (Lee, 2003). The system uses an artificial flower to house a display device and various control components (Figure 2.10). When a wearer enters the vicinity of a strong wireless signal, the display will grow brighter. Similarly, its intensity will grow weak with a diminishing signal. In this way, viewers can immediately understand the availability of a wireless network within a certain area, increasing awareness and interest of their surrounding environment. The physical embodiment of data within this system is based heavily on the field of ambient display, creating an aesthetically appealing and functional wearable display that is peripherally viewable.

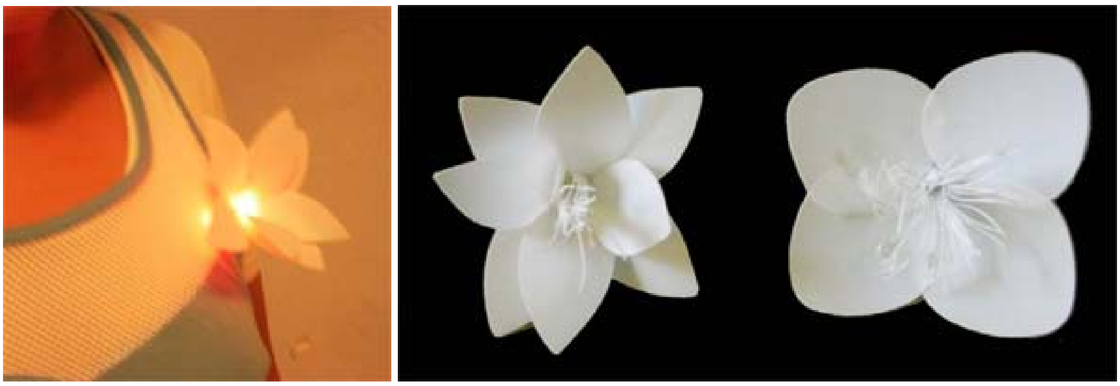

Figure 2.10. Left: Hotspot Bloom system in use. Right: various system designs (Lee, 2003).

A valuable aspect of this work is that it does not look out of place in its everyday context of use. It is at the extreme end of badge-based wearable display design, resembling a flower-brooch that is both wearable and fashionable. The design of the TeamAwear system will maintain a similarly appropriate physical appearance, consistent with a team sports environment. Hotspot Bloom is also based heavily on ambient display research, allowing it to be observed peripherally as well as remain wearable. This research will also consider ambient principles during the design and development stages, as periphery of display is a crucial factor within a team sports context.

2.2.2.2 Clothing Integrated Wearable Display

These works describe wearable display systems which are seamlessly integrated within fashion products and items of clothing. They are more unobtrusive than badge-based systems, and can be embraced by viewers for their information content or ignored as simply a fashion statement. They can be manufactured into many kinds of attractive items, becoming more 'beautiful' and acceptable in public situations. The following cases demonstrate clothing integrated wearable display.

HearWear: This system is described as electronic apparel which keeps the wearer and surrounding passers-by in touch with their environment with a playful display of the surrounding urban sounds (Iossifova and Kim, 2004). *HearWear* uses an everyday skirt enhanced with a flexible electroluminescent (EL) wire display arranged in an aesthetic pattern (see Figure 2.11). The display is activated by environmental noise pollution such as: common street sounds, patterns such as car horns and sirens, and large crowds. People's understanding of noise pollution is often small, so this system aims to increase awareness by allowing them to sense noise pollution data through beautiful patterns. In this sense, viewers are able to learn information about a wearer such as their location, but also about their own surrounding environment (i.e. tranquil or noisy).

The seamless integration of the display components within HearWear is specifically relevant to this research. The work is designed to be a very discreet technology, so that even when it is not 'on' it is equally fashionable, attractive and comfortable to wear. Based on this work, the TeamAwear system will provide a similar level of subtlety, and will appear aesthetic both when in use during game-play and when inactive. This research will expand on the work of Iossifova and Kim by creating a more viewer-oriented display system. This will provide users with more usable information about the wearer which they are specifically interested in knowing. This will be achieved by including end users in the design process.

Figure 2.11. The HearWear display varying from quite to noisy environment (Iossifova and Kim, 2004).

Noise Shirt: Many current wearable applications include a variety of maintenance-related setbacks that prevent their use and acceptance by the wider community. Iso-Ketola et al provides a solution to two of the most notorious of the maintenance problems, by developing a wearable display which can withstand machine washing and be recharged wirelessly (Iso-Ketola et al., 2005). The *Noise Shirt* system is a wearable display integrated within an ordinary t-shirt, which measures the surrounding environments noise levels. This information is then represented within the shirt via an easily interpretable equalizer bar display (see Figure 2.12, left). As the sound levels surrounding the wearer increase, the shirt reflects by activating more LED's. The electronic and display components of the shirt are coated with a water-proof polymer coating to allow for machine washing after use. The shirt also contains embedded conductive coils that allow the system to be recharged wirelessly.

The display system used for the Noise Shirt is easily understandable, with an upward increase in activated displays denoting an increase in environmental sound levels. A similarly simple display will be afforded by this research, with the intention of the TeamAwear system to be easily and quickly interpretable, even by non-experts. The notion of a washable electronic display is also favourable, though this system is let down since an electronic failure can render the shirt useless. This research will also extend the work of Iso-Ketola et al by not only making the clothing washable, but also allowing the electronic components to be easily removed. This will be essential for a team sports context, as clothing can become quite wet from perspiration, but also because contact is quite high and damage to electronic components quite probable.

Glow: The *Glow* system by Co (2001) consists of a custom-made raincoat which mirrors the rhythm of rainfall. Water sensors built into the hood, back and sleeves are activated as rain falls onto the coat, causing three electroluminescent panels to light up (see Figure 2.12, right). A flickering pattern therefore emerges when a wearer is out in the rain based on which areas of their body are becoming most wet. Similarly to Iso-Ketola et al's Noise shirt, the raincoats display panels are specially sealed to protect against water damage. When worn out in the open on a rainy day, the system is capable of creating public awareness about a wearer's surrounding environment. The raincoat indicates to viewers the current state of weather conditions, specifically whether there is rainfall and if it is light or heavy.

The display materials used in the Glow system, as well as their aesthetic arrangement, effectively blends computationally behaviour with functional fashion. The raincoat does not sacrifice the ability to keep the wearer dry for display benefit, but instead complements it. Comparable to Co's luminescent raincoat, this research will not sacrifice form for function. The primary objective of a team sports jersey is to offer some kind of identification for the athletes wearing it. The objective of displaying game-related data to surrounding viewers will be secondary for the TeamAwear system, though still significant. The aesthetic effect of the flat EL material used in the Glow system is similarly relevant for this research. These panels take up a large surface area and glow quite bright, they are therefore ideal for use in a team sports context where visibility is essential.

Figure 2.12. The noise shirt with washable coating for electronics (Iso-Ketola et al., 2005) (left); the Glow luminescent raincoat system (Co, 2001).

Compass Coat: The *Compass Coat* extends the concept of a compass, enabling a user to find his or her direction. By making the device a piece of clothing, the wearer literally becomes the direction pointer of a compass (Ossevoort, 2002). The interface and information then become available to more people than just the wearer. The coat contains a number of strategically positioned displays which have been seamlessly integrated into its fabric. When in use, the section of the coat that points north will light up, while the surrounding sections glow dimly. In this way, surrounding viewers and the wearer themselves gain a sense of direction from the coat which they can then follow like a digital map. This work relied heavily on user involvement prior to the development of a working prototype. The coat was intended for use by people who like to spend time outdoors. Issues such as ‘what materials to use’, and ‘how the coat should appear and behave’ were therefore considered with the help of these intended users.

The display material used within this system was selected based on its ability to deliver a suitable quality of light without being too intrusively visible (see Figure 2.13, left). A flexible electroluminescent (EL) wire display was used that could be augmented into aesthetic ‘natural’ patterns. The TeamAwear system will equally require the capabilities of a display material such as the EL wire used here, which is bright, flexible, and non-intrusive. The custom appearance achieved by Compass Coat in sewing displays into the clothing, is also favored by this research. One crucial aspect of the Compass Coat is the user involvement during the design process. This reveals the advantages user studies can provide during the early stages wearable display development, such as understanding the potential relationships between users and the system. This research will likewise utilize a user-based approach. However, this will expand on Ossevoort’s Compass Coat work by allowing users to determine not just the physical design, but the actual information content of the display and its representation.

Tactile Vest: The *tactile vest* is a current example of a sports wearable display. Implemented for training in rowing and skating sports, the tactile display uses a matrix of vibrational devices integrated within a vest (see Figure 2.13, middle and right), and is based on the notion of the skin as a display medium (Vannieuwland, 2005). The vest is capable of delivering minor yet effective vibrations signals to the entire upper body of the wearer. This is used for the specific purpose of improving athlete performance through coaching in sports such as ice skating. For example, the vest allows a coach or trainer to physically ‘steer’ an athlete by projecting outside information onto their body. If it is desired that an athlete turn their body left, the vest will send a subtle vibration to their left side. Not only does this allow for athlete performance to be improved in real-time during training, it provides a mechanism for universal coach-athlete communication in cases where the two may speak different languages, or be separated by large distances.

The tactile vest slightly opposes the wearable display definition given above, in that the information displayed is only privately accessible by the wearer. However it is particularly relevant in this case due to its applicability to sports. In contrast, the TeamAwear system will be used to communicate information publicly. Still, the tactile vests ability to allow athletes to become more aware of performance-based information in real-time is closely related to this research. The TeamAwear system will be developed to achieve a similar ability of increasing athletes’ awareness of performance-based information and other game-related data.

Figure 2.13. Compass coat provides information about direction (Ossevoort, 2002) (left); tactile display vest for sensing performance data during sports training (Vannieuwland, 2005) (middle, right).

A common aspect in each of the wearable display systems described above is their relatively simple representation of information. Rather than display information in a complex manner, such as text or complex graphics, these works tended to use a more subtle and non-distracting approach similar to ambient display, by using light, colour, or even small vibrations. Many of the works also included some kind of user involvement during system development. This was shown to help design wearable display systems which are better suited for the end-users and context. Ultimately, many factors need to be considered during the design and development of a wearable display for team sports. By referring to the aforementioned related work provides valuable insight into current 'tried and tested' methods for wearable display research in a variety of contexts. Many of these methods will be incorporated throughout the implementation stages of this research, as will be described in the following chapters.

3 The TeamAwear System

The TeamAwear system has thus far been classified by a number of keywords and phrases, including: display, wearable, team sports, sports technology, awareness-increasing, and visualization. The term ‘TeamAwear’ is in effect a combination of several of these classifiers, so named for ‘Team Sports Awareness Wearable Display’. The focus of this chapter will be to conceptually describe the intentions of this system, and how this is relevant within the context of team sports.

3.1 Concept

Team sports clothing currently serves two purposes: for one they provide protection for the body, but they also act as a means of communication via graphics and colour which have become an identification system for athletes (O'Mahony and Braddock, 2002). This research proposes to extend the use of team sports clothing (i.e. jersey) as a communication medium, by displaying more meaningful information than just an athlete’s identity, such as relevant statistics or time restrictions. In this way, the notion of the jersey is transformed into a *wearable visualization* that allows athletes to wear their performance on their sleeve, literally. By merging visualization with fashion, clothing is considered as a sort of public display that is meant to ‘signal’ an interpretable meaning (Liu and Donath, 2006). This raises the question of whether athletes would change their game-play when they have such ready access to relevant information, and would this affect the performances of the other stakeholders.

The TeamAwear system is based on the hypothesis that a wearable display, worn in a team sports context, can positively alter the subjective experience of its typical stakeholders, such as the athletes, coaches, referees, and spectators. By representing specific information, and thus making people aware of aspects that are normally hidden from view during game-play. A wearable display can potentially enhance the experience of persons present in its immediate vicinity, including that of its wearer.

3.2 Context

The TeamAwear system is a novel development, grounded firmly in the team sports domain. Accordingly, the implementation of the TeamAwear system has been shaped by the many features of this domain, including sport itself and the media. The following section describes the context-related features which bear significant influence on the application of this research.

3.2.1 BASKETBALL

Basketball is a competitive team sport which is currently played in over 200 countries (Davydov, 2005), and captures the interest of millions yearly through both live and broadcasted game-play. Basketball is chosen as the initial application domain for implementation of the TeamAwear system for several reasons, which include:

- **Rich** sets of relevant **information**, which influence the actions and outcomes of a game
- A high reliance on **team-based strategies**
- **Rapid pace** of game-play, often causing game-related data to change quickly and invisibly
- **Small** playing **environment**, so that there is often only a short distance between athletes and surrounding stakeholders
- Relatively **low** physical **contact** during game-play, potentially reducing damage to any body worn electronic devices
- Game-play occurs mostly **indoors**, allowing increased visibility of displays

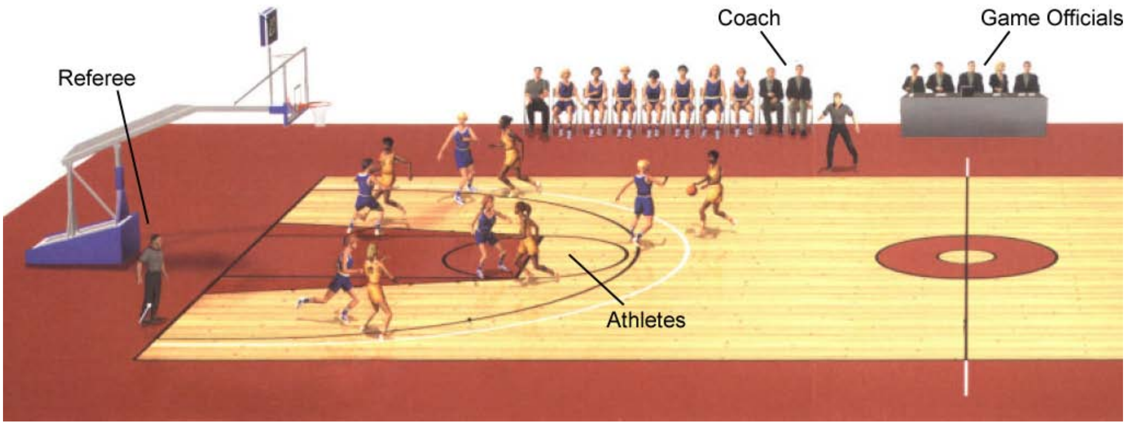

Figure 3.1. A typical game of Basketball, spectators not shown (Fortin, 2000).

A typical basketball match involves a variety of stakeholders, consisting principally of two teams of athletes competing for the common goal of winning a game (see Figure 3.1). These **athletes** are able to think fast, and possess good peripheral vision and a solid understanding of the game (Fortin, 2000). Athletes are instructed by a **coach** who advises and directs the team on strategies. A **referee** monitors the athletes and makes decisions to ensure game-play is fair and error-free. **Spectators** observe the game for personal enjoyment and to gain insight, either locally (e.g. surrounding the playing environment) or remotely (e.g. live broadcasts). Game **officials** use a score sheet to keep record of game-related information sources (score, fouls, time), although they have no significant impact on the game-play itself. The ability of each stakeholder to carry out these tasks is crucial to the success of the game. Accordingly, it is believed that basketball will benefit from the implementation of an awareness-increasing technology that can potentially improve the ability of stakeholders to carry out tasks during game-play. Moreover, *Basketball Australia* has permitted this research and use of the TeamAwear system by athletes during basketball games that are not part of official competition (see Appendix A for letter of approval).

3.2.2 ON-SCREEN SPORTS GRAPHICS AND VIDEO GAMES

The development of the TeamAwear system has been inspired by visualization techniques and tools used by the media and entertainment areas. On-screen sports graphics and sports-related video games are two well established applications for awareness-enhancing visualization technology. These 'alternative' forms of sport visualization are a familiar aspect of our technologically driven society, providing intuitive representations that specifically influence ones perception of game-play.

On-screen sports graphics are commonly displayed during televised sports broadcasts or webcasts. The types of graphics used can include dynamic real-time visualization or information graphics, such as performance history graphs, shot charts, and Sparklines (see Figure 3.2). These graphic are used across a wide spectrum of different sports to enable stakeholders, primarily spectators, to track and understand the complex information sources and statistics making up a sporting event (Bennett, 1998). They heighten the level of interest and enjoyment for spectators, particularly those who are inexperienced. Without these graphical visualizations, game broadcasts can become difficult to follow. A strong case for this modern reliance of on-screen graphics occurred during the coverage of the Eighteenth Commonwealth Games. At the conclusion of a crucial track event, the broadcaster failed to display on-screen graphics representing the outcome. This confused and frustrated the spectators, with one radio announcer exclaiming that: *"people need this information… They are interested and they want to know"* (Jones, 2006).

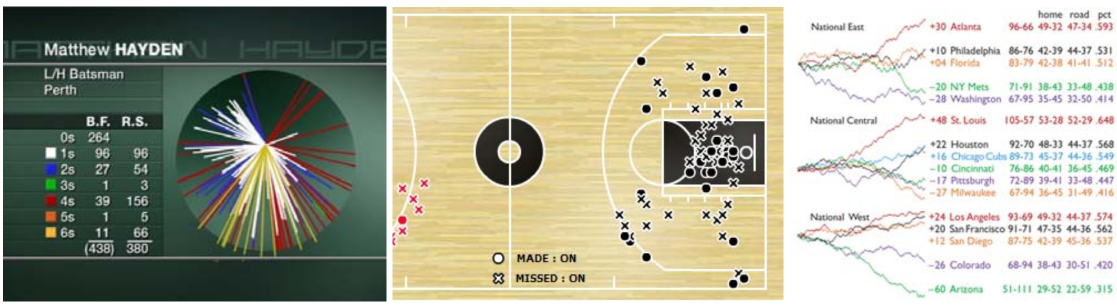

Figure 3.2. On-screen sports visualization: performance history graphs (Virtual Spectator, 2006); shot charts (ESPN, 2006); and Sparklines (Tufte, 2006).

The use of graphical visualizations during sports-related video games is now common practice. It is especially well-known among younger generations who have grown up playing these games, and concurrently learning the incorporated sporting concepts. These visualizations are used to represent game-related information sources, which are continually presented on-screen during ‘virtual’ game-play, and are essentially controllable and customizable by the user (see Figure 3.3). Some visualization is even ‘tied’ to video game avatars, so information is constantly available at the focal point of the user’s attention. For instance, in the sports video game *NBA Jam* (Acclaim Games Inc., 2006), users control the actions of a professional basketball team. Throughout the game, various graphics and icons appear on-screen to represent the status or performance information of the virtual players (such as points, fouls, accuracy, etc). These representations can be quite abstract, such as when a player is performing exceedingly well they will appear to ‘glow’, or even possess a fluctuating vitality indicator. Therefore, the user is able to gain an almost instantaneous understanding of the current state of a game. In cases where two users play against one another, these graphics provides an opportunity to identify a competitor’s top scorer, weakest player, and so on.

Figure 3.3. Sports-related video games use graphical visualizations to represent game information (XBoxExclusive.com, 2006).

These alternative sport visualizations provided during broadcasts and within video games, incorporate commonly accepted representations for concepts such as ‘big’, ‘small’, ‘good’, ‘bad’, and ‘warning’. In this way, they are widely understood across different cultures and societies. Presently though, the use of these visualization techniques is currently restricted to television and computer displays. The extreme familiarity most people possess with these visualization techniques forms a reference point for the implementation of a wearable visualization for team sports. Moreover, the TeamAwear system has the capacity to take broadcast and video game graphics out of the screen, and bring them into the stadium.

3.2.3 SPORT PSYCHOLOGY

Sport psychology is a field concerned with the study of human behaviour in sports (Gill, 1986). Research in this area, including the study of cognitive issues and visual perception, reveals a link between the knowledge of relevant information and performance in sports. In team sports for instance, an athletes uses their knowledge of the environment or surrounding athletes to formulate intended goals of actions, and facilitate in-game performance (Starkes and Allard, 1993). Similarly the awareness of visual information obtained from the sports environment has been shown to play a valuable role in the successful actions of an athlete during game-play (Williams et al., 1999). An increased awareness of information such as the location of an object or event, distances between objects or athletes, and timing, have all been shown to improve player performance. The reinforced awareness of results in team sports is also understood to be a source of athlete motivation, which again is linked to increased athlete performance (Singer, 1975).

The notion of the TeamAwear system is in strong support with the field of sports psychology, in that an increased awareness of relevant information during sports events inexorably leads to improved performance. Although this takes into account only the athletes, it is expected that an increased awareness of game-related information sources would result in improved performances of both the coach and referee. This would almost certainly produce more interesting and enjoyable game-play, which is therefore beneficial to all stakeholders, particularly the spectators.

3.3 System Description

TeamAwear is a wearable display in the form of an electronically-augmented jersey. It is capable of representing game-related information sources in real-time via an onboard wearable computing and display devices. By regulating what information is shown and when, TeamAwear preserves the existing philosophy of technology within sport, which attempt to enhance games by improving factors such as: fairness, enjoyment, understanding and performance (Loland, 2002).

The application setting for the TeamAwear system is within a team sports environment, where it is simultaneously worn by multiple athletes during the game itself. By perceiving the display devices, it is expected that the different sports stakeholders become more consciously aware of otherwise hidden or fast-changing crucial game-play related information in the periphery of their attention, hereby positively influencing their sports experience. For instance, an increased awareness potentially allows athletes to make improved in-game decisions, supports more accurate coaching assessments, augments the understanding of game situations and increases the enjoyment of the actual game for spectators.

3.3.1 USAGE SCENARIO

Athletes from each team are fitted with a TeamAwear wearable display jersey prior to game-play. Typically a game official will monitor the game courtside, or from a designated monitoring booth. This official, or team of officials, will operate a wireless central computer that is running a custom program made specifically for communicating with the TeamAwear jerseys. The game official closely monitors game-play, and when relevant game-related data is created or altered (e.g. a team scores a point, an athlete awarded a foul, etc), he or she will immediately record this using this custom program. Once an update has been recorded, the computer will then communicate this information to the appropriate TeamAwear jersey. Once this information is received, display devices embedded within the jersey will automatically update to reflect this new game-related data. In cases when the information sent is relevant to more than one jersey, for instance a whole team, then all applicable jerseys will be updated to reflect this data. Figure 3.4 illustrates this usage scenario. A more technically-oriented description of this process is provided at the conclusion of Chapter 5: Technical Development.

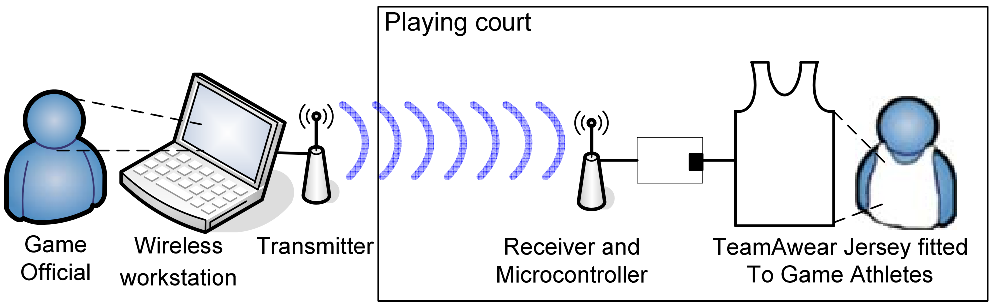

Figure 3.4. A typical usage scenario involving the TeamAwear system.

4 User-Centred Design

The relative novelty of wearable computing, and wearable visualization for sports in particular, supported the selection of a user-centred design approach. *User-centred design* is a Human-Computer Interaction (HCI) method based on the active involvement of specific users, for a clear understanding of user and task requirements, and the iteration of system design and evaluation (Vredenburg et al., 2002). The design process would inevitably encounter critical ethical, ergonomic and usability issues that required insight from experienced or expert users, which could be achieved by iteratively incorporating insights and comments from relevant stakeholders. The design process consisted of three consecutive stages: Evaluative Ethnography, Participative Design Studies, and Prototyping.

4.1 Evaluative Ethnographic Study

An evaluative ethnographic study determined how the TeamAwear system could be useful in a team sports context, and what design requirements it should possess. This study served as a starting point for this research, allowed for initial design decisions to be made, and design constraints to be identified.

4.1.1 EVALUATIVE ETHNOGRAPHY

Ethnography is a research approach which provides valuable means of analysing the contextual circumstances of a systems usage (Crabtree, 2003). In a design context, the application of ethnography as a research tool is simply referred to as an ‘ethnographic study’. However, this is typically an extensive process which can often take many months or even years to perform (Ball and Ormerod, 2000). *Evaluative ethnography* does not require a long-term period of fieldwork, but rather seeks relevant information quickly in order to establish the ‘work-ability’ of a proposed design system (Hughes et al., 1995). This approach aims to make issues apparent which may impact the acceptability and usability of a proposed system. It is particularly well suited when applied to the design of technological artefacts, as well as for gaining insight into the human factors which may affect the design process. Figure 4.1 illustrates a typical evaluative ethnographic study.

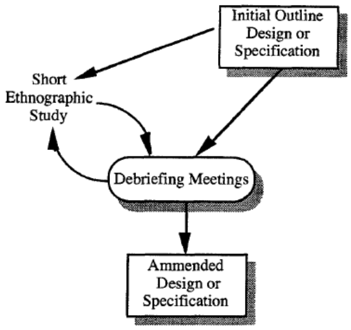

Figure 4.1. Diagram of evaluative ethnography process (Hughes et al., 1994).

4.1.2 FIELD WORK

An evaluative ethnography study was carried out over a period of approximately eight weeks to examine the intended users during their normal ‘sporting state’. Based on the conceptual notion of the TeamAwear system, prior motivated choices were made with regards to ‘what’ and ‘who’ to study. Field work occurred during scheduled training sessions and competitive basketball games, as shown in Figure 4.2. The intended users observed during this time were the primary basketball stakeholders (i.e. athletes, coaches, referees and spectators). *Unobtrusive observation* was the primary data collection method, which requires minimum researcher participation in the users activities (Angrosino, 2004). This involved studying the actions of stakeholders as a passive observer, such as: watching the athletes during game-play and taking notes of their movements and actions; observing the instructive and guiding behaviours of the coaches; studying the decisions and adjudication procedures of the referee; and observing the viewing patterns and interests of the spectators. These observations were facilitated with the aid of specific documentation tools, such as written field notes, and *proxemic* diagrams to study peoples use of space, in this case a basketball court (see Figure 4.3).

Figure 4.2. Environmental factors and the roles of stakeholders are observed during competitive basketball games (left, middle); training sessions reveal the physical demands of athletes (right).

"Pace of game drastically increased during the final minutes of game-play. The athletes made more mistakes and took risky shots"

"Coach calls 'timeout' during game-play and uses this time to give new instructions to the athletes based on their observed performance"

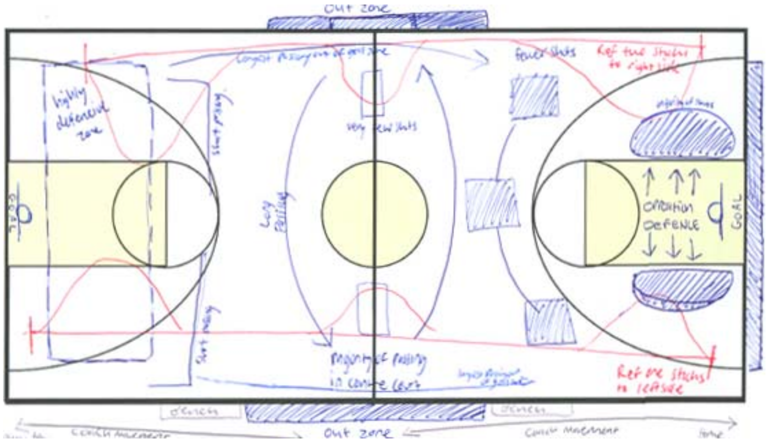

Figure 4.3. Extract from field notes collected during senior men's competition, North Sydney Sport Centre 16/05/06 (left); proxemic study reveals how athletes use the environmental space during game-play (right).

4.1.3 FINDINGS

General observations carried out during field work allowed several primary system design tasks to be discerned, such as: environmental parameters (e.g. the typical amount of light, noise and distances on a sports court), the cognitive load on human senses, and a thorough understanding of each stakeholder's role during game-play and their typical actions. Observation of the players themselves revealed the relatively high demands and constraints on the potential design of the wearable display, including:

- Physical design (i.e. relatively high amount of physical contact between players, so that even falling is not uncommon)
- Efficiency of information display (i.e. rapidly changing game development)
- Perceptual abilities (i.e. players dedicate full cognitive attention to game-play)
- Game-related restrictions (i.e. devices are not allowed to protrude or advantage any team or team member)
- Environmental parameters (i.e. bright and loud physical setting)

A more detailed description of these findings is given in Table 4.1. Accordingly, several preliminary design decisions were made regarding the choice of technical parts, including the wireless communication, power supply and display media materials (see Section 4.3.1: Design Considerations).

TABLE 4.1. Summary of findings from evaluative ethnographic study.

Category	Aspect	Findings	Basic requirements
Visualization	Human perception	Game-play highly cognitively demanding for auditory and kinesthetic channels	Visual displays only, Sound or tactile display will be less effective / distracting
	Activity level	Quick understanding of situations / decision making	Simple display (e.g. on/off), Peripherally visible, intuitive rather than complex
	Environmental setting	Bright environment outside or inside	High brightness visual displays, Viewable from distance
Wearability	Movement	Fast paced movements, un-restricted, bending and jumping	Cannot be protruding outside body due to safety concerns and rules, must be light-weight
	Contact	High amount of physical contact, falling not uncommon	Flat and flexible displays, Non-breakable separation of wearable devices
	Perspiration	Athletes perspire during game-play, sometimes profusely	Devices waterproof or protected against moisture
Intended users	Athlete	Centre of game-play, control ebb and flow of game	Enhance performance / decision making
	Coach	Analyses, instructs and guides players	Increase knowledge of athletes performance
	Referee	Maintains rules and fairness	Improve adjudication / fairness
	Spectator	Observes, learns, enjoys	Increase understanding / enjoyment
Information source	Availability	Publicly available information accessed by all users, but usually hidden	Displayed information sources should be publicly relevant
	Game-related	Game-clock, shot-clock, foul, score, rebound, assist, steal, block, turnover, points, historical performance	Display 4 to 5 information sources, Hidden datasets not widely available but interesting (e.g. fouls, individual points)
	Physiological-related	Activity, position, physical performance, handiness	Identify best / worst performers, No display of personal / unfair information

4.2 Participative Design Studies

A set of three user-centred participative design studies were organized based on the knowledge obtained during evaluative ethnography. A general principle for user-centred design is to involve users as much as possible, so they can influence the design at all stages (Preece et al., 1994). The goal of the participative design studies was to identify potential usage scenarios and critical design requirements for the TeamAwear system, based on the needs of the end-users. The studies were conducted over nine weeks, allowing design decisions to progressively become more refined. Each study covered a separate issue (i.e. conceptual design, physical design, and data refinement), involved several participants, and followed a similar format.

Representatives for each of the typical basketball stakeholders (i.e. athlete, coach, referee and spectator) were invited to participate in these studies. The number of participants recruited was based on the relative importance of their roles to the intended application: each of the sessions involved at least 6 athletes, 1 coach and 1 referee, and 3 spectators. The athletes (age range: 19 to 25) were semi-professional basketball players, many with over seven years experience. The coach and referee (age: 38) boasted advanced basketball knowledge, with over five years experience. The spectators (age range: 18 to 23) were all regular basketball viewers and had minor player experience at a non-completive level. The initial recruitment occurred via distributed flyers and handouts at sports centres. The study specifically appealed for female basketball players, due to an assumed (and ethnographically observed) reduced amount of physical aggression during game-play, and a reduced risk of potentially harming the device or its wearer. The recruitment resulted in a limited but sufficient response due to the relative scarcity of female basketball players, and the fact that the subjects did not receive any reward for their significant time investment. The same participants were recruited for each of the three studies in order to maintain design fidelity and obtain consistent results.

The studies occurred inside a seminar-styled room, and involved forum-type discussions that encouraged participants to autonomously voice their concerns, combined with guided design tasks. Participants were given ready access to pens and paper so that they could continually write down their responses and sketch ideas. Each study began by (re)introducing the research, followed by guided discussion topics (i.e. usage scenarios, design requirements). To obtain a variety of design conclusions, participants were later divided into small groups consisting of the following formations: two athletes and one coach; three athletes; one athlete and one spectator; one referee and one spectator. Following a typical constructivist studio-based approach (i.e. users reflect on their own experiences to construct understanding), each group creatively designed a set of proposals, which would then be presented, critiqued and refined by the whole group. The individual outcomes of each participative study considered a different aspect of the TeamAwear systems design, including: conceptual design, physical design, and data refinement.

4.2.1 PARTICIPATIVE DESIGN STUDY ONE: CONCEPTUAL DESIGN

The aim of the first study was to identify a need for the proposed system amongst the participants, and then to identify potential uses, requirements, user needs, as well as some preliminary design decisions. Discussions were intentionally left open-ended, allowing the concept of a sports-related wearable display to be discovered and developed by the focus group itself. Collection methods such as written responses, audio recordings, and photography were used to record the user responses. The following outcomes were achieved during this study:

Proof of Concept: During the sessions, it was clear there was a genuine interest for real-time information access during game-play. All participants agreed that such a system would likely be used to improve athlete performance on-the-field, and increase the understanding of those that are off-the-field (e.g. spectators believed it may be used to track the progress of their favourite athletes). The coach also suggested that it would *“make a suitable training aid, allowing the athletes and coach to become more aware of the individual and team weaknesses”*. There were some negative voices, some athletes stating that it might be *“distracting”* or advantage their competitors. Some athletes also felt that it could make the game *“robotic”*.

Requirements and User Needs: All participants independently outlined a strict visual display requirement for the system. The possibility of a tactile or auditory display was dismissed in this respect, being considered “*applicable to athletes only*”. Athletes inadvertently bounced ideas off one another to create the most abundant list of requirements among the participants, taking into account aspects such as appearance and wearability. The referee put forward a number of stringent requirements to ensure fairness and uphold game rules, while the coach and spectator participants both listed visibility the utmost importance. Table 4.2 summarises the requirements and needs described by each participant type.

TABLE 4.2. Requirements and user needs of each stakeholder type.

Stakeholder	Requirements / User Needs
Athlete	High visibility, bright colours, unobtrusive, easily interpretable, peripheral, comfortable, light-weight, power supply to last at least length of game, perceived by wearer
Coach	Visibility, comfortable for the athlete
Referee	Above the waist, not near jersey numbers, no protruding parts, safe, no possibility of injury, must be the same for all players
Spectator	Visibility, interesting to watch, no interference with game-play

Information Sources: Several game-related information sources were identified that were considered valuable during a typical competitive basketball game. Athletes listed only those which they felt would *“help to increase awareness and decision making”*. The coach identified an interest in knowing the individual player stats for each team member. The referee listed time-related datasets, stating that by reinforcing these datasets would *“ensure a fairer game as there would be a universal understanding of time among all stakeholders”*. As one would expect, no athletes wanted to display their personal physiological or environmental data (e.g. stress level, heartbeat, amount run) to the surrounding stakeholders, as it could be misleading or potentially benefit their opponents. Instead, it was agreed to display only ‘publicly available data’, related to the actual game itself. However, spectators did express an interest in personal data and being able to know *“how players are feeling”*. The game-related information sources listed by each stakeholder are summarized in Table 4.3.

TABLE 4.3. Information sourced considered ‘useful to know’ by stakeholders during a basketball game.

Stakeholder	Information Sources
Athlete	Foul count, score, amount of time played, individual points, wins/losses
Coach	Individual points scored, individual foul count, rebounds, steals, turnovers
Referee	Time remaining during a game (game-clock), time remaining for a shot to be made without penalty (shot-clock)
Spectator	Individual points scored, stress, fatigue

Visualization Options: Potential visualization options for the system were proposed before revealing the potential display materials, so that participants were not restricted in their decisions. Participants had already outlined a visual requirement for the system, and indicated that any visualization should be *“subtle”* because it meant they would be *“less overwhelmed”* by information. The following visualization options were identified: blinking, binary on/off (e.g. positive or negative data), sequential on/off (e.g. linear fluctuating data), and combination on/off (e.g. non-linear data). Table 4.4 shows the rationale behind each visualization option. In terms of timing, the participants unanimously agreed that all updates to the wearable visualization must occur in real-time, so that the most current information is shown at all times. Participants also indicated that the *“visualization should be active as long as the information is current”*.

TABLE 4.4. Participant feedback to possible visualization options.

Visualization	Rationale
Blinking	Distracting, annoying for players, referees and coaches
Binary on/off	Favoured, suitable for binary data (e.g. whether a team is winning or not, whether a player performing good or bad)
Sequential on/off	Favoured, feasible to display fluctuating or increasing datasets (e.g. points or time)
Combination on/off	Feasible, appropriate for more complex or multiple datasets, could reveal ‘too much’ data to digest, maybe overwhelming

Display Materials: The participants were presented with several previously identified visual display materials (see Section 4.3.1: Design Considerations), including: Electroluminescent (EL), Flexible LED, and scrollable text displays. Participants initially liked the idea of a scrollable display for revealing statistical data, but felt that this would ultimately be *“too distracting”*. The flexible LED displays were considered *“rigid”* and possibly *“fragile”*, potentially causing injury during physical contact. There was an overwhelmingly positive response to the EL display materials (i.e. flat panels and wire), which the participants observed as unobtrusive, clearly flexible, and highly visible.

Design Sketches: Participants were separated into small groups to creatively sketch design concepts for the system (see Figure 4.4, left). By leaving this task until the end of the study, the sketches were generated based on the previous discussion results, including: requirements, display materials, information sources, and visualization options. Each group presented their sketches to the whole group for critique and refinement, which resulted in a number of early design decisions, in particular revealing several suitable locations for display materials to appear (see Table 4.5). Participants expressed a wish for continuous visibility of the display, and a desire to make the jerseys fashionable and aesthetically appealing. Figure 4.4 (middle) reveals some of the participants design sketches. A set of more refined preliminary designs were able to be produced from these sketches (Figure 4.4, right).

TABLE 4.5. Suitable locations for display materials, based on the participants design sketches.

Location	Rationale
Shoulders	Out of the way of athlete contact and obstruction, viewable by all basketball stakeholders
Chest	Suitable for the players and for the wearer, able to be perceived by the wearer's peripheral vision, ideal for displaying data that is important for players to know at all times (e.g. time)
Back	Reasonable location to display data relevant to the spectators, (spectators are often presented with an player's back more than front)
Sides	Visible most of the time, viewable when athlete holding ball/ defending/ passing/ shooting, would not restrict athletes movement
Trimming	Trimming located around the neck and arms (apparent on most basketball jerseys), good location for a thin flexible display such as the EL wire, would not significantly change the jersey

Figure 4.4. Group design proposal sketching (left); some of the design sketches (middle); Preliminary designs resulting from the sketches (right).

4.2.2 PARTICIPATIVE DESIGN STUDY TWO: PHYSICAL DESIGN

The focus of the second study was to finalize the leading design criteria for the system (i.e. information sources, visualization options), and to generate an appropriate physical design layout. First, all participants were reacquainted with the research project and with the outcomes they had achieved during the previous study, reinforcing the importance of their contributions. The participants were also given a more detailed explanation of the TeamAwear system which included the use of a wearable computer to 'control' the displays. The data collection methods used in this study included audio recording and photography, as well as a hands-on design session to model physical layouts. The following outcomes were achieved in this study:

Finalise Information Sources and Importance: A total of four game-related information sources were selected to be displayed: time, fouls, points, and the winning/losing team. The relatively small amount of data was selected by the participants, in particular the athletes, so they would *"not be overwhelmed by information during game-play"*. Time was considered one dataset, although it is actually made up of two interrelated datasets: the time remaining during a game (game-clock), and the time remaining for a shot to be made without penalty (shot-clock). Initially a few athletes were sceptical of the inclusion of fouls, with one indicating: *"specific players could be targeted for mistakes and penalties"*. However, the majority agreed that this was negligible given that counting fouls *"is normally done during basketball games as an advantage manoeuvrer"*, and additionally it *"would help stimulate game-play strategies"*. Overall, the information sources chosen revealed a general consensus on the relative importance of specific data, in particular those which are publicly available. Table 4.6 presents the final information sources selected by participants, arranged in order of importance. The importance rating is based on the perspective of the athletes primarily, followed by the referee, coach, and spectators.

TABLE 4.6. Game-related information sources selected to be displayed, listed in order of importance.

Information	Stakeholder	Rationale
Time Limits	athlete coach referee	Athlete: a reminder to hasten teams actions to take a shot (shot-clock), or before end of game Coach: strategic decisions depending on game-clock Referee: identify clock related errors more effectively
Individual Fouls	athlete coach spectator	Defensive Athlete: in-game decisions and playing style, i.e. provoke offensive faults. Offensive Athlete: in-game decisions and playing style, i.e. attempts to provoke defensive faults. Coach: reminder of team members with fouls (for both teams), i.e. determining exchange of players, game strategies to protect players with high amount of fouls, or influence competing strategy. Spectator: increased awareness of influencing factors, 'catch up' when the start of the game has been missed
Individual Points	athlete coach spectator	Defensive Athlete: in-game decisions and playing style, i.e. more attention to top scorers. Offensive Athlete: affects in-game decisions and playing style, i.e. more passes to actual top scorer. Coach: choice of strategies and exchange of players. Spectator: focus on top versus poorly performing players
Winning versus Losing Team	spectator athlete	Athlete: increased awareness, especially in a tight competition. Spectator: increased engagement in game

Physical Layout: The participants determined a final physical design of the system, including the materials, information content and positioning of the displays. Participants were divided into small groups to creatively generate physical designs. Each group was provided with dress maker pins, to-scale paper cut-outs, and strips of coloured ribbon to simulate the EL displays. A mannequin fitted with a generic basketball jersey was provided for the groups to plot various physical layouts onto the jersey. The jersey in this exercise was a v-neck style, which the participants agreed was more suitable than singlets which are *"not as solid"*. Each group generated an individual layout which was presented and critiqued by the whole group, until one final was generated by combining the preferred aspects of each groups design. Careful positioning of the simulated displays avoided areas where logos and numbers normally appear. Table 4.7 summarises the final physical design decisions. Figure 4.5 illustrates the final physical layout as generated by the participants.

TABLE 4.7. Physical design decisions for each information source as made by participants.

Information	Display Material	Location	Rationale
Time Limits	2 X EL Panels	Chest	Large display area reinforces importance of dataset, perceived peripherally by wearer, clearly seen by surrounding athletes,
Individual Fouls	8 X EL Wire	Shoulders	Thin display becomes more apparent when dataset is critical (i.e. high foul count), perceived peripherally by wearer, clearly seen by surrounding athletes, appearing on both shoulders increases visibility from literally any angle
Individual Points	3 x EL Panels	Sides	large surface area covered by displays that can be easily detected, appearing on both sides allows viewing from all directions
Winning versus Losing Team	1 x EL Panel	Back	Large display area easily seen from a distance, increased visibility for spectators

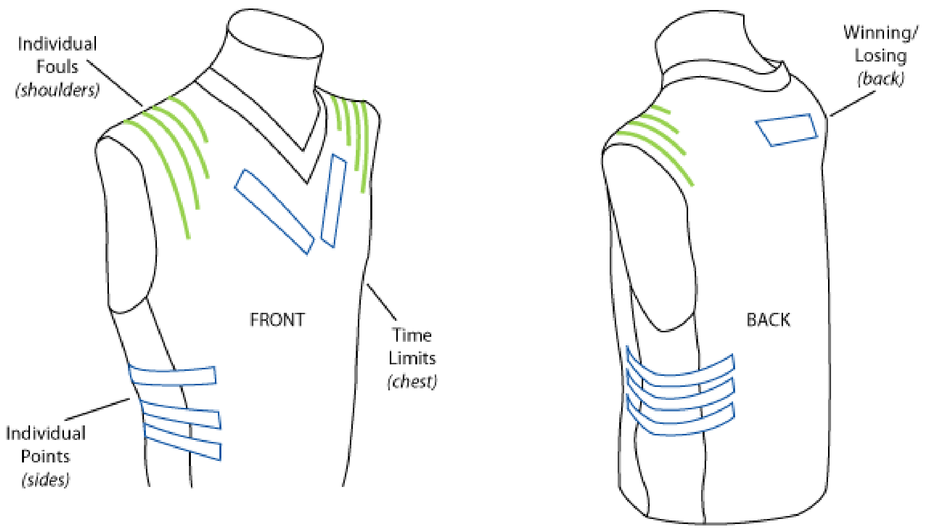

Figure 4.5. Final physical layout generated by users, revealing displays and information sources.

Final Visualization: Participants discussed and finalised the visual mappings for each of the final information sources (see Table 4.8). Only two types of visualization were chosen: a binary on/off display to represent data which are either true or false, and a sequential display for numerical data which fluctuate throughout game-play. These visualizations were simple and intuitive representations, and were based on making the displays easily understandable (i.e. even for a novice).

TABLE 4.8. Visualization options chosen for each information source including participant rationale.

Information	Visualization	Rationale
Time Limits	Binary (on/off)	Rather than monitor the entire dataset, on/off indicator lets the stakeholders know when a time limit is approaching
Individual Fouls	Sequential	Fouls increase from 0 to maximum 5, intuitive increase in sequence (e.g. display increases until maximum capacity reached), easy for all stakeholders to understand
Individual Points	Sequential	Increasing display sequence correspond to points continually increasing, easily perceive high and low point scorers, three panels indicate increasing score (e.g. 1 good, 2 better, 3 best)
Winning versus Losing Team	Binary (on/off)	Easy to differentiate between winning team and losing team (e.g. winning team display on, losing team display 'off'), extremely intuitive even for a novice, understood immediately

Wearability Design: The athlete participants – who are the sole wearers of the system – determined the ergonomic position of the wearable computing box (see Figure 4.6, right), which was chosen to be attached below the lower chest or waist. A weighted 'non-electrical' plastic box was fixed to an elastic ribbon harness to simulate the wearable computer, which was yet to be constructed at this stage. Female participants preferred the waist location whereas males preferred the lower chest, indicating that the final wearable computer harness should be adjustable for both sexes. One athlete suggested (and was supported by several others) that *"shoulder straps would be useful"*, to prevent the wearable device from slipping or falling down during use.

Figure 4.6. Hands-on physical design to determine display locations (left and middle); determining appropriate positioning of wearable computing box (right).

4.2.3 PARTICIPATIVE DESIGN STUDY THREE: DATA REFINEMENT

A final participative design study was required to finalize the display design of the more complex information sources: time limits and individual points. Although the majority of design issues had been considered in the previous two studies, some aspects had been left undetermined. This included the exact data parameters for the data sources, as well as the visual arrangement of the displays. The following outcomes were achieved:

Time Limits: The time limit information source consisted of the game-clock and the shot-clock, represented by two separate displays on the chest. Participants were asked to specify the parameters and arrangement of the time limits. Both time limits were given equal weighting by the participants, so that the arrangement of the displays came down to personal preference. The majority voted in favour of the game-clock appearing on the right-side chest, and the shot-clock shown on the left-side. Participants unanimously decided that the game-clock display was shown one minute before a game quarter expires (four quarters to a game), advising players to make hasty final decisions. Similarly, the shot-clock was shown 10 seconds before the timer expires (shot taken every 24 or 30 seconds), effectively warning the team in possession of the ball. Additionally, the athletes believed that the two separate time limits would be *"difficult to distinguish during game-play"*, and might be *"confusing"*. The participants requested that the time limit displays be represented by contrasting colours, not only to help the athletes but other stakeholders too. Table 4.9 Summaries the final design decisions for the time limit displays.

TABLE 4.9. The final arrangement and parameters for the 'time limit' information source.

Data Source	Arrangement	Parameters
Game-Clock	Right-side chest	1 minute before game-quarter expiration
Shot-Clock	Left-side chest	10 seconds before timer expiration

Individual Points: The individual points data consisted of three displays positioned on both sides of the jersey to represent a player's increasing score throughout game-play. The participants were asked to determine the range and arrangement of the individual point data on the jersey. Participants expressed a desire to: *"understand who the top scorers are at a glance"*. It was agreed that the displays should be arranged intuitively from a lower score at the bottom, to a higher score at the top. Participants were provided with print-outs displaying the average point scores of individual players in both the American NBA/WNBA games and Australian NBL/WNBL games. Based on these values, which averaged from 5 to 45 points per player, as well as their own subjective notion of a 'low' and 'high' scorer, the participants decided the displays should represent gradations of 10 points. This put the top most display at 30 points, which athletes indicated was achievable for the top players in their socially-competitive basketball competitions. All participants agreed that the displays should be accumulative, with one spectator adding this would be *"easier to understand at a distance"*. For instance, even after a player has scored 20 points, the display representing 10 points would still remain active. Table 4.10 reveals final design of the individual point data.

TABLE 4.10. The final arrangement and parameters for the 'individual points' information source.

Data Source	Arrangement	Parameters
Individual Points	2 x Lower display	0 - 10 points (e.g. good player / low scorer)
	2 x Middle display	10 - 20 points (e.g. great player / medium scorer)
	2 x Upper display	20 - 30 points (e.g. excellent player/ top scorer)

4.3 Prototyping

Four TeamAwear jerseys were developed based on findings from the evaluative ethnography study, and in particular the participative design studies. Each prototype takes into account the requirements and needs of the end-user (i.e. team sports stakeholders), and moreover the intrinsic physical constraints associated with a team sports context. This section will describe the prototyping of the TeamAwear system, including: the various design considerations which were met, further participation and refinement by users, and the design of the final prototype.

4.3.1 DESIGN CONSIDERATIONS

A number of factors concerning the design of the TeamAwear system were considered early during the user-centred design stages, such as the identification of suitable development materials, and ethical and technical issues. These factors were based on findings and basic requirements from the evaluative ethnographic study (Section 4.1), which lay outside the expertise of the participants.

4.3.1.1 Design Constraints

Several design constraints for the TeamAwear system were recognized, ranging from safety concerns based on ethical considerations, to design requirements enforceable by the official rules of basketball (International Basketball Federation, 2006). These constraints ensured that the TeamAwear system was designed to preserve the normal physical activity of the players. Adverse influences which needed to be averted included simple long-term tiredness due to wearing additional weight, to subtle alterations in physical movements potentially affecting a player's overall sports performance. The prototypes have taken into account the following constraints as a result of the activities witnessed ethnographic observation, the identified user needs, and the technical feasibility of the selected electronic components.

Safety: Safety is of the utmost importance for any sports-related activity, and the most important reason why technology is not readily accepted in a sports context (Busch, 1998). Typical safety risks include physical contact with electricity-conducting elements, accidentally hitting or being caught in protruding parts, or even falling on top of the wearable devices. Inevitable technical failure must also be considered in the design, for instance by deliberately including 'weak spots' that allow quick and safe detachment, instead of uncontrollable breakage.

Wireless: The wearable displays fitted to each jersey require constant visual updates during game-play, and so must receive instructions from a remote source. It will not be feasible to have players fitted with cables or extended wires to perform these updates, therefore wireless connectivity is ultimately required to send and receive instructions during use. The required range of this wireless connection is greater than, or equal to 30 meters (the maximum length of a basketball court).

Washable: Due to the heavy perspiration during team sports game-play, sports wearables can become quite wet and unhygienic. In order for the TeamAwear jerseys to remain reusable, they need to allow for easy washing. In addition, all non-waterproof electronic parts are required to be removable and protected against moisture (also a safety concern).

Portable: Due to the electrical nature of the system, a portable power source (i.e. a battery) is required to effectively keep each jersey 'on' during use. The battery requires a usable lifetime of at least the length of a basketball game (48 minutes).

Unisex: Basketball is played by both male and female athletes. It follows that the TeamAwear system needs to be usable by both male and female athletes with little modification required. Therefore the jerseys were designed with both sexes in mind, and included no features which would advantage one sex over the other.

Layout: A typical basketball jersey includes several physical layout features which are required by the rules of the sport, such as: sleeveless, tucked-in, and graphical identification numbers on the front and back. Wearable components (i.e. displays) cannot obstruct these layout features, but instead should be placed around them.

4.3.1.2 Materials Review

An early investigation of materials identified several components suitable for a wearable display technology. This primarily focused on display materials, specifically those which were: visual-based, highly visible, light-weight, non-obtrusive, and shock-resistant. Additionally, this investigation included a review of the electronic components required to operate these displays, which are discussed in detail in Chapter 5: Technical Development. The following display materials were identified:

- **Electroluminescent** (EL) displays are wire or panel based, which are extremely flexible, bright, and come in a variety of colours
- **LEC** (light emitting capacitor) are flexible display panels, offering high quality light and brightness
- **LED-Flex** is a type of bright LED (Light Emitting Diode) technology which is contained within a flexible and durable tube
- **Flexible LED Array** displays consist of a series of bright LED modules mounted within a flexible backing
- **Scrolling LED** is a non-flexible, bright LED panel, but capable of easily displaying simple text and graphics

4.3.2 PRELIMINARY PROTOTYPE

An early working prototype of the TeamAwear system was developed to experiment with the capabilities of selected display and electronic materials, while working within the limits of the various design constraints. The underlying purpose of this early prototype was to assess several construction methods for the TeamAwear system prior to its final development, which were reviewed and refined by the users to ensure the reliability of the prototype design. Requirements from the participative design studies were applied to this prototype, while other design issues, such as the precise methods for integrating electrical components, were left open to experimentation. Table 4.11 describes the different integration methods tested on the preliminary design, with one half of the prototype using Option 1, and the other half using Option 2. Both options are shown below in Figure 4.7.

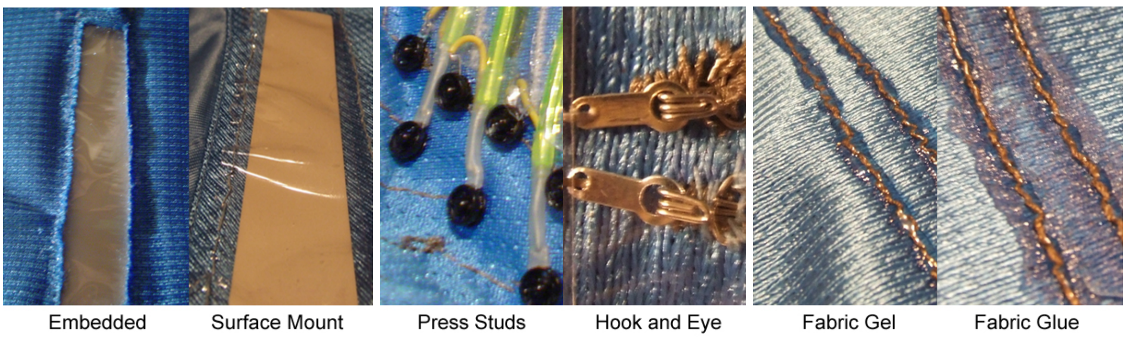

Figure 4.7. Different integration methods tested: display attachment (left); Connecting displays (middle); sealing electric connections (right)

TABLE 4.11. Different methods for integrating electrical components tested on the preliminary prototype.

Design Issue	Option 1 (Favoured Option)	Option 2
Basketball jersey	Generic V-neck, inner mesh-lining for added protection against electrical components	Generic V-neck, no inner mesh-lining
Attachment of Displays	*Embedded* beneath the fabric, required a section of the jersey fabric to be removed and sewn around the display location. Created a seamless transition between fabric and display	*Surface mounted*, left the jersey itself intact, but added additional thickness to the fabric
Connecting Displays	*Press Studs*, firm and stable connection, non-obtrusive and easily attached/removed	*Hook and eye clips*, provided firm connection, but protruded on outside of jersey
Protecting Electrical Connections	*Fabric Gel*, sealed the connections and dried non-sticky	*Fabric Glue*, efficiently sealed the connections but remained sticky even after drying.

4.3.2.1 User Refinement

Once completed, the preliminary jersey design was examined by the stakeholders from the participative design studies. They were asked to review the different integration methods used for the display and electronic components. They even wore the jersey to comment on its wearability (see Figure 4.8). The users provided several suggestions to refine the design, ultimately selecting the integration methods described in Option 1 from Table 4.11:

- Athletes **favoured** the **inner mesh-lining**, as it made the jerseys safer to wear
- It was pointed out by the referee that the **surface mounted** attachment of displays would **not be permitted** in basketball, as a player's finger or clothing may become caught
- From an aesthetical standpoint, all stakeholders **preferred** the **embedded** displays as opposed to the surface mounted kind
- The **hook and eye** connections were **ruled out** by the referee as being too obtrusive
- Athletes **chose** the **fabric gel coating** for electrical connections, which was more comfortable to touch and wear
- Spectators sensed the **displays** would **not** be **bright enough** to be visible from outside the playing field, and suggested a more powerful display regulator (i.e. inverter) be used
- Tall and short athletes **found** the wearable computer **harness restricting**, and requested that it should be completely adjustable (i.e. waist, shoulders, and chest)

Figure 4.8. The preliminary TeamAwear prototype (left); and being examined by users (middle, right).

4.3.3 FINAL PROTOTYPE

The final TeamAwear system prototype consists of two parts: (1) a wearable display jersey capable of visually conveying game-related data in real-time, and (2) a small wearable computer responsible for controlling and updating to the jersey. Both parts have been custom-made and refined to meet the needs of the stakeholders, and the demanding requirements of a competitive basketball match. Figure 4.9 reveals the final prototype in static state (left), wearable computer and harness (middle), and while active (right).

Figure 4.9. Final TeamAwear prototype (left); showing wearable computer connection and harness worn underneath the jersey (middle); final prototype during use (right).

Design constraints affecting the implementation of TeamAwear have been addressed in the final prototype design. The wearable display jersey is safe to wear, can be washed after use, contains no obtrusive parts, adheres to the rules of the game by displaying both front and back numbers, and is able tucked in with no difficulty. Similarly, the wearable computer is light-weight, wireless-enabled, battery-powered, and is easily attached to the body using a fully-adjustable unisex harness that is worn underneath the jersey.

Several design factors are also worth noting that ensure fairness is maintained when using the TeamAwear system prototypes. The final colour of the jersey itself is black, providing a high contrast between the displays and the jersey, increasing the visibility for all stakeholders on and off the field. Additionally, the exact same materials have been used for each of the four prototypes, to ensure that no player is advantaged or disadvantaged (i.e. identical: jersey size, colour displays, wearable components and harness).

4.3.3.1 Information Display

The final physical appearance of the TeamAwear prototypes, and the game-related information sources to be displayed, are based on decisions made by users during the participative design studies and the preliminary design refinement. These are further described below, and shown in Figure 4.10.

Time Limits: Consisting of the ‘game-clock’ on the upper left chest (shown when only 1 minute of game-play remains for a particular round), and the ‘shot-clock’ on the upper right chest (shown when only 10 seconds remain for an athlete to make a goal attempt). This information is considered important by the participants as it acts as an urgent warning signal to take action, a signal which is often neglected or inefficiently communicated verbally during game-play. For this reason, the displays appear on the upper chest for maximum visibility towards own team members. The two displays also have contrasting colours (i.e. purple and yellow), so they can be easily distinguished.

Individual Fouls: The fouls are shown using wire displays which operate symmetrically on the shoulders from the inside-out and smallest to largest, according to the accumulation of fouls by the respective player. The foul displays are placed on the shoulder area so the wearer themselves can more easily refer to and even peripherally detect their own number of fouls. As the maximum amount of fouls allowed in basketball is five, only four wires are shown. Each display remains active as more fouls are accumulated, so that players become more aware when ones foul count is higher.

Individual Points: Embedded symmetrically on each side of the jersey, are three panels representing the player’s individually scored points. These displays are illuminated sequentially upwards as more points are scored over the entire period of game-play, in gradations of 10 points. In this way, all participants can perceive who the game’s top scorers are. These displays are placed along the sides to maximize visibility, especially during passing/shooting scenarios at which an athlete’s arms are often raised.

Winning/Losing Team: A simple on/off display is embedded in the back of the jersey to indicate which team is winning ('on' for winning, 'off' for losing). This display is visible at quite far distances from the court, such as for spectators who might have missed parts of the match. It also acts as a useful reminder for the athletes themselves, as they can easily detect which team is winning when moving between goal areas, a time when often only the athletes' backs are visible.

Figure 4.10. The final information sources displayed on the TeamAwear jersey during use.

4.3.3.2 Setup

The setup procedure for the TeamAwear system prototype is by intention as simple as possible. Certain features have been included to allow the setup process to be performed by the player themselves, even with little to no technical expertise. The jersey has a common ribbon cable on the inside with a plug attached at the end. The wearable computer contains a similar port at the top, which the ribbon cable plug easily connects to. Additionally, a familiar 2-position safety switch at the side of the wearable computer allows a wearer to easily turn the prototype on or off.

In practice, a player is fitted with the TeamAwear prototype just prior to the commencement of a basketball match. The setup process takes on average less than one minute, and can be completely removed in the same amount of time. The setup of the TeamAwear system occurs within four relatively simple steps:

1. The **wearable computer** is fastened to the front of the harness using Velcro strips which are affixed to its base.
2. The **unisex harness** is attached to the player's body around the waist and the shoulders. The harness can then be adjusted to position the wearable computer between the players upper chest, down to their waist.
3. The **wearable display** jersey is put on in the same manner as a normal basketball jersey over the top of the harness and wearable computer.
4. The **ribbon cable** inside the jersey is plugged into the corresponding port at the top of the wearable computer to establish a connection between the two separate parts. The wearable computer is then switched on to complete the setup procedure.

Figure 4.11 illustrates the set up procedure for the TeamAwear system prototype. A more technically-oriented description of how each of these parts work is provided in Chapter 5: Technical Development.

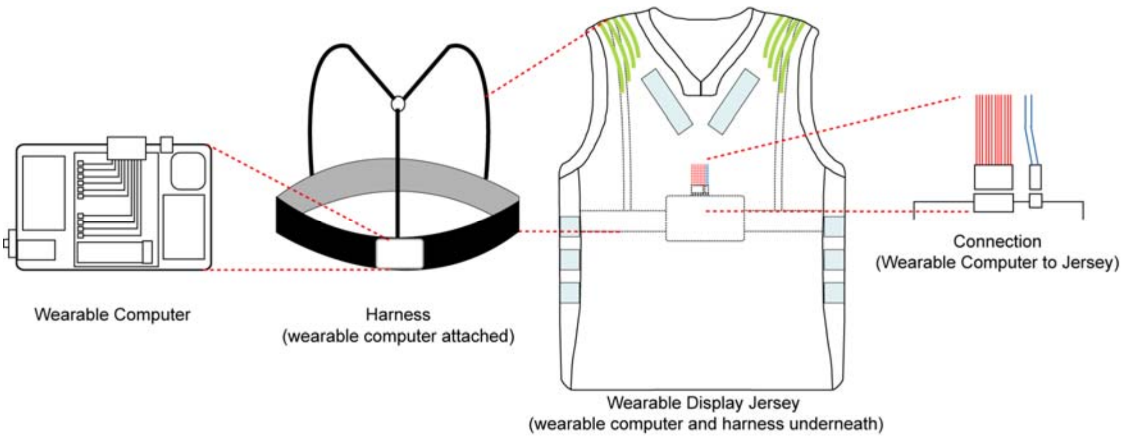

Figure 4.11. The setup procedure for the TeamAwear system prototype.

5 Technical Development

This chapter documents the technical development of the hardware and software used in the final TeamAwear system prototype. First, the hardware components involved in each of the four working prototypes are described, including the assembly process. The hardware consists of both pre-made and custom-made components, all which are assembled completely by hand. A description of the software applications used to program and control the operation of the hardware devices is provided. A summary of the technical operation of the TeamAwear system is provided at the conclusion of this chapter.

5.1 Hardware

The TeamAwear system hardware is separated into three separate parts, including: a wearable display, a wearable computer, and a harness (see Figure 5.1). The technical development of each part was treated collectively, so the design of one naturally influenced the others. In total, four identical TeamAwear prototypes were developed.

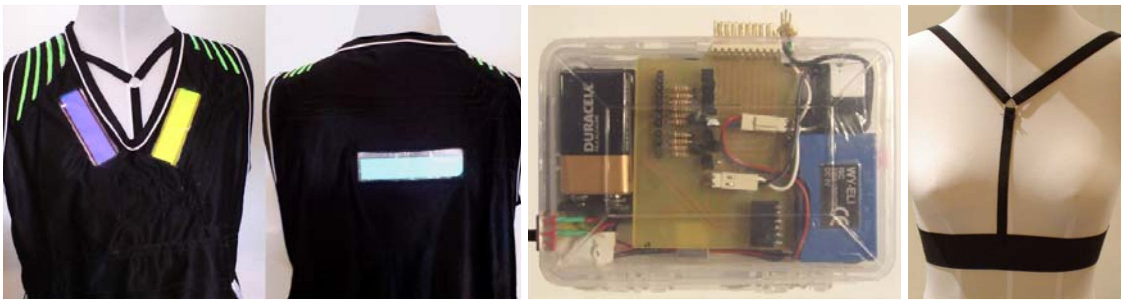

Figure 5.1. Wearable display jersey front and back (left); wearable computer (middle); harness (right).

5.1.1 WEARABLE DISPLAY

The primary hardware device is the wearable display, in the form of a basketball jersey. Brightly illuminating displays are integrated within the jersey fabric using conductive thread (see below), forming a seamless article of electronic sports clothing. Emphasis was placed on maintaining the overall shape and comfortable-fitting of the jersey, which is crucial for allowing athletes free-flowing movement during game-play. Accordingly, only flat, unobtrusive display and connection components have been integrated within the jersey. Each of the wearable displays consists of the following elements:

Basketball Jersey: A generic basketball jersey is the framework for the wearable display. Various sections of material are cut-out of the jersey for attaching the displays at the predetermined locations identified during the user studies. An additional fabric mesh lining is sewn inside the jersey to add an extra protective layer between the electronic components and the wearer's body. This extra layer also makes the jersey more comfortable to wear.

Panel Displays: Nine *electroluminescent* (EL) panel displays are integrated within the jersey on the front, back, and sides. The entire surface of each panel contains a sealed white phosphor-based substance that changes to a perceivable bright blue in response to a high-frequency electrical signal (see Figure 5.2, left). Additionally, two of the panels are coated with yellow and purple plastic-film, transforming the normally bright blue display to a bright green and violet respectively. The panels are entirely flexible, and can endure physical impact without breaking. Each panel measures 127x25mm.

Wire Displays: Eight electroluminescent wire displays are embedded within the shoulders of the basketball jersey. Each wire contains a phosphor-coated inner core sealed within dark-green tubing that glows a visibly brighter green in response to a high-frequency electrical signal (see Figure 5.2, right). The wires are flexible, and can be easily bent into any direction or shape. They are arranged in four lengths, measuring 120, 140, 160, and 180mm, with a diameter of 3.2mm.

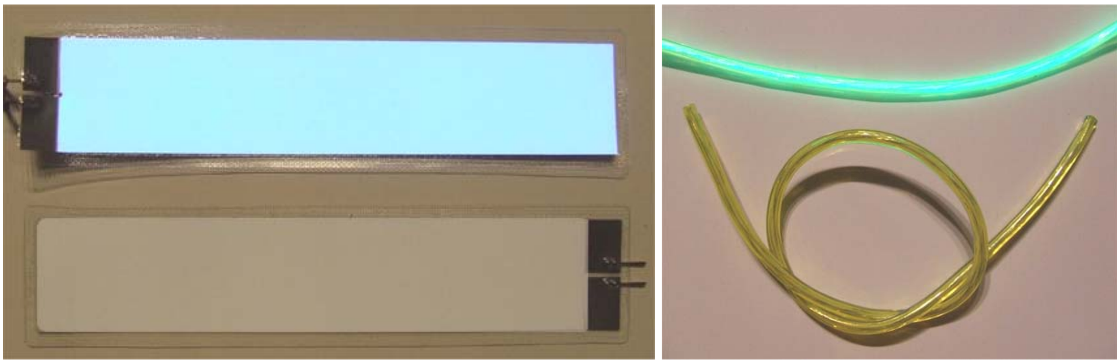

Figure 5.2. EL panel display in on and off states (left); EL wire display in on and off states (right).

Conductive Thread: An electrical circuit is sewn into the fabric with *conductive thread*, a type of silver-coated synthetic fiber able to pass an electrical signal with little resistance (<0.2 Ohms). By sewing a single negative-connection throughout the jersey, and one positive-connection per display, a complete circuit is created as the conductive thread acts as a power conduit to each of the displays (Figure 5.3, left). Each thread is sealed with water-resistant and non-flammable fabric gel to prevent direct contact with the body and short-circuiting. Figure 5.4 reveals the conductive thread circuit sewn into the jersey.

Press Studs: Conductive press studs allow the displays to be firmly attached and easily removed from the jersey (see Figure 5.3, middle). The studs consist of a bottom and top part. The bottom half is stitched into the ends of each conductive thread, while the top half is joined to the displays. The studs ‘snap’ together to provide a secure yet still flexible electrical connection between the displays and jersey.

Display Housing: All display materials (panel and wire) are contained within specially made transparent vinyl pockets. The pockets are stitched beneath the surface of the jersey with one side left unstitched, allowing the displays to be easily inserted or removed from the jersey (see Figure 5.3, middle and right).

Ribbon Cable: A short 12-wire ribbon cable is embedded beneath the surface at the front of the jersey, which allows electrical signals to flow from the wearable computer into the jersey. One end of this cable is attached to each of the individual conductive threads in the jersey, and the other end is fitted with a snap-socket that easily connects and detaches from the wearable computer. Of the total twelve wires, ten are reserved for positive electrical signals designated for the displays, while the remaining two are for the shared-negative (or ground) electrical signals.

Figure 5.3. Vinyl pockets for panel displays (left) and wire displays, also showing press studs (middle); conductive thread sewn into jersey fabric (right).

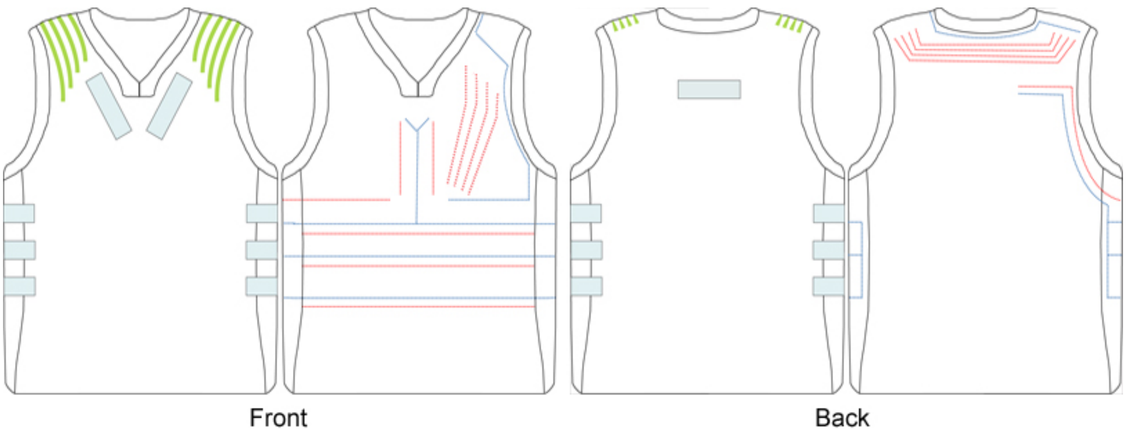

Figure 5.4. Complete wearable display layout (panels shown in blue, wires shown in green) and conductive thread circuit pattern sewn into jerseys (red shows positive connections, blue shows negative).

5.1.2 WEARABLE COMPUTER

The primary role of the wearable computer is to control the operation of the wearable display, but also to provide power to the system. During operation, the wearable computer maintains a continuous connection with each individual display via the application of several electronic components. Although technical operation is the primary focus of the wearable computer, consideration was also given to wearability aspects. The smallest possible components were utilised to ensure a comfortable, light-weight enclosure. Each wearable computer consists of the following components:

Microcontroller: A purpose-built microcontroller-board (Figure 5.5, left) converts input data into an appropriate electrical signal, which can then be used to control physical devices (i.e. displays). The microcontroller-board is based on *Arduino*, a community-driven physical computing platform that aims to reduce technical complexity for interaction designers (Arduino, 2006). The board includes a dedicated serial connection (RX/TX ports), and up to eleven digital output ports. A USB port is also fixed to the board for easily uploading programming instructions to the board using a computer.

Bluetooth: A 'Class 1' (range: 100 meters) Bluetooth module acts as a wireless receiver for the wearable computer. It was selected for its fast communication speed and far physical range, good reliability, and easy hardware availability. The small module (43 x 15 mm) is linked to the microcontroller via RX/TX ports (see Figure 5.5, middle and right), which allows data to be received (RX) and transmitted (TX) between the two. Input data sent wirelessly from a central computer is received by the module, and is instantaneously transmitted to the microcontroller.

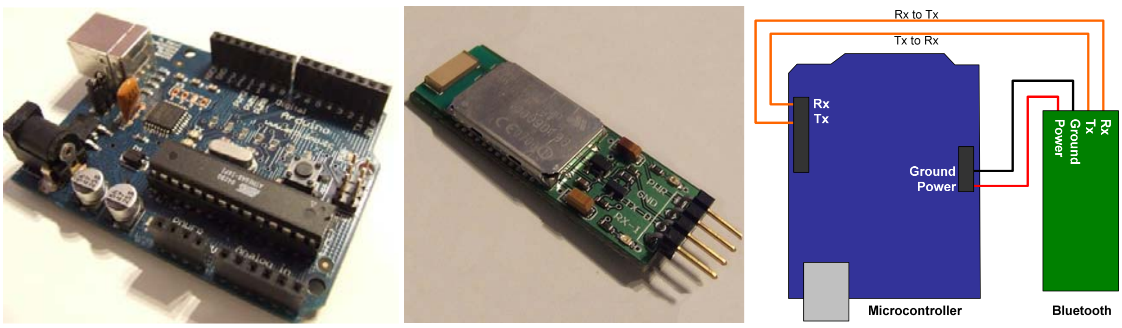

Figure 5.5. Arduino microcontroller (left); Bluetooth (middle); Arduino-Bluetooth connection (right).

Custom PCB: A custom-made Printed Circuit Board (PCB) is connected on-top of the Arduino microcontroller's digital output ports (total: 10), acting as a 'shield' (see Figure 5.6, right). For each digital output port, the PCB consists of a resistor (100 ohms) to reduce electrical current, and a triac that acts as a small electronic switch. The resistors and triacs control the flow of electrical signals to a snap-socket mounted at the front of the PCB. The snap-socket is similar to an electrical plug, providing an easy connection/detachment point between the wearable computer and the ribbon cable embedded within the wearable display jersey. A port for the Bluetooth module is also provided. Figure 5.6 reveals the PCB development, from 'breakout board' circuit (left) to custom PCB (middle, right).

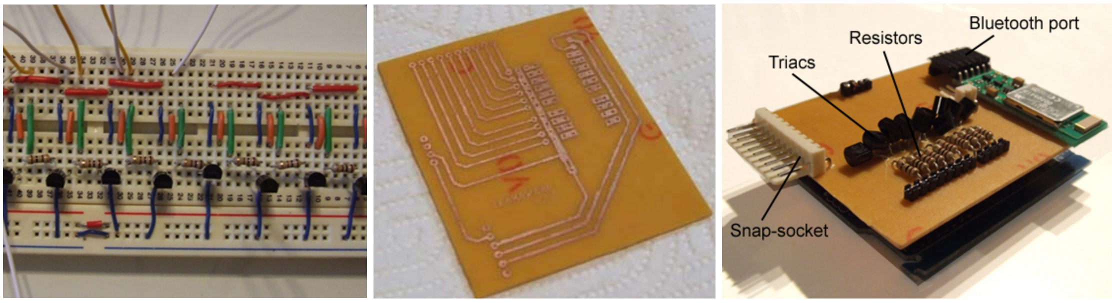

Figure 5.6. Circuit in 'breakout' form (left); breakout circuit as PCB (middle); final PCB (right).

Display Inverters: Two electroluminescent inverters produce a high frequency AC signal that is necessary to illuminate the displays. One larger inverter (frequency: 2000 Hz) drives the panel displays, while a smaller inverter (frequency: 600 Hz) is reserved for the wire displays.

Safety Switch: The electrical connections of all components (i.e. microcontroller, Bluetooth module, inverters) are hardwired to a standard 'on/off' safety switch (see Figure 5.7). This switch is included to disconnect all electrical power to the wearable computer and jersey in case of emergency, but can also further conserve power to the electrical devices when not in use.

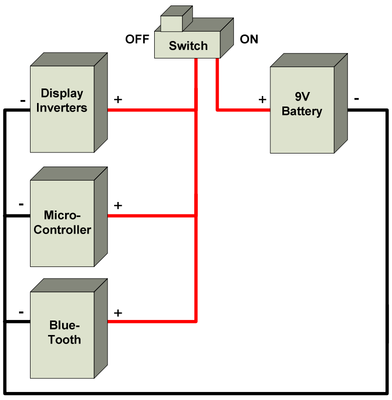

Figure 5.7. Safety switch circuit.

Power: A single 9 Volt battery powers all wearable components. 9 Volts is the power requirement for the display inverters, which is reduced to 5 Volts to power the microcontroller-board and Bluetooth module. The battery provides approximately over 1.5 hours of continuous power-supply, which could be extended by turning the wearable computer 'off' during designated break periods (e.g. half-time, time-outs, etc).

Containment Box: Each of the components is embedded within a non-breakable plastic box measuring 125x85x25mm (see Figure 5.8). The box is contoured for comfortable wearability, and is transparent, so that the state of the system (e.g. on, off, broken, disconnected, etc) can be easily observed from the outside. The total weight of the setup is approximately 200 grams, similar to an average mobile phone. This weight is dispersed evenly within the box to ensure a good balance during use. Velcro strips sewn to the base of the box allow it to be easily attached and removed from the harness.

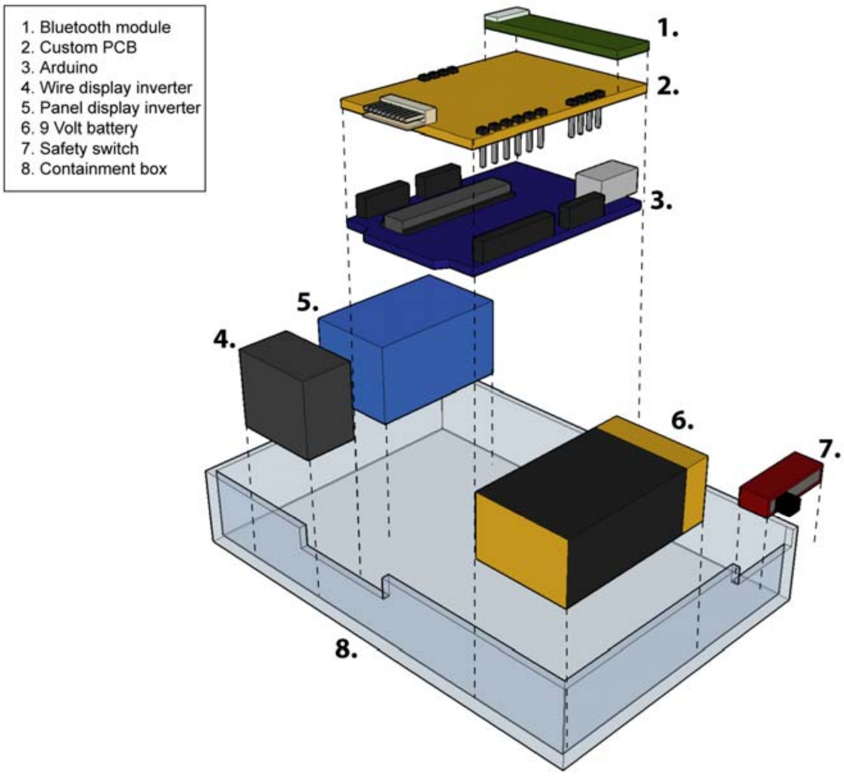

Figure 5.8. The wearable computer consists of seven distinct components embedded within a wearable box.

5.1.3 HARNESS

A unisex harness worn underneath the jersey 'carries' the wearable computer, to allow for a firm and comfortable attachment to the body. Integrating the wearable computer into the jersey itself was not practical, as the constant motion caused by the loose-fitting nature of the jersey could damage the hardware or injure the wearer. The harness assures that the wearable computer is continuously fixed, even during brisk movements, causing little harm to the wearer's body even after unintentional physical contact.

The harness is made from elastic ribbon (width: 50mm, thickness: 1mm) fitted around the wearer's chest or waist, which is secured using a common fabric-covered 'hook and eye' fastener. The elastic ribbon includes two attached straps (width: 10mm, thickness: 0.5mm) which are positioned over the wearers shoulders. The straps form a Y-shape front for female wearers, and can be worn in the reverse for male wearers. The harness is designed for comfortable wear and is completely adjustable, can be customized for any body size or preferred wearing position (males preferring the upper chest, and females preferring the waist). The harness is shown in Figure 5.9.

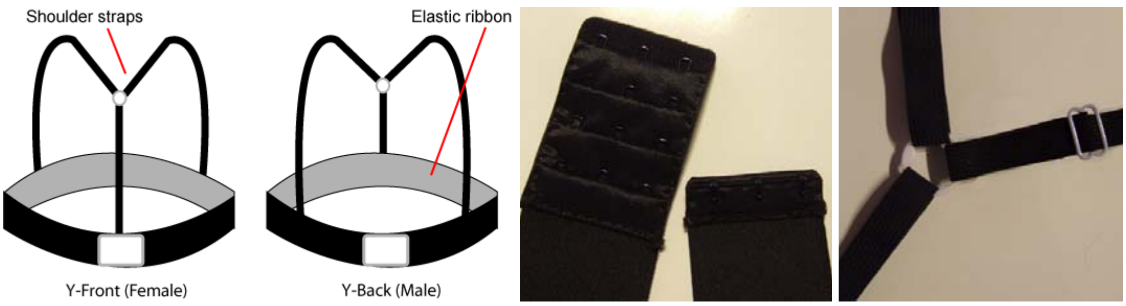

Figure 5.9. Diagram of harness with wearable computer attached (left); harness fastener to secure elastic ribbon around body (middle); adjustable shoulder straps (right).

5.2 Software

The software development stage aimed to create an application that could control the jerseys from a central computer. Two types of software were utilised: physical computing software to preload initial instructions onto the TeamAwear system, and control software to steer the jerseys remotely during game-play.

5.2.1 PHYSICAL COMPUTING SOFTWARE

The embedded Arduino microcontroller-board is programmed with instructions to control the wearable display jersey. The software used to program the Arduino microcontroller is based on the open-source development environment of the same name. Arduino software is based on the creation of 'sketches', very small programs (less than 8 Kb) written in the Arduino programming language, which is C/C++-based (Arduino, 2006). A programmed sketch is compiled and can be uploaded directly to the microcontroller from a computer, via a standard USB connection. A special hardware control program was developed for each microcontroller to achieve the following tasks:

1. Create a **serial connection** to receive input data transmitted from a central computer (facilitated by the Bluetooth module),
2. Perform **operations** on the input data to determine what action to perform,
3. **Output** the performed action in the form of an electrical signal

In practice, the custom sketch initiates a serial connection and appropriate data transmission speed using the inbuilt `beginSerial(9600)` function, where `9600` refers to the connection speed in Bytes Per Second (BPS). A check is repeatedly performed to determine whether any data has been received. The variable `val` refers to the received input data:

```
if ( serialAvailable() > 0){
   val = serialRead();
}
```

All input data is sent to the microcontroller as integers, according to a custom-design protocol. The integers mostly consist of three digits, with the first digit representing the target TeamAwear prototype (1 through 4: where 1 and 2 assigned Team A, 3 and 4 assigned Team B), and the last two digits representing the action to be performed. For instance, when the integer `140` is received by the microcontroller within the first TeamAwear prototype, the following statement would be executed where `digitalWrite` refers to the creation of an electrical signal, and `HIGH` refers to the output of that signal:

```
if ( val == 140 ){
  digitalWrite(foul1, HIGH);
  }
```

The statement above will turn on the displays representing ‘1 foul’ within the first TeamAwear prototype only. Table 5.1 shows the full protocol, including all possible integer combinations and the predetermined actions for each. During development some integers were found to conflict with the wearable computer’s Bluetooth module, so that the integers shown in Table 5.1 represent relatively ‘safe’ data values for wireless transmission. Appendix B provides a more detailed description of the microcontroller Arduino program code.

TABLE 5.1. Protocol for input data (integers) sent to the microcontrollers (in each TeamAwear prototype).

Information Source	Integer (preceded by: 1, 2, 3, or 4)	Action to perform
Time Limits	61 (no preceding)	Turn game-clock display on
	62 (no preceding)	Turn game-clock display off
	31	Turn shot-clock display on
	32	Turn shot-clock display off
Fouls	29	Turn all foul displays off
	40	Turn first foul display on
	41	Turn second foul display on
	42	Turn third foul display on
	45	Turn fourth foul display on
Individual Points	19	Turn all point displays off
	20	Turn first point display on
	21	Turn second point display on
	22	Turn third point display on
Winning versus Losing Team	17 (no preceding)	Turn winning displays on (All Jerseys)
	18 (no preceding)	Turn winning displays off (All Jerseys)
	11 (no preceding)	Turn winning display on (Team A) / off (Team B)
	12 (no preceding)	Turn winning display off (Team A) / on (Team B)
ALL	20 (no preceding)	Turn off ALL displays from ALL jerseys

5.2.2 CONTROL SOFTWARE

A custom software program, coined *TeamAwear Control Center*, remotely controls the operation of each prototype using a central computer (see Figure 5.10, top). The program is based on the Processing software development platform, a community-driven Java-based framework that allows for easy communication with the Arduino microcontroller (Fry and Reas, 2006). Processing is typically used to create so-called ‘sketches’, highly graphical programs with little required coding. The TeamAwear Control Center sends real-time instructions (i.e. input data from Table 5.1) to each of the jerseys via a Cadmus Micro Class 1 ‘cable-replacement’ Bluetooth USB adapter (see Figure 5.10, bottom-left) connected to the central computer (Cadmus Micro Inc., 2006). An intuitive Graphical User Interface (GUI) allows a user to click buttons corresponding to instructions which are to be sent. The role of the TeamAwear Control Center program can be summarised in five steps:

1. Initiate a **serial connection** with each the wearable computer,
2. Generate **intuitive GUI** for user interaction,
3. Record **the user interaction** provided via the GUI,
4. Check and **convert** the instructions into the appropriate input data (integer),
5. Finally **transmit** the input data wirelessly.

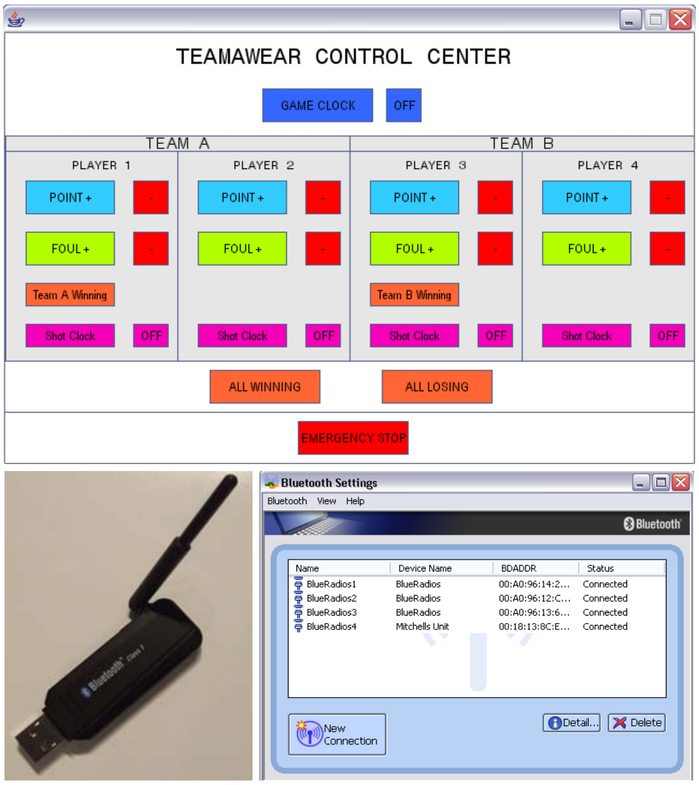

Figure 5.10. Prototypes controlled using the TeamAwear Control Center (top); Class 1 Bluetooth USB adapter (bottom-left); Bluetooth software establishes a connection with each prototype (bottom-right).

Toshiba Bluetooth software (Toshiba Corporation, 2006) is used to create a wireless serial connection from the central computer's Bluetooth USB adapter, to the Bluetooth modules contained by each prototype's wearable computer (see Figure 5.10, bottom-right). The TeamAwear Control Center software performs a search for all available serial ports using the function `String[] availablePorts = Serial.list()`. This function returns an array from [0 to n], where the first and second elements (i.e. [0] and [1]) refer to pre-assigned ports in the central computer. A serial connection is established with the each prototype using the function `Serial port = new Serial(this, availablePorts[portIndex], 9600)`, which is repeated until a serial connection with all prototypes is created. Appendix C provides a more detailed description of the TeamAwear Control Center code:

```
String[] availablePorts = Serial.list();
println(availablePorts);
ports = new ArrayList(portIndiciesToUse.length);
for (int i = 0; i < portIndiciesToUse.length; i++) {
   int portIndex = portIndiciesToUse[i];
   if (portIndex < availablePorts.length) {
      Serial port = new Serial(this, availablePorts[portIndex], 9600);
      ports.add(port);
   } else {
```

The intuitive GUI allows a user to selectively control each prototype separately. Each button represents a unique game-related information source (i.e. fouls, individual points, time, and winning/losing team). When a user clicks on a button, an integer value is immediately created. Where the buttons correspond to fluctuating information sources (i.e. fouls or individual points), a variable is incremented until a critical value is reached, and then an integer value will be created. The created integer value is assigned to the `currentData` variable, which is transmitted to each TeamAwear prototype as input data:

```
for (int i = 0; i < ports.size(); i++) {
   Serial port = (Serial)ports.get(i);
   port.write(currentData);
}
```

For instance, when a user selects to award a foul to the player wearing jersey number 1, this instruction is transmitted wirelessly from the central computer as input data. This input data is instantaneously received by all four wearable computers, however only the first jersey recognizes its ownership to use the data. As a result, the display representing the input data (in this case a foul) will be activated.

5.3 Technical Operation

The following process describes the technical operation between the TeamAwear hardware and the software. The diagram in Figure 5.11 illustrates the entire control process:

1. A user clicks a button within the TeamAwear Control Center interface, which **initialises** an **instruction** to activate a display attached to one of the jerseys.
2. The instruction is **sent** to the computers outgoing **serial port**, which has a Bluetooth USB adaptor attached.
3. The Bluetooth adaptor instantly **transmits** the instruction **wirelessly** as input data.
4. The Bluetooth module inside the wearable computer **receives** the input data, and immediately **passes** it into the Arduino microcontroller.
5. The microcontroller performs an **operation** on the data to determine which display to activate, then converts the data and **outputs** an appropriate electrical signal.
6. The output electrical signal **flows** into the **PCB** attached to the microcontroller.
7. The signal flows through a **resistor** within the PCB, where the **current is reduced** to a safer working value.
8. The low-current electrical signal flows into a **triac**, which **switches** ‘open’ and allows the signal to progress through to the PCB snap-socket.

9. The signal **flows** straight **into** one end of the **12-wire ribbon cable** connected to the PCB snap-socket, the other end is embedded within the wearable display jersey (only one of the ten reserved positive wires will be carrying the signal).
10. The signal then flows into the **jersey**, where it will flow through the appropriate **conductive thread** sewn into the fabric.
11. The signal then passes through the **positive** (+ve) terminal of the **display**, which is connected to the conductive thread.
12. The signal then flows back through the **negative** (-ve) terminal of the **display**, back into the conductive thread.
13. The signal passes **back** through the **12-wire ribbon cable**, this time through one of the two reserved negative (ground) wires.
14. The signal then flows into an **inverter**, where a complete circuit is then formed. The inverter **boosts** the electrical signal to high frequency AC.
15. Once the signal is boosted, the **display** will now **illuminate**. When the signal is later terminated from the control program, the display will be deactivated.

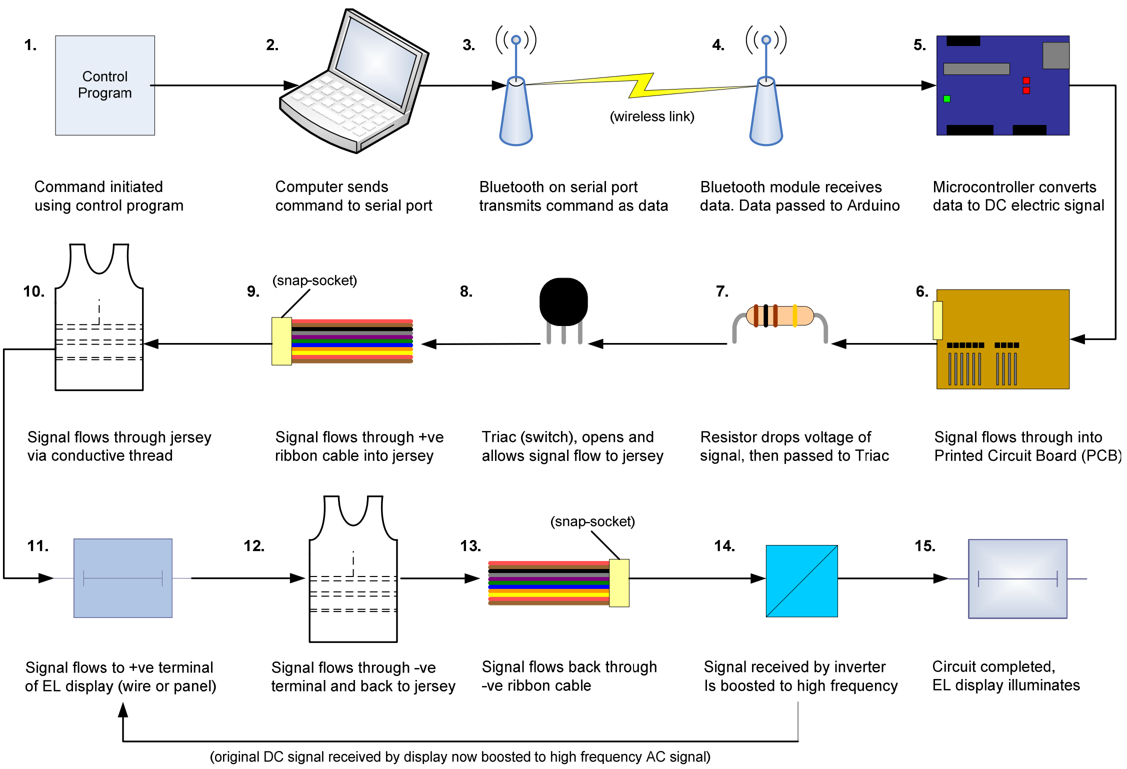

Figure 5.11. Diagram shows entire control process, revealing how the wearable displays are ultimately steered by the control software.

6 Evaluation and Results

A case study was carried out to evaluate the implementation of the TeamAwear system within a team sports context. This included an examination of the systems ability to increase the typical stakeholders' awareness of game-related information sources, as well as its ability to enhance their experience of game-play. This chapter explains the evaluation methodology, followed by the ensuing results and notable insights gained. Based on these results, a description of guidelines for the design of awareness increasing devices in team sports is provided.

6.1 Methodology

The case study evaluation took place in a normal basketball hall at the University of Sydney campus, within the context of a socially competitive match. Throughout the evaluation, game-play was limited to a half-court to ensure all stakeholders were in close viewable distance from one another. All participants were informed as to the meaning of each display on the jersey. The evaluation consisted of two stages: an *awareness investigation* involving pairs of game-like scenarios, with and without wearing the TeamAwear system; and a *game-play simulation* during which the TeamAwear system was worn by athletes during a socially competitive basketball game, followed by questionnaires and interviews.

One of the issues inherent with user-based evaluation is ethical approval, which is especially true for wearable computing devices. Prior to the evaluation, important ethical concerns were raised due to the inherent electrical properties of the device, which is positioned in close contact to the human body (e.g. heavy perspiration), and the unpredictable and active usage context (e.g. potential physical contact and falling, damaging the device and/or injuring body). The TeamAwear system was therefore personally inspected by ethical representatives before approval for evaluation was permitted.

6.1.1 PARTICIPANTS

The case study evaluation focused on all team sports stakeholders, including athletes, coaches, referees and spectators. The evaluation participants were recruited using flyers and handouts, which were distributed in sports halls and handed out after basketball games. This included, but was not restricted to those involved in the previous participative design studies (see Section 4.2). Since subjects were made aware of the system's purpose beforehand from the flyers' content, and additionally received no incentive for their participation, their attitude might therefore be seen as positively biased towards the use of technology in sports. Ten participants took part, including: four athletes (female: three; age range 19-25), one referee (age 38), one coach (age 23), and four spectators (age range 16 to 55). All athletes had semi-professional to amateur basketball experience, and spectators indicated beginner to amateur basketball knowledge. No participants reported any vision, hearing, or other disabilities that could potentially disadvantage them from using the system and efficiently participating in the evaluations. The athlete category in particular initially seemed very enthusiastic, some stating they considered it to be completely acceptable "*for people of their generation to … be fitted with small computers*". Before the evaluation began, all participants were briefly informed about the meaning of each display, while players were allowed to wear the jerseys for 5 to 10 minutes during training to become accustomed and learn its visual use.

6.1.2 PREPARATION AND SETUP

The length of game-play during the evaluation was significantly reduced to accommodate the participants' time-schedules, so that game-play scenarios and simulations would run for 10 to 15 minutes, rather than the standard 48 minutes required for most basketball games. Therefore, the parameters for the 'individual points' dataset were also reduced. Typically, the displays would correspond to an individual score of 10, 20, and 30 points respectively. This was changed to 2, 5, and 10 throughout the evaluation.

Although four jerseys were completed during development of the TeamAwear system, due to an unforeseen technical failure, only three were used during evaluation. The TeamAwear Control Center software (described in Section 5.2.2: Control Software) was modified to only support the three working jerseys, and all program code corresponding to the fourth jersey was removed. The jerseys were provided in the following formation:

- All three jerseys were used during the awareness investigation, three players with and one without (see Section 6.1.3 below)
- Two jerseys were used during the game-play simulation between teams of two players each, one team with the jerseys, one team without (see Section 6.1.4 below)

Throughout the evaluation, the researchers assumed the role of a game official, and were positioned just outside the playing area. The game official's role included monitoring a central laptop-computer, and therefore the responsibility of controlling each TeamAwear jersey wirelessly. The non-visible game-related information sources for controlling the displays (i.e. fouls, time limits) were initiated by a referee where necessary.

6.1.3 AWARENESS INVESTIGATION

An initial investigation was executed to test the TeamAwear system's ability to increase the stakeholders' awareness of game-related information sources. Players followed through four different game-play scenarios, firstly without, and then while wearing the TeamAwear jerseys. Each scenario simulated a change in one of the game-related information sources represented by the displays. Four scenarios were carried out in total, consisting of the following:

1. Assigning **fouls** to a random number of athletes.
2. Observing individual athlete **scores**.
3. Observing the **winning** and losing teams.
4. Assigning **time limits** to the athletes.

At the conclusion of each scenario, small paper-based surveys were handed out which queried each stakeholder about their in-game awareness in regard to the information source changed. In the cases which used the TeamAwear system, all displays would be completely switched off immediately after the play so users could not see or be influenced by them at the time of answering. A copy of the survey handouts can be found in Appendix D.

6.1.4 GAME-PLAY SIMULATION

A 15 minute social competitive basketball game was carried out and recorded on video, with two players in each team and one of the teams continuously wearing the jerseys (see Figure 6.1). The purpose of this game was to evaluate the TeamAwear system's overall impact on team sports game-play, and to determine any possible changes or influences which may refer to an enhanced experience (e.g. actions, decision making, understanding, enjoyment). The game constituted a two-on-two scenario, which the athletes were especially familiar with when limited to half-court game-play. The game was followed off-court by a referee, a coach and an audience made up of the spectator participants. The small teams naturally limited any overly 'strategic' influences, but were considered sufficient for the goals of this prototype case study, which focused on detecting the fundamental usefulness and usability of a visual and highly technological intervention in team sports game-play.

An *experience questionnaire* was issued directly after the game, querying the users in issues of wearability, visibility, and user experience. The questionnaire involved short-answer binary and long-answer open-end questions, allowing users to offer detailed explanations for their responses. A copy of the questionnaire is included in Appendix E. Because of the fast-paced nature of the game-play, it was understood that the stakeholders, in particular the athletes, may find it difficult to accurately remember their precise mental considerations for specific game-play related actions. Therefore, a video recording of the game-play simulation was shown on a television screen immediately following the experience questionnaire. During the video play-back, the stakeholders were *retrospectively interviewed* as a group. This approach aimed to allow the participants, specifically the athletes, to perceive their actions from a third-person viewpoint and 'recall' eventual in-game reasoning, and possible influences caused by the TeamAwear system, similar to a *post think-aloud* session.

Figure 6.1. Various scenes from both the awareness investigation scenarios and game-play simulations, revealing the TeamAwear jerseys in use by athletes

6.2 Results

The evaluation results represent the effects of the TeamAwear system's presence within typical basketball game situations. This section will first describe the awareness investigation survey results, followed by the key findings of the questionnaire and retrospective interview responses from the game-play simulation.

6.2.1 SURVEY RESULTS: AWARENESS INVESTIGATION

The results of the surveys showed a noticeable increase in awareness for the non-playing stakeholders, and a slight increase in awareness for the athletes:

- There was a **25% increase in awareness for athletes:** Of the four scenarios carried out, the athletes could correctly recall game-related data 75% of the time when using the jerseys, as opposed to only 60% without.
- There was a **70% increase in awareness for non-playing stakeholders:** For the non-playing stakeholders viewing the game off-court, the difference was more significant, with 85% correctly recalling game-related data when the jerseys were used as opposed to 50% without.

This result seems to strongly suggest a difference in use between the in-game experience and non-player experience of the display. Due to the fast-paced nature of a typical basketball game-play, with its need to focus on the ball, competitors and team mates, a player can only afford quick glances at the displays. However, non-playing stakeholders such as spectators are able to view the each displays as frequently as they feel necessary, without any time restrictions. Also, the error rate for recalling data was more pronounced (31% versus 40%) with the wire displays on the shoulders (i.e. fouls). This was likely due to the lower visual perceptibility of these displays, which were positioned quite closely together and appeared to ‘merge’ when viewed from a distance. No errors were recorded in regard to the winning versus losing team scenario (100% responded correctly), as players seem to have an already intrinsic strong interest in this information, while the non-players had no trouble observing the display which indicated this information (i.e. shown on the athletes back). Overall it seemed non-playing stakeholders tended to require less cognitive effort to observe the jerseys, becoming more aware of the information communicated on the displays.

6.2.2 EXPERIENCE QUESTIONNAIRE RESULTS: GAME-PLAY SIMULATION

The experience questionnaire responses indicated that the physical design of the TeamAwear system (i.e. wearability, visibility, operation) was extremely appropriate for the team sports environment. In terms of the user experience, the results indicated the TeamAwear system had a less than expected influence on athletes. However, the results revealed an unexpectedly high influence on non-playing stakeholders (i.e. spectators, coach, referee). The results of the questionnaire are separated based on the question category, either: wearability, visual display, or user experience.

Wearability: The issue of wearability was only applied to the athletes, who felt that the jersey and wearable computer were comfortable to wear and did not restrict their normal physical movements during game-play ("*I actually forgot I was wearing it*"). All of the athletes responded that that they *"liked"* the appearance of the jersey, and indicated that they: *"would wear such a jersey during an actual match"*. The flexible and user-adaptable harness assured that the athletes' movements were not restricted, with only one slightly larger male-athlete indicating it felt: *"a little tight but still comfortable"*. Importantly, none of the players seemed to have any safety concerns while wearing the jersey. However, some players were bothered by the heat emission from the wearable computer box, and noted that the jersey made them feel considerably hotter than usual (*"it was a little hot"*). It was noticed that condensation was forming underneath the plastic surfaces protecting the displays, which not only limits the natural dissipation of sweat, but ultimately might later become a security risk in terms of short-circuiting the electrical parts on a long-term basis. Although the increased heat could be a possible reason why athletes would not wear the jersey for longer periods of time (i.e. full game, 48 minutes), it did not seem to disturb the athletes in this evaluation: *"once the game was in progress I wasn't really thinking about it"*.

Visual Display: All participants reported that they could clearly perceive the displays during use, and were able to understand and remember what each display represented. Several responses referred to display arrangement as "*intuitive*" and "*easy to understand*". This revealed a high-rate of learnability for the TeamAwear jerseys, considering participants were only once briefly informed about the meaning of each display within 5 to 10 minutes prior to evaluation. All participants agreed that the displays were not overwhelming or distracting, even when multiple displays were activated, with one spectator writing: *"it wasn't distracting but informative"*. Importantly, on the playing field where the effect of the displays is most obvious, the players were not troubled: *"the jerseys and the information displays on them did not take away from the game"*. The visual displays were clearly visible even at a distance, with a spectator located outside the playing field commenting: *"it was easy to refer to the jerseys when you wanted to gain information"*. The athletes revealed that they were not able to perceive most of their own displays, other than the time limit panels on their chest. Instead, they often relied on the *"other players' jerseys*" for general game-related information. athletes sometimes deliberately stretched the shoulder part of the jersey in front of their face to double-check its actual state, an undesirable action that is possibly related to self-assurance and not trusting the technology: "*I wanted to be sure my fouls were represented correctly*". All participants agreed that the EL-panel displays were significantly easier to perceive than the glowing EL-wires (see Section 5.1.1 for further explanation), which were sometimes confusing as the difference between multiple active wires spaced closely together was not easily discernable.

User Experience: In terms of the overall game-play user experience, the questionnaire responses revealed that the athletes might benefit the least from the TeamAwear system, indicating their performance was influenced *“only slightly”* as a result. In relation to questions requesting whether they noticed a ‘change in their actions’, most athletes did not answer or unconfidently answered “not really”, presumably because they could not remember or because of difficulties in gauging their own actions. However, the response from non-playing stakeholders was significantly positive. Spectators claimed the game was “*more interesting to watch*” and “*easier to follow*” as a result of the wearable displays. In particular, inexperienced spectators with only a rudimentary knowledge of basketball indicated they were able to “*understand the play better*” and that this “*made the experience richer*”. When asked to comment on the overall experience involving the TeamAwear system, half of athletes and all non-playing stakeholders alleged that game-play was *“better”*. Additionally, all participants unanimously agreed that there exists a definite use for this technology in the future.

6.2.3 RETROSPECTIVE INTERVIEW RESULTS: GAME-PLAY SIMULATION

The results of the retrospective interview provided further explanation into three main aspects of the TeamAwear systems usage, including: when and why decisions were influenced during game-play, changes in athlete confidence, and the impact on non-playing stakeholders. Findings which were not entirely evident from the experience questionnaire results – because of difficulties in recalling game-play actions – were able to be highlighted in the retrospective interview.

Influencing Decisions: The feedback provided by athletes during the video replay was substantially greater in comparison to the questionnaire, though it still reflected only subtle changes in some aspects of their playing style. Most athletes described that during the majority of the game, the jerseys did not overly influence their in-game decisions. One athlete mentioned that when she saw her team mate had a high individual point score based on her display, “*it made me want to pass to her more”*. The athletes indicated that they mainly glanced to the jerseys during time periods when the pace of game-play naturally slowed or stopped, such as after a goal was scored or a foul was called, “*whenever the ball was reset, I would take the time to look at the displays before starting the play again*”. All of the athletes, even those who were not wearing the TeamAwear jersey, reported that the time limit display had the most influence: "*I played harder [more aggressively] when I saw the game had little time left*", and “*I noticed the game-clock, and*

I yelled this to my team mates". Some athletes indicated that even when they perceived some useful information, such as the foul amount of their competitors, such knowledge inherently would not change their game-play anyway. These results suggest that the intensity of the game itself supersedes any consideration of perceiving and interpreting the display: the players were not able to pay enough attention to the displays as they were too preoccupied with the game situation itself, and even when they perceived the displays during calmer moments, they did not consider (or forgot) this knowledge when making in-game decisions.

Confidence: An awareness of one's own and the team's performance during game-play emerged to boost a personal feeling of self-belief. When one player noticed their particularly high score indicated by the displays on the side, "*being reminded of my high score gave … a general feeling of confidence*". Also, athletes felt more confident in their own actions during game-play, as one athlete stated that "*I felt more comfortable passing to a team mate I could see had scored more points than myself*". This feeling relieved some pressure placed on athletes during game-play, with one athlete exclaiming that when she could see her team was winning "*it made me feel more relaxed*". Although the jerseys were originally intended to enhance the athlete experience indirectly through improved decisions and actions, it seemed they especially enhanced self-assurance and morale, as scores are represented on an individual level, rather than on an anonymous scoreboard.

Non-Player Experience: Spectators seemed to benefit the most based on their interview responses, indicating they were able to follow the game more closely. This was a surprising result, considering that TeamAwear had been designed primarily with the playing athletes in mind. Spectators who were inexperienced with the rules and plays of basketball seemed to benefit the most, with one declaring that "*I didn't have to think a great deal to know what was going on*". One novice spectator indicated that the jerseys "*did enhance the experience for me*" as she could see and understand when a player had received a foul. This opinion was also reflected by other novice spectators, one saying the jerseys "*gave me the basic information I otherwise wouldn't have known*". Overall this contributed to a more enjoyable experience for spectators who were able to better understand game-play, even finding it *"more interesting than normal"*. The coach indicated she had a better overview over the game flow, as *"you can keep track of your players and more easily make decisions of which players to keep on and which to take off"*, "*you can tell your players which opponents to 'double-up on' based on observing their fouls or points*". This knowledge can normally only be accessed by a dedicated person scouting the players, or by verbally requesting information from the official bench. The referee indicated "*it could really speed up the game from the referee's perspective, having to consult the bench less*", as much of the useful information is literally represented 'on' the player themselves. The referee also felt the fairness of decisions was not influenced by the jerseys, as the "*game pace is too fast to incorporate the displays in … decisions*."

6.3 Design Guidelines for Awareness Increasing Devices in Team Sports

Based on the experiences and outcomes encountered during the development and evaluation of the TeamAwear system, a number of design guidelines became increasingly apparent with regards to awareness increasing devices in team sports. Many of these guidelines are equally applicable to the design of devices for team sports in general, specifically those which are wearable or display-based. The following section describes these guidelines, which include: ethics, safety, wearability, perception, intuitiveness, and the process for design.

6.3.1 ETHICAL CONSIDERATIONS

This study revealed several general ethical considerations for an awareness increasing application in the team sports domain. First, there is the aspect of potential injury of the wearer: any additional object worn by a player might directly or indirectly inflict personal harm, or possibly cause a deficiency in sporting performance (see Section 6.3.2 below for safety considerations). Evidently one needs to consider whether the advantage of being more aware of information during game-play weights up against wearing a less comfortable jersey or an extra weight on the chest. For instance, the Human Ethics Committee had difficulty to assess the TeamAwear systems true risk, due to its perceived technological novelty and the high-risk 'competitive' sports application domain.

Second, one needs to consider the potential change in competitiveness when only a portion of the players allow their information to be exposed to the competing team. In terms of fairness, either all or no players should wear a potentially performance enhancing (or deteriorating) device. Wearing externally controlled information on one's body necessarily results in giving up the right for self-expression: the wearer has no direct control to what information is shown, in what context and during what time. More particularly for the display of information within the TeamAwear system, the top players, but also the least productive ones, become rapidly visible. Such an immediate visual disclosure to external critique might not be desirable, depending on the wearer's self-confidence level. This aspect might also explain why no athletes agreed on displaying individual physiological data, such as heartbeat, stress level, tiredness or energy usage. Athletes were quick to point out early in the design stage that any display of such personal data would be damaging to individual and team performance. It could easily result in players losing motivation, as well as opposing teams taking advantage of one's obvious weak points. Conversely, the issue to display athletes personal data was approved by spectators, who agreed this would contribute to a more intriguing and entertaining spectator experience. This raises the question of whether athletes should be forced to wear such revealing devices solely for the sake of the spectators. One should also note that some typical game-related aspects considered of high value in a basketball game are not explicitly shown on the jerseys, such as shot accuracy, defence actions, steals, rebounds, or assist passes. Consequently, by highlighting only a subset of information, the wrong emphasis might be created towards players, coaches and spectators, to what a good 'basketball performance' really is about.

Lastly, there is the issue of stakeholders inherently 'relying' on technology, especially in this application where there was no technology previously in place. For instance, what happens if the system breaks, causing players, coaches or referees to rely their actions on wrong information: should the match be halted, the end results altered, or should the jerseys only be treated as non-essential and non-trustworthy gadgets? A consensus needs to be reached among designers, stakeholders, and governing sports bodies as to how the application will be used, and whether new rules or training are required.

6.3.2 SAFETY

Extending the ethical considerations is the matter of ensuring the safety of users. Although there is already an element of risk in all sports, it is widely accepted that any new devices or technologies which increase this risk or could potentially harm participants will be banned from use (Busch, 1998). The design of the device should take into account the high level of physical contact in team sports, so that it is non-obtrusive (i.e. no sharp parts) and non-breakable (i.e. will not shatter, but instead hold together). If electronic in nature, the device can be inspected and tested prior to use. Essential features, such as the safety switch used in the TeamAwear system to disconnect power, should be included for all electrical components. It is necessary to ensure that the electrical output of the device is safe for human exposure, so in the event of device breakage, the user is not exposed to a potentially dangerous electric shock.

The issue of safety also affects the display of information. In the case of this study, athletes pointed out that an opposing player with a high foul count may be susceptible to increased defensive tactics, an already apparent feature in basketball. However, in the case of high-contact sports, the display of information which may encourage aggression towards a particular player should not be included.

6.3.3 WEARABILITY

The inherent characteristics of the sports domain highly restrict the range of technical design possibilities, which are primarily determined by strict wearability and usability requirements. This is true of all sports which involve physical contact, but is especially applicable to high-contact sports. Several guidelines for wearability already exist which are relevant to the design of wearable devices in sports, including the attachment of devices to accommodate various physical sizes (i.e. adjustable materials such as elastics), and the containment of these devices to avoid constraints (Gemperle et al., 1998). For instance, wearable devices for sports should focus on the miniaturization of all wearable elements to reduce restriction to athlete movements. Similarly, containment of electrical and digital components should be protective (i.e. insulated), so that physical contact with the whole device will not cause its components to fail. In physically demanding and fast-paced sports, wearable devices will easily be exposed to moisture as a result of perspiration. They must therefore allow washing to remain usable and hygienic for the wearer. If the device is attached to an article of clothing, suitable means for allowing the clothing to be washed should be provided (i.e. removable device and/or electrical components).

6.3.4 PERCEPTIBILITY

The evaluation made apparent that the type of display used plays a significant role. First, in a team sports context, visual displays are ideal as these become available to the maximum number of stakeholders. Athletes revealed that they often made decisions based only on their peripheral vision. For instance, players can immediately decide to pass a ball to others based only on seeing a glance of clothing colour, posture, body height or hair colour. Therefore, displays with a large surface area are favoured, as they are more distinguishable from any distance. There also needs to be a substantial contrast between the “visibility of states” that the display embodies. For instance, it was found that the EL-wire displays could be quite deceiving, as they glow bright green when turned on, but still appeared greenish when turned off. In contrast, the EL-panels could be discerned more easily due to their absolute colour change. It is important to keep displays subtle: flashing or fading displays can be confusing or show false information when in an ‘intermediate’ state. Spacing between displays is crucial, as it was found that displays placed close together were perceived as merged. To assure that no faulty information is provided, the state of the whole system should be visible at all times: for instance, is a display turned ‘off’ because of the information source, or because it is broken?

6.3.5 INTUITIVENESS

Unlike ambient and fashion displays, which are intended to be learnt over time, wearable visualization should be discernable in as little time as possible. Although all participants of this study were briefly informed about the meaning of each display, it was found they did not need to 'think' about what the displays were showing. For instance, the wire displays representing the fouls were intentionally placed on the shoulder to 'warn' players when they had many fouls, analogous to the aggressive raise of shoulder blades. Similarly, the displays representing athletes' individual points were arranged in an upward fashion, reminiscent of a music equalizer or data visualization bar chart. An intuitive layout design requires input from its end-users, so that familiar representations can arise for concepts such as 'big', 'small', 'good', 'bad', or 'warning'.

6.3.6 DESIGN PROCESS

This research has demonstrated the advantage of user participation, which has provided valuable insights that would be impossible to gather in a different way. The user contributions were particularly useful in determining the system's physical and ergonomic design, which performed effectively during the game-play evaluation. It was also helpful in identifying the most important game-related information sources to display, and the most suitable position for these on the jersey. Additional support can be provided by users throughout the prototyping stage, so that even the final physical design, including materials and construction methods, can be improved before a working prototype is produced. In this research, a 'preliminary' prototype was completed first, which the users could examine and even wear, identifying design and construction refinements which would have otherwise been overlooked. The largest problem with a user-based design process in this case, however, was recruiting enough suitable and committed people for a technological application that was virtually unknown.

7 Conclusions and Future Work

This research introduced the design and case study evaluation of a novel wearable display system, termed TeamAwear, which augments the awareness of game-related information sources during a basketball game. Several conclusions are able to be drawn from this research, which are given as summaries within this chapter. From these conclusions, suggestions for further implementation of the TeamAwear system (or a similar system) arise, which are addressed as future work and directions.

7.1 Summary of Contributions

The main contributions of this research focus on its design and development process, which was constrained by the complex demands of the high-risk sports application context, and its original usage of wearable computing as an output medium for meaningful and useful information in real-time. In addition, the results of the case study evaluation further contributed a number of insights for discussion.

7.1.1 BENEFITS OF USER-CENTRED DESIGN

Through practice, this research has demonstrated the importance of a user-centred design approach with regards to a novel wearable system for team sports. An initial evaluative ethnographic study provided valuable knowledge concerning the design context (i.e. basketball game), and its users (i.e. stakeholders: athlete, coach, referee, and spectator), which accordingly led to some early design decisions for the TeamAwear system. A series of progressive participative design studies involving experienced stakeholders further developed the design, from which a set of requirements and user-needs were identified that complied with the physical demands of a basketball game. Moreover, the physical and technical development heavily benefited from a user-centred approach, including: the selection of suitable materials, the formation of a design layout, and the refinement of a preliminary prototype. As a result, the technological design of the TeamAwear system proved to be highly successful among its user stakeholders, in terms of its wearability and visual display.

7.1.2 EVALUATING A WEARABLE DISPLAY FOR TEAM SPORTS

The TeamAwear system was found to increase team sports stakeholders' awareness of game-related information sources. Additionally, several unforeseen conceptual insights were discovered. Although this research initially claimed a wearable display system would increase awareness, it was expected this would enhance the stakeholders' game-play experience via positively influencing or changing their actions. Unexpectedly, the influence of the wearable displays on the athletes showed to be very limited, due to the fast-pace and highly demanding cognitive load of the game itself. As the information was shown onto the athletes themselves, the displays rather seemed to influence their self-confidence level. In contrast, the non-playing stakeholders (i.e. referees, coaches and spectators) seem to benefit the most from an increased game awareness, able to make decisions more effectively and efficiently, and to understand the actual game dynamics more profoundly. Therefore, a wearable display for team sports is revealed as an effective awareness-enhancing visualization for non-players, conceptually similar to the superimposed explanatory graphics during television broadcasts or game-related video games.

7.1.3 DESIGN GUIDELINES

A set of design guidelines for awareness increasing devices in team sports were generated, based on the evaluation results and outcomes of the user-centred design approach. The guidelines exemplify some of the issues which need to be considered prior to and during the design and development of an awareness increasing device, including: ethical issues, safety, and wearability. Furthermore, they suggest several procedures which can be followed to support implementation, such as user participation, and perceptible and intuitive display design. It is expected these design guidelines may encourage further exploration in this area, as future research can benefit from the practical knowledge provided.

7.2 Future Work and Directions

The results of this research demonstrate the current usefulness of a wearable display system within the context of team sports, and present opportunities for future work in this area. Throughout the design and evaluation stages, all participants indicated that they understood the system's value and even agreed to use it in the future when it would become more user-friendly. Therefore, future research could include fine-tuning the design of the jerseys, to reduce or avoid the high cognitive load on athletes during game-play, and to re-position displays which are not easily visible by the wearer (i.e. players could not see their own fouls). Additional directions include evaluating the system during approved matches with competition parameters (i.e. five against five, full time), and the display of more complex information sources that cannot be easily discerned or remembered by the stakeholders (e.g. shot accuracy and assists, or aggregated data such as defensive and offensive statistics).

The case study evaluation of this research is considered successful for further investigation in the area of wearable visualization in the sports domain. Even when a similar system would not be accepted by the relevant sports federations for official-competitive use, the system can still be used for training, collaborative or socially competitive purposes. For instance, the jerseys can be worn to reflect the player's performance during training, can visually indicate strategic 'plays' (e.g. which player has to move when and where), or communicate strategies from the coach to the players. Outside of the sports domain, a similar system could be used to convey strategic information or increase situational awareness for emergency services during crisis operations.

Finally, in terms of a professional sports application, one can imagine a wearable display system such as TeamAwear tied-in with team sports broadcasters, to display sponsor advertisements outside of game-play periods (i.e. before and after games, during half-time, etc). Since the sports domain is already heavily dominated by advertising and sponsorship deals, the dual-role of displaying game-related and advertisement information might support the use of wearable displays, both as a functionally and financially viable professional sports technology.

References

Acclaim Games Inc. (2006). http://www.acclaim.com/, accessed 13 October 2006.

Angrosino, M. V. (2004). *Projects in Ethnographic Research*, Waveland Press

Arduino (2006). What is Arduino? http://www.arduino.cc/, accessed 12 April 2006.

Ball, L. J. and Ormerod, T. C. (2000). Putting ethnography to work: the case for a cognitive ethnography of design, *International Journal of Human-Computer Studies,* **53** (1), pp. 147-168.

Barkhuus, L. (2005). Ubiquitous computing on the run: motivating fitness by computing technology. Workshop paper in UbiComp 2005 Workshop: W10 – Monitoring, Measuring, and Motivating Exercise: Ubiquitous Computing to Support Physical Fitness. Tokyo, Japan.

Bennett, J. (1998). *Statistics in sport*, Arnold New York

Bonanni, L. A. (2005). Design of intelligent interiors, Media Laboratory, Massachusetts Institute of Technology

Borovoy, R., McDonald, M., Martin, F. and Resnick, M. (1996). Things that blink: computationally augmented name tags, *IBM Syst. J.,* **35** (3-4), pp. 488-495.

Bryson, S. (1996). Virtual reality in scientific visualization, *Communications of the ACM,* **39** (5), pp. 62-71.

Busch, A. (1998). *Design for Sports: The Cult of Performance*, Princeton Architectural Press.

Cadmus Micro Inc. (2006). Class 1 USB bluetooth adapter, http://www.cadmusmicro.com/products.htm, accessed September 29 2006.

Card, S. K., Mackinlay, J. D. and Shneiderman, B. (1999). Using vision to think, *in* (eds), *Readings in information visualization: using vision to think*, Morgan Kaufmann Publishers Inc., pp. 579-581.

Chi, E. H. (2005). Introducing wearable force sensors in martial arts, *IEEE Pervasive Computing,* **4** (3), pp. 47- 53.

Chi, E. H., Borriello, G., Hunt, G. and Davies, N. (2005). Pervasive computing in sports technologies, *IEEE Pervasive Computing,* **4** (3), pp. 22-25.

Chi, E. H., Song, J. and Corbin, G. (2004). "Killer App" of wearable computing: wireless force sensing body protectors for martial arts. Proceedings of the 17th annual ACM symposium on User interface software and technology. Santa Fe, NM, USA, ACM Press.

Co, E. D. (2001). Luminescent raincoat, http://acg.media.mit.edu/people/elise/glow/, accessed 20 May 2006

Consolvo, S., Everitt, K., Smith, I. and Landay, J. A. (2006). Design requirements for technologies that encourage physical activity, *Proceedings of the SIGCHI conference on Human Factors in computing systems,* pp. 457-466.

Crabtree, A. (2003). *Designing Collaborative Systems: A Practical Guide to Ethnography*, Springer

Davydov, A. (2005). Do you speak English? FIBA Assist Magazine: 43-45.

Deltow, B., Hercher, W. and Konzag, G. (1984). *Basketball: A manual for coaches, instructors and players*, Sportverlag

ESPN (2006). NBA scoreboard, http://sports.espn.go.com/nba/scoreboard, accessed 17 July 2006.

Falk, J. and Bjork, S. (1999). The BubbleBadge: a wearable public display. CHI '99 extended abstracts on Human factors in computing systems. Pittsburgh, Pennsylvania, ACM Press.

Falk, J. and Bjork, S. (2001). Crossbreeding wearable and ubiquitous computing: design experiences from the BubbleBadge, The PLAY studio, The Interactive Institute, Göteborg, Sweden.

Fortin, F. (2000). *Sports: The Complete Visual Reference*, Firefly Books Ltd

Fry, B. and Reas, C. (2006). Proccessing.org, http://www.processing.org/, accessed 12 October

Gemperle, F., Kasabach, C., Stivoric, J., Bauer, M. and Martin, R. (1998). Design for wearability, *Second International Symposium on Wearable Computers*, pp. 116-122.

Gessler, N. (2001). Wearable computers and microcontrollers: a "participatory simulations" project of the UCLA center for computational social science., http://www.sscnet.ucla.edu/geog/gessler/topics/wearables.htm, accessed 24 September 2006.

Gill, D. L. (1986). Psychological dynamics of sport, Champaign, Illinois: Human Kinetics Publisher, Inc.

Gustafsson, A. and Gyllensward, M. (2005). The power-aware cord: energy awareness through ambient information display. CHI '05 extended abstracts on Human factors in computing systems. Portland, USA, ACM Press.

Hallberg, J., Svensson, S. and Synnes, K. (2004). Enhanced experience of sport events. The Sixth International Conference on Ubiquitous Computing. Nottingham England.

Harris, R. L. (1999). *Information Graphics: A Comprehensive Illustrated Reference*, Oxford University Press, Inc.

Hibbert, L. (1999). Decisions you can't argue with, *Professional Engineering,* **12** (13), pp. 26-27.

Horn, R. (1999). Information design: emergence of a new profession, *Information Design*, pp. 15-33.

Hughes, J., King, V., Rodden, T. and Andersen, H. (1994). Moving out from the control room: ethnography in system design. Proceedings of the 1994 ACM conference on Computer supported cooperative work. Chapel Hill, North Carolina, United States, ACM Press.

Hughes, J., King, V., Rodden, T. and Andersen, H. (1995). The role of ethnography in interactive systems design, *interactions,* **2** (2), pp. 56-65.

International Basketball Federation (2006). Official basketball rules 2006. FIBA Central Board.

Iossifova, M. and Kim, Y. (2004). HearWear: The fashion of environmental noise display. The Sixth International Conference on Ubiquitous Computing. Nottingham England.

Iso-Ketola, P., Karinsalo, T., Myry, M., Hahto, L., Karhu, H., Malmivaara, M. and Vanhala, J. (2005). A mobile device as user interface for wearable applications, *The 3rd International Conference on Pervasive Computing*, pp. 5-9.

Jafarinaimi, N., Forlizzi, J., Hurst, A. and Zimmerman, J. (2005). Breakaway: an ambient display designed to change human behavior. CHI '05 extended abstracts on Human factors in computing systems. Portland, USA, ACM Press.

Jin, L. and Banks, D. C. (1996). Visualizing a tennis match. Proceedings of the 1996 IEEE Symposium on Information Visualization (INFOVIS '96), IEEE Computer Society.

Jones, A. (2006). 2GB Radio: Alan Jones Breakfast Show, accessed 24 March 2006.

Jones, L. A., Nakamura, M. and Lockyer, B. (2004). Development of a tactile vest, *in 12th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pp. 82 - 89.

Kientz, J. A., Lederer, S. and Dey, A. K. (2002). Design and evaluation of ambient displays, *SUPERB Technical Reports*, University of California, Berkeley, CA.

Lee, K. (2003). Hotspot Bloom: a personal ambient display for Wi-Fi hotspots, Parsons School of Design

Liu, C. M. and Donath, J. S. (2006). Urbanhermes: social signalling with electronic fashion, *Proceedings of the SIGCHI conference on Human Factors in computing systems*, pp. 885-888.

Ljungstrand, P., Bjork, S. and Falk, J. (1999). The WearBoy: a platform for low-cost public wearable devices, *Third International Symposium on Wearable Computers*, pp. 195-196.

Loland, S. (2002). Technology in sport: Three ideal-typical views and their implications, *European Journal of Sport Science,* **2** (1), pp. 1 - 11.

Mankoff, J., Dey, A. K., Hsieh, G., Kientz, J., Lederer, S. and Ames, M. (2003). Heuristic evaluation of ambient displays, *Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 169-176.

Mann, S. (1997). Wearable computing: a first step toward personal imaging, *Computer,* **30** (2), pp. 25-32.

Mann, S. (1998). Wearable computing as means for personal empowerment, *in The First International Conference on Wearable Computing, ICWC-98*, Fairfax VA.

Matthews, T., Dey, A. K., Mankoff, J., Carter, S. and Rattenbury, T. (2004). A toolkit for managing user attention in peripheral displays. Proceedings of the 17th annual ACM symposium on User interface software and technology. Santa Fe, NM, USA, ACM Press.

Michahelles, F. and Schiele, B. (2005). Sensing and monitoring professional skiers, *IEEE Pervasive Computing,* **4** (3), pp. 40-46.

O'Mahony, M. and Braddock, S. E. (2002). *Sportstech: Revolutionary Fabrics, Fashion, and Design*, Thames & Hudson

Orad (2005). http://www.orad.tv/, accessed 2 October 2005.

Ossevoort, S. (2002). Wearable dreams, Interaction Design Institute, Ivrea.

Page, M. and Vande Moere, A. (2006). Towards classifying visualization in team sports, *3rd International Conference Computer Graphics, Imaging and Visualization*, pp. 24 - 30.

Petersen, C., Ackerly, P. and Rosemergy, H. (2005). Unlocking the potential of GPS athlete tracking technology: data for the specific metabolic conditioning of female national league hockey players, University of Otago, Human Performance Centre, New Zealand, Wellington Hockey Association

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S. and Carey, T. (1994). *Human-Computer Interaction: Concepts And Design*, Addison Wesley

Rhodes, B. J., Minar, N. and Weaver, J. (1999). Wearable computing meets ubiquitous computing: reaping the best ofboth worlds, *in The Third International Symposium on Wearable Computers*, San Francisco, USA, pp. 141-149.

Singer, R. N. (1975). *Myths and truths in sports psychology*, Harper & Row

Starkes, J. L. and Allard, F. (1993). *Cognitive Issues in Motor Expertise*, North Holland

Tan, H. Z. and Pentland, A. (1997). Tactual displays for wearable computing, *Personal and Ubiquitous Computing*, **1** (4), pp. 225-230.

TeamSportswear.com (2006). Sports uniform applications, http://www.teamsportswear.com/, accessed 2 October 2006.

Thomas, J. J. and Cook, K. A. (2005). *Illuminating the Path: The Research and Development Agenda for Visual Analytics*, IEEE Press

TNO (2006). Fit for Football, http://www.fit-for-football.org, accessed 6 June 2006.

Toshiba Corporation (2006). http://www.toshiba.com/tai-new/, accessed 25 October 2006.

Tufte, E. R. (2006). *Beautiful Evidence*, Graphics Press

United States Soccer Federation Inc (2005). Laws of the game, Fédération Internationale de Football Association

Vannieuwland, R. (2005). Tactile technology: the skin as untapped sense. TNO Magazine: 20-21.

Virtual Spectator (2006). Cricket super score, http://www.virtualspectator.com.au/, accessed 25 July 2006.

Vogel, D. and Balakrishnan, R. (2004). Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. Proceedings of the 17th annual ACM symposium on User interface software and technology. Santa Fe, NM, USA, ACM Press.

Vredenburg, K., Mao, J.-Y., Smith, P. W. and Carey, T. (2002). A survey of user-centered design practice. Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves. Minneapolis, Minnesota, USA, ACM Press.

Wall, S. and Brewster, S. (2005). Hands-on haptics: exploring non-visual visualization using the sense of touch, *Conference on Human Factors in Computing Systems*, pp. 2140-2141.

Weiser, M. (1993). Some computer science issues in ubiquitous computing, *Communications of the ACM*, **36** (7), pp. 75-84.

Wenner, L. A. (1989). *Media, Sports, and Society*, Sage Publications

Westfall, P. H. (1990). Graphical presentation of a basketball game, *American Statistician*, **44** (4), pp. 305-307.

White, M. (2005). Keeping track, http://www.fremantlefc.com.au, accessed 7 June 2006

Williams, A. M., Davids, K. and Williams, J. G. (1999). *Visual Perception and Action in Sport*, Spon Press

Wisbey, B. and Montgomery, P. (2005). Quantifying AFL player game demands using GPS tracking, FitSense Australia

XBoxExclusive.com (2006). XBOX reviews: NBA Jam, http://www.xboxexclusive.com/, accessed 18 September 2006.

Index of Terms and Acronyms

AC: a type of electric current of varying magnitude

AFL: acronym for Australian Football League, it is the national competition in Australian Rules football

Ambient Display: aesthetic displays of information which sit on the periphery of a user's attention

Array: in computer programming, a group of similar elements of the same data type

Basketball Australia: the governing and controlling body for the sport of basketball in Australia

BlueTooth: an industrial specification for wireless personal area networks, commonly used to exchange information between enabled devices

BPS: acronym for Bytes Per Second, refers to the transfer of data

Breakout Board: a reusable device used to build a prototype of an electrical circuit

Constructivist: theory by which a learner selects and transforms information from past and current knowledge into new constructs and decisions

Electroluminescent (EL): a phosphor-based substance that emits light in response to a high-frequency AC electrical signal.

Ethnography: a method of studying and learning about a person or groups of people

Evaluative Ethnography: a form of ethnography involving a shortened period of field work

Force Sensor: a device that measures pressure or force and converts this into an electrical signal

Game-Play: the time frame occurring between when a team sports game begins and ends

Game-Related Data: any information or dataset which directly results from or affects game-play

GPS: acronym for Global Positioning System, is a satellite navigation system used to determine location

GUI: acronym for Graphical User Interface, used for interacting with a computer

HCI: acronym for Human-Computer Interaction, the study of interaction between people and computers

Hz (Hertz): the International System of Units derived unit for representing frequency

Information Graphics: the use of images such as maps, charts and cartograms used to represent data

Inverter: an electrical device which converts Direct Current (DC) to Alternating Current (AC)

Java: an object-oriented program language

Kb (kilobyte): a unit of information or computer storage equal to 1024 bytes

LCD: acronym for Liquid Crystal Display, a type of flat panel display device

LEC: a high quality and brightness, phosphor-based light material available in the form of a flexible panel

LED: acronym for Light-Emitting Diode, a small semiconductor device that emits light when electrical current is applied

NBA: acronym for National Basketball Association, the USA's professional men's basketball league

NBL: acronym for National Basketball League, Australia's top-level professional basketball competition

NBA Jam: a sports video game in which users control the roles of a virtual basketball team

Proxemics: has to do with the study of peoples use of space

PC: acronym for Personal Computer

PCB: acronym for Printed Circuit Board, essentially an electronic board etched from a copper sheet

PDA: acronym for Personal Digital Assistant, is a handheld device which can include some of the functionality of a computer

Real-time: a general term to describe a system that responds to events or signals as fast as possible, or as they happen

Resistor: an electrical component which resists the flow of electrical current

RX/TX: radio abbreviations for ‘receive’ and ‘transmit’

Tactile: pertaining to the sense of touch

Triac: a bidirectional electronic switch which can conduct current in either direction

Ubiquitous Computing: computers available throughout the physical environment, and invisible to users

USB: acronym for Universal Serial Bus, a standard to interface devices with a computer

Visualization: the representation of data to allow discovery and increase understanding

Visualization (Information): the visual representation of abstract data to amplify cognition

Visualization (Scientific): the use of visual images to aid the understanding of complex scientific concepts

Watt: the International System of Units derived unit for representing power

Wearable computing: small body-worn computers which are always on, ready and accessible

Wearable Display: a body worn display used to publicly communicate information about a wearer

WNBA: acronym for Women’s National Basketball Association, the professional basketball league for women in the USA

WNBL: acronym for Women’s National Basketball League, the premier women's basketball league in Australia

Appendix A: Letter of Approval from Basketball Australia

BASKETBALL AUSTRALIA

6 March 2006

Mr Mitchell Page
Faculty of Architecture
University of Sydney

By email: mpag5967@mail.usyd.edu.au

Dear Mitchell

Thank you for providing details of the research project you wish to conduct as part of your studies toward your thesis on "A wearable display for team sports".

I do not believe that the wearing of the display technology you have described would be permitted in competitions under the rules of basketball. However, for research purposes it is permitted for athletes to wear such devices during a game that is convened by the researchers and is not part of an official competition.

Indeed, research projects are regularly carried out at the Australian Institute of Sport through our basketball programs, which involves athletes wearing various devices (such as heart rate monitors) that would not be permitted in competition.

Please contact me if you have any questions. I would be interested to receive details of your findings.

Yours sincerely

Michael Haynes
General Manager, Community Basketball
Direct line: 02 9469 7215
Mobile: 0414 835 414
Email: haynesm@basketball.net.au

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Appendix B: Physical Computing Software

The attached CD contains the custom programs which were loaded onto the Arduino microcontroller boards mentioned in Chapter 5: Technical Development. The programs have been packaged on the CD within the Arduino Software Development Kit (SDK). The following files refer to the custom programs for each of the four TeamAwear prototypes:

- TEAMAWEAR_JERSEY1.pde
- TEAMAWEAR_JERSEY2.pde
- TEAMAWEAR_JERSEY3.pde
- TEAMAWEAR_JERSEY4.pde

To access these files, run the Arduino application (arduino.exe) from folder titled ‘arduino-0003’. The files are located within the sub-folder titled ‘sketchbook’. Please note that the program-code was written using the Arduino software version 0003 ALPHA, available January 2006. Some coding structures may have changed since the release of this version.

Appendix C: TeamAwear Control Center Software

The attached CD contains the custom software program, termed TeamAwear Control Center, which was described in Chapter 5: Technical Development. This is the final version of the software used during evaluation, which operates only three of the jerseys (as opposed to the original four). The program has been packaged on the CD within the Processing Software Development Kit (SDK). The following file refers to the TeamAwear Control Center program:

- TeamAwear_Control_Center.pde

To access this file, run the Processing application (processing.exe) from the folder titled ‘processing-0115’. The files are located within the sub-folder titled ‘sketchbook’. The program uses the MyGUI library, which has been included within the Processing SDK on the CD. Please note that the program-code was written using Processing software version 0115 BETA, available May 2006. Some coding structures may have changed since this version.

Appendix D: Evaluation Survey Handouts

Scenario 1: *Not* Using TeamAwear Jerseys	**Scenario 1: Using TeamAwear Jerseys**
Your Name:______________________	**Your Name:______________________**
Question: How many fouls did each player have?	**Question: How many fouls did each player have?**
Player 1 _______ **Player 2** ______	**Player 1** _______ **Player 2** ______
Player 3 _______ **Player 4** ______	**Player 3** _______ **Player 4** ______

Scenario 2: *Not* Using TeamAwear Jerseys	**Scenario 2: Using TeamAwear Jerseys**
Your Name:______________________	**Your Name:______________________**
Question: Which Athlete had scored the most points?	**Question: Which Athlete had scored the most points?**
Player 1 _______ **Player 2** ______	**Player 1** _______ **Player 2** _______
Player 3 _______ **Player 4** ______	**Player 3** _______ **Player 4** _______

Scenario 3: *Not* Using TeamAwear Jerseys	Scenario 3: Using TeamAwear Jerseys
Your Name:______________________	**Your Name:________________________**
Question: Which team was winning?	**Question: Which team was winning?**
Team A (player 1 & 2) ____________	**Team A (player 1 & 2)** _____________
Team B (player 3 & 4) ____________	**Team B (player 3 & 4)** _____________

Scenario 4: *Not* Using TeamAwear Jerseys	Scenario 4: Using TeamAwear Jerseys
Your Name:______________________	**Your Name:________________________**
Question 1: Did you know when the shot-clock was about to expire? __________________________	**Question 1: Did you know when the shot-clock was about to expire?** __________________________
Question 2: Did you know when the quarter was about to end? __________________________	**Question 2: Did you know when the quarter was about to end?** __________________________

Appendix E: Evaluation Experience Questionnaire

A Wearable Display for Team Sports Research Study
Final Evaluation Questionnaire

You have just participated in a number of tests involving the **TeamAwear System**. Please answer the following questions as accurately as possible based on your OWN experiences during these tests. Not every question will need to be answered by you, so please carefully read each question to make sure it applies to you.

YOUR DETAILS

i. Name:____

ii. Age:____

iii. Sex:

- ☐ Male
- ☐ Female

iv. Basketball Experience:

- ☐ Beginner
- ☐ Amateur
- ☐ Semi-professional
- ☐ Professional

v. Contact Number or Email:____

vi. What role did you play during the tests?

- ☐ Athlete (wearer)
- ☐ Athlete (non-wearer)
- ☐ Referee
- ☐ Coach
- ☐ Spectator

SECTION 1: WEARABILITY QUESTIONS

1. **Athlete (Wearers) Only:** Did the TeamAwear Jersey fit *comfortably*? Please explain your answer

2. **Athlete (Wearers) Only:** Did any part of TeamAwear Jersey significantly *restrict* the way you moved or make you feel *constrained* in any way? If so, which part?

- ☐ Yes – the harness
- ☐ Yes – the wearable computer
- ☐ Yes – the jersey
- ☐ No

3. **Athlete (Wearers) Only:** Did you *like* or *dislike* the appearance of the TeamAwear Jersey while wearing it? Would you wear such a jersey during an actual match?

- ☐ Yes
- ☐ No

4. **All:** Did you have any *safety concerns* regarding the TeamAwear Jersey? Please explain your answer

5. **Athlete (Wearers) Only:** Can you think of any reasons (eg physical or mental) that may prevent you from wearing the device for *longer* periods of time? Please explain your answer

SECTION 2: VISUAL DISPLAY QUESTIONS

1a) Athlete (Wearers) Only: Were the top displays on your own TeamAwear Jersey, as well as the displays on the other athlete's TeamAwear Jerseys *visible* or *not visible* to you during game-play?

- ☐ Yes
- ☐ No

1b) All: Were the displays on the TeamAwear Jerseys *visible* or *not visible* to you during game-play?

- ☐ Yes
- ☐ No

2a) All: Did you *understand* what the displays on the TeamAwear Jerseys *meant* during game-play? In other words, did you know what information the displays on the TeamAwear Jerseys were showing?

- ☐ Yes
- ☐ No

3) All: Was the *way* information was shown on the TeamAwear Jerseys *easy* or *difficult* to understand? In other words, were the displays *intuitive* or *complex*?

- ☐ Easy to understand, intuitive
- ☐ Difficult to understand, complex

4. **All:** Thinking about when *multiple* displays were on (i.e. when the TeamAwear Jerseys were showing more than one type of information), were you able to *distinguish* between them?

- ☐ Yes
- ☐ No

5. **All:** Were you *overwhelmed* by the amount of information shown on the TeamAwear Jerseys during game-play (i.e. was there too much information to take in)?

- ☐ Yes
- ☐ No

6. **All:** Did you find the TeamAwear Jerseys *distracting*, and if so, *when* were they distracting? In other words, did the TeamAwear Jerseys significantly demand attention away from your responsibilities during game-play? Please explain your answer

7. **All:** Did the TeamAwear Jerseys display information that was *useful* or *meaningful* to you?

- ☐ Yes
- ☐ No

SECTION 3: EXPERIENCE QUESTIONS

1. **All:** Were you *more aware* of game-related information sources (i.e. fouls, points, score, time limits) during game-play as a result of the TeamAwear Jerseys?

- ☐ Yes
- ☐ No

2a. **Athletes Only:** Did the TeamAwear Jerseys *change* your game-play experience? In other words, did it *change/influence* the way you played the game or *change/influence* your actions during game-play in any way? If so, please explain *when* and *how*

2b. **Referee Only:** Did the TeamAwear Jerseys *change* your game-play experience? In other words, did it *change/influence* the way you judged the game or *change/influence* your actions during game-play in any way? If so, please explain *when* and *how*

2c. **Coach Only:** Did the TeamAwear Jerseys *change* your game-play experience? In other words, did it *change/influence* the way you would coached your team or *change/influence* your actions during game-play in any way? If so, please explain *when* and *how*

2d. **Spectators Only:** Did the TeamAwear Jerseys *change* your game-play experience? In other words, did it *change/influence* the way you watched the game or *change/influence* your actions during game-play in any way? If so, please explain *when* and *how*

3. **All:** If the TeamAwear Jersey did *change/influence* any of your actions during game-play, do you think this made your overall game-play experience *better* or *worse* (e.g. did you make more or less accurate decisions, did you enjoy the game more or less, etc)?

- ☐ Yes – the TeamAwear Jerseys made game-play better
- ☐ No – the TeamAwear Jerseys made game-play worse

4. **All:** Do you believe there is a use for this *kind* of technology in the future?

- ☐ Yes
- ☐ No