ABSTRACT
The ability to drive and increase human performance is greatly sought after. Reaching high levels of performance, in many areas has seen the use of technology to maximize efficiency of a variety of tasks. This paper will look at the more recent research in the field of Augmented Reality (AR) in relation to sport, focusing on how it is being used to improve human performance. It will investigate pioneering and notable recent technologies used in three main areas of sport (Training, Analysis and Officiating) and using a set of criteria, attempt to evaluate the use of AR in such fields.

Keywords
Augmented Reality, Human Performance, Sport

1. INTRODUCTION
As human beings we are constantly trying to push the boundaries of what can and has been done before. Reaching the “unreachable” is the goal of many and leads to a variety of new and exciting approaches to human development. The convergence between human performance and technology is extremely notable as of late with technology aiding development in many areas. Using new technologies as a driving force behind performance is something that is increasing in popularity, particularly with the use of a somewhat “buzz” technology. Augmented Reality (AR). One area in which there can be seen a large increase in the use of Augmented Reality technologies is sport. This area revolves around human performance and has seen great numbers of athletes, trainers and enthusiasts looking into technological solutions to aid improvement. This paper will address some of the more new and innovative uses of AR in this field and then evaluate its impacts.

2. What is human performance?
It is important to firstly explain what is meant by human performance. Whilst the term is a quite vague, in the interest of this paper it can be summed up roughly as: the standard to which a human can execute either a single or sequence of movements or tasks based on based on knowledge, rule or skill based behavior [12].

3. Background/Related Work
The term Augmented Reality surfaced in the early 90’s when looking at solving the issues of tele-robotic manipulation. Louis Rosenberg used the concept of a ruler to form the foundation of his explanation in that using a ruler to draw a line could be seen as overlaying a tangible information source on top of a workspace. Essentially, stating that AR uses abstract resources to supplement reality as opposed to substituting it. The first official research paper [12] submitted in terms of AR looked at its use and how it could enhance human performance. Results suggested that the experiment taken increased operator performance by 70%. This was due to the way in which AR altered the conceptualization of a problem and enabled users to tackle issues from different angles.

Related work in sport
By its very nature, sport is based at human performance, be it running, tennis, golf or any other sport we see athletes constantly trying to improve. In a non-technological sense it is common to see people interacting with equipment geared at improving performance eg figure 1.A. The large selection of such equipment highlights the extent to which we as humans are looking to enhance our performance. While AR in sport is relatively new, there are a variety of examples of using technology to further enhance human performance through interaction with specific equipment.

The use or AR in this sport can be seen in a number of areas, ranging from broadcasting and monitoring to training, development and umpiring. Various technologies such as visual overlays, haptic surfaces, motion sensor cameras and tangible interfaces contribute to the success of many sporting members and teams.
4. Current research and AR technologies

4.1 AR in sports training and development
Looking at human performance we can see that a high percentage of improvement comes when knowledge and skill are used based on specific circumstances [10]. Be these sporting circumstances or simple tasks such as hand and arm movements we see that through practice and understanding, human performance has the potential to increase [14, 10, 8].

4.1.1 Tangible Interfaces
The use of augmented reality in human training and development can be seen across a broad spectrum of sporting activities, being sport or non-sport specific. The use of tangible interfaces is one commonly used technology in the field of AR. The use of an interactive surface that can take and provide information in real time as a user interacts with it. One particular example of this is the PingPongPlus system (1999) [4] which acts as an “athletic tangible interface” to use and enjoy whilst playing ping-pong. The system is used as a regular ping-pong table that makes use of both video and audio collection and processing to allow the table and the user to interact. The set up comprises of a table with 4 microphones attached on the underside of each half, and a video projector above the table. When the ball strikes the table, the sound waves are processed by an algorithm, which measures the ball distance from each microphone, thus pinpointing the location of a ‘hit’. With the knowledge of where the ball has landed, there is scope to output a variety of visual overlays on the system (figure 2.A).

The ability to measure this data displays one of the main advantages of such interfaces in sports training; precision and accuracy. Through the use of the video projector a picture of the game can be constructed on the surface. Factoring in training methods and tendencies of sports displays how such a tangible interface could enable the user to practice accuracy (attempting to keep the ball within one “painted” section of the table.

Figure 2.A Photographs of the Ping Pong Plus system in use [4]

Using tangible interfaces in sport also allows the scope of making gameplay more fun as can be seen by the use of various games included within the PingPongPlus system, potentially making practice seem not so monotonous and extremely exciting. [9]

4.1.2 Augmented Haptic Technology
Along with tangible interfaces, a common and quite popular technology seen in AR is the use of haptic interfaces. In terms of augmented haptic interfaces these act as a tool to provide users with a real environment augmented with artificial haptic stimuli [6]. These stimuli enable users to be guided by haptic feedback in an effort to experience a particular outcome. [6]

A more recent system that employs this technology is presented by Huang [5] in an attempt to aid golfers in practicing putting. It is clear that one key element in sports training and practice is the development of good technique and form in specific movements [5]. The ability to have an interface that ensures the correct movements are carried out in practice can lead to great results in actual competition [7,10].

This system is designed to keep the head of a putter at the correct angle. By attaching the putter head to 4 motorized wires, the system uses planar haptic feedback in the horizontal plane to guide the putter head in the right direction. By tracking the Cartesian co-ordinates of the putter and the angle of the putter head, the wires are pulled tightened loosened by their respective motors to ensure that the putter is at the correct angle. The ability to disable the haptic feedback is also included so that users can check performance accuracy without being guided.

The use of such technology can be key in gaining stability and muscle memory in sport specific movements thereby improving performance of athletes greatly. There is the argument however, that athletes will tend to rely more on the haptic feedback and struggle to emulate the forces applied in reality[5, 7].

4.2 AR in Sports officiating & umpiring
Officiating plays a major part in almost every sport. Keeping order of the game/event and ensuring that equal opportunities to all are key to what makes sport so exciting to watch. Unfortunately we often see human error impacting sports greatly eg. (football referees awarding penalties or disallowing goals) and this can add a somewhat sour taste to an otherwise excellent game or event. Whilst many sports have turned to video replay to help officials, Fraser discusses how in many cases that this is not enough and that more advanced technologies need to be implemented [2].

In many sports, events happen at such speeds and angles that for an official to make an accurate decision, assistance is needed. Possibly the most common method of aiding officials is the use of vision based 3d rendering. In tennis, cricket and more recently snooker, Hawkeye has become the first port of call on any contentious or marginal decisions.

Hawkeye (2008) is a vision-based system that uses several cameras positioned around a field of play to create a 3D representation of the ball movement and create replays and attempt to predict future ball location for ball-based sports games [3]. By placing 6 cameras in specific locations of the court/field, it is possible to accurately find the position of the ball in each frame of each camera. By using cameras in pairs, the system can effectively triangulate the balls position relative to each camera, thus tracking its actual movement in real time and space. By using cameras that record actions at 60 frames per second, the
movement of the ball can be analyzed enough to effectively generate the spin and trajectory of the ball. Once this information is gathered, it is positioned in position on the pre-measured court[3] and can be seen as a replay. By supplementing reality with computer generated renditions, we can see information that the naked eye wouldn’t be able to see, clearly an issue that is key in officiating sport.

The ability to predict exactly where the ball has been/will go enables a variety of decisions to be made. For example, in tennis the system is used to check whether or not a player’s shot is out of play. By accurately rendering the flight of the ball, a detailed rendering can be displayed to show officials the correct decision. Such decisions, vital or not, all constitute to a fair game and uphold the integrity of many sports.

4.3 Sports Monitoring and analysis
In order to truly get better, it can be extremely beneficial to be able to watch our failures and struggles. This will lead to a better understanding of what went wrong and how to improve in the future [10]. In sport, the use of technology is improving on a large scale to enable sportsmen and women to monitor and analyze performances and techniques etc.

4.3.1 Autonomous Training through Video Cues
One particular method commonly used to monitor and analyze performance is autonomous training through the use of visual cues. This allows a user to see personal flaws or strengths in technique or ability, usually by comparing to other video or images.

Figure 3a displays SimulCam, a technology designed by the software company Dartfish. The designed system enables the superimposing of one athletic movement over another. This can act as a tool for real-time analysis of performance. The use of visual overlays and freeze frames are imposed upon the moving video enabling various statistical analyses to be made.

SimulCam uses specially modified cameras with depth and angular sensors to enable the chosen sporting movement to be shot from a different location or at a different time yet still play part in the exact comparison. By comparing the two video clips in terms of distance and angulation from the athlete, the system augments one video clip on top of the other, both appearing as semi transparent. The style, speed, and trajectory of two athletes can be compared, down to 1/30th of a second.

In the context of training, these types of tools can be extremely valuable in making visual discoveries with regards to an athlete’s technique or approach to an event. With common uses in racing sports such as skiing and athletics, athletes are commonly using such tools in preparation for big sporting events [13]

Another technology from Dartfish is their Stromotion technology. Looking at figure 3b we can see the use of freeze frame images in the use of Stromotion. The technology takes still images of a movie sequence and again overlays them on top of the real life clip. From a more sport specific technique this will enable athletes to look at posture, balance and stance at various motions in their specific sport to analyze errors.

4.3.2 AR in statistical analysis
Whilst training through visual cues can offer great opportunities in improving human performance, it only allows for athletes to make visual comparisons. The use of statistical data in sport is a commonly used method of making comparisons and suggestions about athletes. Many types of statistical details are taken in most sports and there are quite a few interfaces being born, which are combining augmented reality with statistical gathering.

EyePly (2010) is an augmented reality system for use in a range of sports including baseball, basketball, golf and American football. Yurwitz describes the technology as one that allows spectators and coaches to convey both information and objects that would otherwise be invisible [15].

The mobile based application takes an input of where the user is sitting in the crowd and from there contextualizes the entire stadium so that the view is as real life would be. Through an internet connection a 3D graphical rendering is displayed to the user with the ability to view a variety of data types. By pulling player specific data from the web, the system uses augmented reality to map data to the rendered players.

The idea is such that whilst watching a game or practice session, a user can use a mobile device to see the sport and select players and access live information. The system contextualizes the game for each user allowing them to view the sport in the same way yet access vast amounts of otherwise invisible data. Figure 4.a shows a prototype of the mobile app that is in development. We can see that from any given location in the stadium, users will be able to track players and select them to read information about a given players performance.
With different sports, the Eyeply system can offer different data and opportunities. When monitoring and analyzing a sportsman's performance, a coach can view this real-time data and offer suggestions or propose solutions to problems posed by the statistics. The use of this technology holds a wide scope as by overlaying information on a sport it offers infinite possibilities to users in many domains, either coaches or spectators. Some see it as a major breakthrough in the relationship between technology and improving sport.

5. Evaluation of Augmented Reality in the given fields.

The variety of different AR technologies in sport clearly shows the ways in which technology can lead to increase in human performance. In each of the 3 fields above, there are a range of technologies geared to aid athletes, however, the question can still be posed, how effective are these technologies as a solution in practicality.

In order to evaluate this, I have compiled a list of evaluation criteria that we can measure each branch of AR against.

5.1 Evaluation Criteria

- **Is the use of AR intrusive to the athlete/official?** – Does the technology used allow for the sport or activity to be carried out in a realistic environment in a realistic manner?

- **Is augmentation a suitable/realistic solution?** - Does the use of the technology aid improvements or does it confuse the action/sport. Is it suitable to use technology at all?

- **Can the technology be implemented widely** – Is the technology used scalable? Can a variety of improvements be made to the activity/sport through technology and at what cost?

5.2 Evaluation: AR in sport

**Is the use of AR intrusive to the athlete/official?**

In its attempts to overlay reality with abstract information sources, augmented reality can still affect the ways in which a sport can be done. Liebermann talks about the ways in which technology can hinder a sport in a physical and mental sense [8]. When training and developing athletes to increase human performance it is vital that the movements practiced are as similar to those that will be used in a real life, competitive situation. Immediately, this brings about issues with the use of augmented haptic technologies as seen in section 4.1.2. The use of four wires to guide the user could potentially lead to muscular imbalance when carrying out the action in isolation. It poses the question, is the athlete using the feedback to improve or merely using it as a crutch? When looking at the PingPongPlus system and many other recent AR systems it seems that due to the lack of development in technology, athletes are often subjected to unrealistic environments to carry out the sport. The hardware aspects of these technologies are not yet as developed to provide total realism.[14]

In terms of both monitoring and officiating sport the use of the technology is quite the opposite. With the majority of monitoring being completed through video footage and graphical overlays, athletes can carry out their sport in a perfectly natural manner. Because the human improvement comes as a result of these video observations, it ultimately allows the user to make improvements based on visual rather than physical feedback. Is this anywhere near as effective in practice though, can humans simply watch what they have done wrong and correct it without any form of haptic or physical feedback?

**Is augmentation a suitable/realistic solution?**

Whilst technology has been openly accepted into sport in most cases, it is not always the most ideal solution. Studies show that in its early stages, 17% of American football players felt that new “fourth and down technology” wasn’t reliable and didn’t really help the sport.[2] With athletes striving to improve it is increasingly important that technology is used only to improve our athletes rather than helping them in an un-useful way.[14, 9]

Looking at Huang’s augmented haptic interface [5], it is clear that the 5 tested golfers putted more accurately when using the system however, there was a noticeable drawback of the system in the slight resistance one feels when moving the putter in free space; These sort of resistances cause athletes to alter technique in potentially negative ways. Although it is not tested in the paper, one could predict that in putting without the resistance, some golfers may accidently over compensate for the resistance. It is in this way that training methods can sometimes hinder athletes. Due to the incredibly difficult task of replicating real life exactly we can often see technology constraining athletes to perform a movement in a limited way rather than allowing total freedom of movement.

Particularly in the fields of officiating and umpiring sport, there have been many disagreements in technology. It is interesting to note that this can often be sport specific. For example, in tennis, Hawkeye has been happily accepted on most parts and is generally seen as a useful tool. On the other hand, the exact same technology, when put to use in cricket is often criticized.[2] Due to a cricket match being played over a considerably long period of time, there is a much greater margin for the change in the playing surface and apparatus. There are cricket grounds that are renowned for being on slopes or for having a particularly bouncy surface. In order to generate a lot of its data, technology relies on standard sizes in terms of pitches etc to accurately position objects virtually[3]. Many cricket fans feel that there is a degree
of inaccuracy in the Hawkeye system when it is used over the period of a day for a match.[2]

The argument about whether or not technology can be used is clearly different in each situation. Being sport specific, it is difficult to pin point whether or not AR is generally a suitable and realistic solution.

Can the technology be implemented widely?

As sport is played in a variety of ways, at many different locations across the world, it is important that these technologies are widely usable. By factoring cost into this we can look at how widely these technologies could realistically be implemented.

For example, both the Stromotion and Simulcam technologies are financial ventures taken by a company and are offered as a service rather than a do it yourself technology. With its application in mainstream sports, this has been very effective however, it is clear that it would be incredibly expensive to analyze an athletes tennis swing every day for a year. These types of monitoring technologies are nevertheless incredibly versatile in helping to analyze a variety of sports. StroMotion permits summarizing an entire sport action into a single picture which could be used for almost any sport. Likewise, the Eyeply system aims at targeting a number of sports with the same technology.

Huang’s putting system on the other hand is a fixed device that takes up a small space (4 X 3.5 feet) in any room. With such training tools, a golf enthusiast could experience hours of putting practice every day [5] but never learn to drive the ball a great distance. Likewise, in the PingPongPlus system[4], the user is playing on a standard table and learning a range of movements however, the cost of the set up makes the technology unlikely to ever be widely used.

Hawkeye and other officiating technologies are and have been openly accepted by many sports and clearly serve multiple services in ball games. The use of Hawkeye in football as goal line technology is one that is often suggested. The adaptability of the system allows it to be used in almost every ball sport with scope to be used in other types of sports [11]. It is clear that in terms of wider usage of AR technologies in sport, there is a trade off between the cost and the scale of the applicability and it seems that the more flexible technologies are much more widely applicable.

6. Conclusions

The research gathered in this paper has led to a wide picture of the use of Augmented Reality in human performance. By assessing the recent developments in AR technology in sport it is evident that through technology, we can see the performance of humans in a sporting context improved. Augmented reality is incredibly useful in breaking down or simulating real time movements, which can then be monitored or analyzed. In evaluating the recent work in this field we can see that there are a few issues for improvement and a lot of opportunity for growth.

Through using training systems, athletes can use AR as a tool to practice certain specific movements or skills in in real life environment. Using tangible and haptic interfaces, we can tailor athletes training to isolate key skills in a real life situation.

Other uses include monitoring of sport where the use of AR can be key in making detailed physical comparisons. The ability to compare one performer directly to another can guide athletes and trainers in new directions to amend errors in technique and ultimately improve performance.

Our sports officials and umpires also make great use of AR technology to aid them in seeing the otherwise un-see-able. 3d rendering of real life events can provide accurate decision making tools, aiding the job of our officials in allowing athletes to compete as competitively as possible.

The variety of technologies that are on the market to train, monitor and officiate our sportsmen/women encompass a range of AR technologies, some more efficiently than others. By evaluating against set criteria we can see the ways in which the technologies fit into the various aspects of sports.

A number of hardware issues are highlighted in the terms of sports training and development with the hardware often struggling to remain unobtrusive. With the hardware being undeveloped or too expensive, there is a need for development.

The application of AR over a broad range of sports is evident through evaluations of the Hawkeye and Simulcam technologies however, we can see that it is often sport specific as to how accepted these are. On top of the application of such technologies, there is also a large trade off in terms of cost and usability.

Just as there is a certainty of sport in our future, I feel there is a certainty of Augmented Reality tied to it. With the level of advancement that can be achieved from some relatively simple technologies, there is clearly scope AR in sport in the future. The technology is still young and in a developing stage but the evidence suggests that it holds great future promise.

7. REFERENCES


