QUANTIFICATION OF ARM JOINT MOTION FOR MONITORING BADMINTON PERFORMANCE USING MEMS BASED WEARABLE SENSOR

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QUANTIFICATION OF ARM JOINT MOTION FOR MONITORING BADMINTON PERFORMANCE USING MEMS BASED WEARABLE SENSOR

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Faculty of Electrical and Electronic Engineering
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DEDICATION

“To almighty God....”

To my beloved parents,
Vadanayagam Stephen and Elizabeth Ghanam

For being the backbone of my life by supporting me from the very beginning

To my supervisor,
Dr Wan Nurshazwani Wan Zakaria

For their consistent encouragement, guidance and support throughout the research

To my siblings,
Adrian Sarron and Aaron Matthew

For their trust and motivation during my studies

To my friends

For their support and encouragement through all these years

Who understand and guided me through the journey of my study.

And for all who believe in me and keep whispering

“You can do it”
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Alvin Jacob A/L Vadanayagam Stephen
Batu Pahat, Johor
ABSTRACT

Recent advancement in wearable sensor technology has made a significant impact in the field of sports performance analysis, as it dramatically changes the conventional ways of training athletes. Sensor based systems help coaches to monitor, interpret and analyse athlete’s performance, where technology is used to train professionals. This study aims to develop a Wearable Sensor System (WSS) to monitor and quantify a badminton players arm motion, especially the wrist and elbow joint when performing serve and drive strokes. Current monitoring systems are unable to classify player’s competency level, due to insufficient technology to quantify joint variables and subsequent analysis on related badminton movement. However, previous studies suggest the vision-based systems, either using high-speed cameras or pre-recorded video analysis; but both systems are costly and are inconsistent in monitoring a badminton player due to environmental conditions (excessive lighting). Therefore, two monitoring modules are developed for the WSS. First, Hand Wrist Monitoring Module (HWMM) that uses flex sensors to measure player’s finger flexion and Inertia Measurement Units (IMU) to measure wrist rotation angle. Second, Elbow Monitoring Module (EMM) that used one IMU sensor to measure elbow joint rotation angle. Additionally, Real Time Operating System (RTOS) is implemented to manage simultaneous sensor data acquisition for synchronisation between monitoring modules. As a result, the WSS provides reliability and accuracy up to 95% for static joint motion measurements. Encouragingly, 6 out of 19 players were found to have improvements in their serve technique, whereas 12 players were able to perform a drive stroke with more than 80% similarities with the coach. Therefore, these findings emphasise the importance of a monitoring tool to help improve a badminton player’s performance, where it contributes by enhancing the coaching process by providing statistical and quantified movement data.
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<td>MEMS</td>
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CHAPTER 1

INTRODUCTION

1.1 Introduction

Badminton is a modern version of an ancient game which was played around 2000 years back in the ancient Greece, China, and India where it was called the battledore (bat or paddle) and shuttlecock (Boga, 2008). Back in the 1600s, the Battledore and Shuttlecock was an upper-class pastime in England and many European countries where these two games were played by two people simply hitting a shuttlecock backwards and forwards with a single bat as many times as they could without allowing it to hit the ground (Guillain, 2004). Later in the 1800s, the game was called ‘Poona’ or ‘Poonah’, which was played throughout India, this version of the match had a net in between and players hit the shuttlecock across the net (Guillain, 2004). Figure 1.1 illustrates how to play a game of ‘Poona’.

Figure 1.1: The Game of Poona (Guillain, 2004)
In the mid-1800s the British officers stationed in India took this game back to England. After being adopted and played, badminton became popular in England and the first badminton championship match held in 1898. Then in 1934, the International Badminton Federation was formed, with the first members including England, Wales, Ireland, Scotland, Denmark, Holland, Canada, New Zealand and France, with India joining as an affiliate in 1936 (Federation, 2006). In 1966, badminton was added to the Commonwealth Games and later in 1992 introduced to the Olympic Games.

Badminton is a fast and dynamic sport that can be classified as one of the fastest racket sports, with the fastest recorded badminton hit in a competition at 408 km/h achieved by Lee Chong Wei from Malaysia in 2015 (Guinness World Records, 2015). Movements performed by badminton players are a combination of different type of motions that consists of hard smashes, short drop and long clears where all these movements force the player to act and react in an extremely rapid manner. About 20% of the attacks performed during a game are smashes, and jump smashes (Tong & Hong, 2000). Badminton is played by anyone regardless of the age or experience; professional players spend hours training to improve their playing skills.

Proper playing technique is crucial, and it is the deciding factor between winning and losing a badminton game. Experienced badminton players have different stroke techniques and faster stroke rate compared to amateur players or beginners which are results of continues training. However, it can be a tedious and long process for beginners just to sit back and watch the professional players play to discover the exact difference in the motion performed. This is because of the difference in movement speed and strokes complexity demonstrated by the professional players. This data is important and can be used to determine player’s competence level. Coaches can improve their teaching and training methods if the competence level of the player is known beforehand.

Scientific research on tactics, strategy, or playing patterns of international level badminton players are, however very limited and restricted by confidentiality issues (Tong et al., 2000). On the contrary, researchers have been conducting research focusing on measuring the speed of the badminton smash stroke, which is pigeonholed as the winning shot. This statement is supported by the research carried out by Salim et al. (2010) to identify the difference of forehand overhead smash performed by male and female players. The researchers concluded that the upper arm
Rotation contributes the most to achieving a rapid smash and that male subject reaches higher racket velocity faster than female subjects do. Similarly, another research was performed to investigating the upper limb movement during a badminton smash conducted by Shan et al. (2015), where the author concluded that the wrist movement contributes the most when performing a badminton smash.

Since badminton, strokes are fast paced; it is certain that the human eye alone is not capable of interpreting the rapid movement of a badminton player. Generally, high dynamics movements are usually analysed using high-speed optometric systems such as high-speed video as demonstrated by Salim et al. (2010) in their research. They conducted arm motion analysis for smash stroke on male and female players, by using four Oqus high-speed cameras by Qualisys (Qualisys, 2004) to record the markers placed on the players. However, due to the technical limitations (e.g. high amount of light) that exist when using this method, these measurements are often performed in a laboratory setting. Hence, this does not comply well with the real competition or training conditions (Jaitner & Gawin, 2010). Furthermore, Optometric systems are expensive and require high-speed equipment’s to operate.

As a result, researchers began experimenting with the development of electromechanical based speed and orientation sensors to overcome previous limitations (Fong et al., 2004; Senanayake, 2004; Zatsiorsky, 1998). The miniature sensors allow data collection at high sample rates with wider measuring range when connected to a microcontroller. Furthermore, the light weight and small size of the sensors does not restrict the performance of the player (Jaitner & Gawin, 2007). Therefore, based on previous study comparisons, the best method suggested to successfully capture a badminton players motion data while still offering flexibility and keeping the cost low is by using wearable sensors.

This concept has been implemented and is being used in other sports type, for example in golf by King et al. (2008) where MEMS-based accelerometer has been used to measure the speed of a golf club swing. Wearable sensors are becoming popular in many fields to measure human movement and dynamics, where it can be used to monitor the body’s physiological response and the kinematic aspects of performance. Continues performance monitoring is the key for players to improve in the court, to monitor this in a natural way there is a need for integrated sensors that are straightforward to use and comfortable to wear (Coyle et al., 2009). The measurement and evaluation process is necessary to make players feel motivated to
perform better, and it helps coaches to analyse and improve the performance of their players (Henao & Fruett, 2009; Morrow et al., 2005).

1.2 Problem statement

The ability to acquire and develop skills is very crucial for badminton, where the difference between winning and losing is often determined by the level of skill and techniques utilised by the players. Although, badminton is one of the most played racket sports in Malaysia; however, with the lack of proper and inadequate training the younger generation seems to be having problems in acquiring professional-level skills. In an interview session with a Badminton coach, the coach expressed that there is no specific tool to measure the skill and competency level of the players except for visual classification by the coach or players themselves (Sazali, personal communication, July, 2015; Shan et al., 2015).

The coach stated that by knowing the competency level of each player, it would be easier to categorise them into groups of beginners, intermediate and advance level players. It is essential, as specialised training programs could be designed and provided to improve players skill sets (Shan et al., 2015; Sen et al. 2015). However, a scientific study carried out to perform this classification are very less as most study focuses on badminton stroke analysis of professional players. In fact, numerous studies have been conducted to measure and analyse the properties of a smash stroke, where the analysis focusses more on the shoulder and elbow joint (Jaitner et al., 2010; Kiang et al., 2009). Due to this, it is not practical to use the system to analyse the wrist joint. Moreover, some researchers have conducted studies to identify the type badminton stroke used by players; however, they all focus on the stroke analysis rather than on the execution.

One of the major problem for beginner level players is the incorrect way of gripping the badminton racket (Sazali, personal communication, July, 2015). Therefore, a method to classify the recommended grip method for each badminton stroke is required. However, to the best of author’s knowledge, no research has been carried out so far to perform this classification. As a result, the grip type identification is a novelty to the proposed monitoring system. Furthermore, current systems are mostly based on vision tracking systems, which requires the use of high-
speed camera and high processing power computers. However, they are costly, require longer set up time and is limited to laboratory conditions. Thus, it is necessary to conduct a research to overcome aforementioned problems.

1.3 Research Contribution

Most of the current research related to badminton performance measurement is focused mainly on the smash stroke and players playing pattern analysis. However, very little attention has been given to the methods required to classify 1) players according to competency level and 2) different badminton strokes. Therefore, this research provides insight on the method used to quantify player’s movement mainly for serve and drive badminton strokes. Moreover, this is the first attempt made to identify and classify the different grip types used by badminton player. Finally, the proposed Wearable Sensor System (WSS) focuses on establishing a comprehensive individual database of the player’s movement data. This research provides coaches with a monitoring tool for performance analysis to help and motivate players to perform better.

1.4 Aim

The primary aim of this research is to develop a Wearable Sensor System to assist in monitoring badminton player’s performance.

1.5 Objectives

The objectives of this study are:-

1) To assess the fundamental joint movements; 1) hand, 2) wrist and 3) elbow of a badminton player.
2) To develop a Wearable Sensor System (WSS) to quantify different grip types and badminton strokes based on identified joint movement.
3) To analyse and evaluate the performance of the developed WSS via a series of test and experimental program.
1.6 Research Hypothesis

The developed WSS could have a significant impact on quantifying a badminton player’s movement to increase their competency level.

1.7 Scope and limitation

The scope and limitation of this project are as follows:

1) The targeted area for this research is badminton singles.
2) This research focused on two badminton strokes, which is the service, and drive stroke.
3) The measurement is limited to three parameters, which are; finger flexion angle, wrist and elbow rotation angle.
4) The experimental study involved 19 badminton players age between 22 to 26 years old.
5) The developed WSS is validated using the following equipment’s, 1) goniometer, 2) Angle protractor and 3) Digital Multimeter.

1.8 Thesis Outline

This thesis is organised as follows:-

Chapter 1 gives an introduction to badminton sport and an overview of sports monitoring systems that are being used. Also, the research background, problem statement, objective and scopes are presented.

Chapter 2 discusses the related work that has been done in sports monitoring area and presents the current technology being used to measure sports performance. Moreover, examples of performance measurement and communication technology used are also discussed.
Chapter 3 elaborates in-depth about the kinematic analysis of the human arm related to badminton stroke and also investigates the major strokes used in badminton.

Chapter 4 discussed the development process of the WSS and the overall monitoring system. Furthermore, the development of the individual sensor modules is presented.

Chapter 5 elaborates on the experiments designed to test the developed WSS system, where the results obtained from the system is analysed by making a performance comparison between the players and coach.

Chapter 6 summarises the presented work and outlines the conclusions of the results. Moreover, the research contribution and future work related to this research are discussed.
CHAPTER 2

LITERATURE REVIEW

Recent advancements in wearable sensor technology have made a significant impact in the field of sports technology, where it has influenced the development of many specific sports training equipment’s used to enhance an athlete’s performance. Therefore, the conventional ways of training an athlete are dramatically changed with the help of technology. A review of the recent technologies currently used in sports has been performed to acquire information related to the research subject. Importantly, this information and methodologies are used as guidelines for selecting suitable and appropriate features for the proposed monitoring system development and the data acquisition. The monitoring system, with which athletes can be monitored and analysed; would help athletes in developing skill and performance in their respective area. Briefly, this research is trying to develop more badminton professionals with the aid of technology.

2.1 Sports Performance Measurement and Evaluation

Performance measurement in sports is a process of collecting and analysing information concerning the performance of an individual or a group. It involves studying and analysing processes to determine whether output received are in line with what was intended or should have been achieved. This research aims to quantify the movement data of a badminton coach using the developed monitoring system to help players to learn and improve their skills based on the data, where players and coaches can compare data to understand if they are in line. Analysing and evaluating the measured data, the difference between a normal player and a professional player
should be noticeable. One major difference between a normal and a professional player can be observed by the level of dedication and effort expressed by the players towards training. Evaluation is a process of making decisions based on statements of quality, merit or value about what is being assessed (Morrow, Jackson, & Disch, 2011). Once an athlete’s performance is evaluated based on how well a task is executed, training programs designed to enhance the ability of the athlete largely dependents upon satisfying the performance aims associated with it (MacKenzie, 1997). Though sport performance measurements are necessary, questions remain on why should it be performed or evaluated. According to Morrow et al. (2011), there are six general purposes for performing these measurements:

1) **Placement** - Grouping players according to their ability based on testing and evaluations done by a professional trainer speeds up the training process, as they have a similar starting point and can improve consistently.

2) **Diagnosis** - Test results provide plenty information about the physiology aspect of a player. Evaluating these results enables the coach to determine the weakness or deficiencies of a player to help them perform better.

3) **Prediction** - One of the main goals for measuring human performance is to be able to use present or past data to predict the future outcomes.

4) **Motivation** - Test results can be used as encouragement to achieve more; where players need the stimulation and feedback from their evaluation to be able to achievements and perform better.

5) **Achievement** - Improving human performance is important in a training program, where players strive to achieve a predetermined goal.

6) **Program Evaluation** - Measurement data taken using players from different competence level of the same training program can be compared with data from another training program to validate the effectiveness of the training program.
Training programs are designed to train athletes and they have predefined goals for the athletes to achieve, this motivates them individually to perform better. As mentioned beforehand, this research aims to develop a WSS that is capable of monitoring the moves of a badminton player. The collected data helps coaches to place players into groups with same skills level, which would speed up training time and help players to develop self-confidence. Coaches play an important role, as all the testing and measurements done; are just ways of collect information. Moreover, the data is used as the baseline for performance evaluation and decision making on the types of training to be provided. Hence, knowing the reason why performance measurements are done, next is to investigate how these measurements are performed and monitored.

2.2 Current Technology on Wearable Sports Measurement Methods

The motivations to measure an athlete’s performance may depend on the six reasons discussed beforehand, but a professional coach or a trainer determines the parameters where these performance measurements are conducted. According to Bartlett (2007), there are three essential parts in taking a measurement as shown in Figure 2.1. First, there should be a method or a device used for measuring the parameter needed. Second, a system that interprets all the data obtained. This system may in the form of a human being or a computer system that interprets the raw data obtained from the measuring devices to provide feedback. Third, a method to provide feedback that could be in the form of visual or practical training. Baca & Kornfeind (2006) quotes that “elite sports training programs use rapid feedback systems to acquire and present relevant performance data shortly after motion execution using embedded sensors and devices.” Thus, the present study investigates how basic human movement is recorded and what type of measurement method researchers use to measure athlete performance from various forms of sport.

Device Interpreter Feedback

Figure 2.1: Process flow for performance measure
2.2.1 Vision-Based Motion Capture Devices

In the 1970s and 1980s, the photogrammetric analysis was used as motion capture tool in research (Generation, 1995). Later around the 20th century, usage of video capture devices was introduced; where it could capture the continuous motion of an object (Fischer, 2013). For example, research conducted by Tong & Hong (2000) uses taped video of total ten recorded match from the 1996 Hong Kong Badminton Open Tournament to analysis the percentage distribution of different shot types utilised by players in a badminton game. Interestingly, the use of computers to analyse human motion is gaining popularity in the field of motion capture. Moreover, the most important part of motion capture is the task of registering the motion performed, a process known as human motion capture (Moeslund & Granum, 2001).

Motion capture covers many aspects, but it is primarily used in capturing large scale body movements, which include movements of the head, arms, torso, and legs (Moeslund et al., 2001). Vision-based Motion Capture is a large topic and has been popularly used through the world in many fields (Moeslund, Hilton, & Krüger, 2006). However, in the recent decade; it has been employed in the animation and movie industries especially to produce Computer-generated imagery (CGI). Motion Capture (MOCAP) is the process of recording the movements of a subject or an object, whereas it is often called performance capture when a living subject is involved (Noiumkar & Tirakoat, 2013). Many research has been conducted by integrating this technology into the development of better sports equipment’s, which proved to be beneficial to the sports industry (Mirabella et al., 2011; Nam, Kang, & Suh, 2014; Shingade & Ghotkar, 2014).

In sports, vision-based MOCAP technique is usually used to create animation model of a human performing certain movement, where the data obtained is reanimated into a 3D model for data analysis (Noiumkar et al., 2013). Table 2.1 shows two basic MOCAP techniques that are used in sports. Vision-based MOCAP system uses data captured from image sensors of two or more camera to triangulate the 3D position of a subject, where reflective markers provide tracking algorithm with points to build a skeleton model of the subject (Moeslund et al., 2001). Advancements in marker technology have enabled MOCAP systems to generate accurate data by tracking surface features (Moeslund et al., 2006).
Table 2.1: Types of MOCAP technique

<table>
<thead>
<tr>
<th>Passive Markers</th>
<th>Active Markers</th>
</tr>
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<tbody>
<tr>
<td>The subject wears a suit fitted with retro-reflective coated markers as shown in Figure 2.2. Cameras emit light, which is reflected by these markers to detect the position of the marker. The intensity of the light produces is controlled so that only the reflective markers are sampled, eliminating skin and fabric (Generation, 1995).</td>
<td>The subject wears a suit fitted with LED-illuminated markers; these markers are tracked using high-speed cameras for the position of the wearer as in Figure 2.3. The illuminated marker results in lower marker jitter and an increase in high measurement resolution that allows the system to track the marker position precisely. Some systems have multi coloured LED markers to distinguish different parts on the human body.</td>
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Figure 2.2: An actor is wearing a suit with passive reflective markers

Figure 2.3: A student wearing a suit with active markers illuminated with red LED in Virtual Reality Lab of University of Texas (Johnson, 2011)

The two different MOCAP method shown in Table 2.1 are popularly being used in many research to record and map human motion into 3D models, where the model can then be analysed to extract further information like movement angles, speed and body physiology. For example, Montazerian et al. (2008) used passive
markers to capture the 3D animation of a full ball delivery action by the Imperial College cricket team bowlers. The goal was to obtain the 3D kinematics of the bowler's elbow angle during the ball swing. Therefore, Euler angles for the arm rotation was calculated in the sequence of $z\times y'$ where $z$ is flexion-extension, $x$ is abduction-adduction and $y$ is the internal-external rotational. Figure 2.4 shows the graphically rendered bowler's upper torso skeleton model, where the motion is represented by obtaining the position of markers.

![Figure 2.4: Elbow-shoulder alignment of a spin bowl (Montazerian et al., 2008)](image)

Noiumkar & Tirakoat (2013) conducted a research using the same passive marker MOCAP method to record the motion of hitting a golf ball. The researchers integrated optical MOCAP technology to capture the swing stroke motion to represent and remodel it into a 3D model. Therefore, Noiumka et al. (2013) used three different MOCAP marker set configurations, which is optimised 24-point, animation 28-point, and normal 42-point. The 3D character model animation is rendered from the data obtained from the three marker sets, where the results indicate the optimised 24-point and animation 28-points were equally good and is suitable to be used to model the golf player. Whereas, the 42-point rendering required more time and resources and showed delays for real-time applications. The transaction from the motion data skeleton model to the fully rendered 3D character modelling of the player is shown in Figure 2.5. The researcher concluded that the usage of optical MOCAP is suitable to capture the movements in sports given that the suitable marker optimisation method is used to track the movement of players.
In another research, Nam et al. (2014) utilised the same concept by using optical MOCAP to track a golf club swing motion. Although the MOCAP method is the same as the previous research, the marker technology used is different. For instance, Nam et al. (2014) used active markers where an infrared LED illuminates each marker. Eight infrared LED’s are mounted on a “T” shaped panel, which is attached to the lower part of the golf club as shown in Figure 2.6.

Additionally, the marker set is tracked using two stereo cameras fixed to an adjustable height rig. However, the usage of active marker system is to provide the initial position and heading information only, whereas the speed and position of the gold club is measured using a XSENS Inertia Measurement Units (IMU).
researcher aims to use the sensor fusion data to illustrate the feasibility of the motion tracking setup. The developed hardware was tested for a full golf swing where the maximum club speed recorded during the experiment was 6.5m/s upon ball contact.

Besides golf, researchers have also conducted experiments to implement the usage of vision-based MOCAP to capture the motion of a badminton player. Salim et al. (2010) used four Oqus cameras (high-speed camera) from Qualisys to record and analyse the motion of players when performing badminton strokes. Experiments were conducted involving student from UniMAP (Perlis) whom have basic badminton knowledge and were between 22 to 28 years old. Figure 2.7 shows the placement of markers on the player's arm and racket, eight markers were placed along the arm. In this experiment, the researcher aims to investigate the difference between forehand overhead smash performed by male and female in a mixed double game. After a series of testing, Salim et al. (2010) concluded that a male player achieves higher racket velocity than a female player. The male players were able to reach racket velocity of 10.52 m/s, while female players reached racket velocity of 9 m/s. This is mainly due to the physiological difference between male and female.

![Figure 2.7: The placement of markers on test subject (Salim et al., 2010)](image)

Further research was conducted by Yang (2013) to investigate and analyse the parameters related to forehand smash motion, where analysis for torso rotation magnitude measurement is focused. In this research, video analysis was used to obtain the coordinates of the human arm joint for a forehand smash stroke, from where the torso rotational angle is calculated. Experiments were conducted using ten
badminton players, where their torso rotational and hand velocity data were collected and analysed. Yang (2013) stated that of all other techniques, the forehand smash uses the most power and is an important badminton stroke that is being used to win points.

In another research done by Jiang & Wang (2013), in-depth analysis of the smashing motion was further performed by identifying two different type of smashes in badminton; which is the ground and in-air shuttle smash. Figure 2.8 and Figure 2.9 illustrates the smash motion captures for ground and in-air shuttle respectively. The researcher used six QUALISYS-MCU500 high-speed infrared cameras to capture the accurate 3D movement made by players when performing the smash. Hence, using data from the MOCAP software, the velocity of the arm is calculated to determine the arm joints stress level. Jiang & Wang (2013) stated that by obtaining this information, the spiking action of players jumping to hit the shuttlecock is regulated.

![Smash motion for ground shuttle](image1)

Figure 2.8: Smash motion for ground shuttle (Jiang et al., 2013)

![Smash motion for in-air shuttle](image2)

Figure 2.9: Smash motion for in-air shuttle (Jiang et al., 2013)
Analysis of the serve stroke has also been carried out by researchers collectively, as it is one of the most important and basic stroke in the game of Badminton (Ahmed et al., 2011; Loong Teng & Paramesran, 2011; Nagasawa et al., 2012; Tsai et al., 2000). On the other hand, Ahmed et al. (2011) performed analysis on the arm movements for forehand long and short serve using Canon Legria HF S10 high-speed cameras. For this, six male badminton player from Aligarh Muslim University was required to perform forehand long and short service strokes a few times repetitively. The recorded video footage was segmented and analysed using the “Silicon Coach Pro 7” motion analysis software to extract biomechanical variables. Ahmed et al. (2011) indicated that the elbow joint influenced the shuttlecock velocity for the service stroke significantly.

The advantages of using vision-based MOCAP technology is noticeable in the increasing number of studies using this technology. Current MOCAP devices that are used by researchers are Kinect (Microsoft, 2010), Vicon Motion Camera (Vicon, 2004), Markerless Organic Motion (Organic Motion, 2006) and Qualisys Motion Camera (Qualisys, 2004). These MOCAP technologies are widely being used to reanimate the motions of a subject into 3D models because the post processing of marker based MOCAP is smoother than videography. Although many research have been conducted on analysing the movement and motion of a badminton player using vision-based MOCAP technology, all of them have one disadvantage in common which is an environmental limitation. The measurements are often performed in a laboratory or studio setting, which does not comply well with the real competition or training conditions (Yuan & Chen, 2014). Although, advancements in camera technology might overcome this limitation, but then the operating cost of such system would be higher. Furthermore, specific hardware and software are required to process the data that also leads to higher operating cost.

2.2.2 Textile-Based Devices

Wearable technology refers to portable computers or electronic devices that are incorporated into clothing or accessories which are comfortable to be worn on the human body (Pantelopoulos & Bourbakis, 2010). Textile-based sensory devices are referred to as embedded electronics that are integrated into wearables sports clothing such as a wristband, knee guard, and elbow cap. This textile-based wearable technology has seen significant advancement over the years where sensors can
provide sensory and scanning details such as biofeedback and tracking of physiological functions (Salazar et al., 2010). Wearable sensors are mostly used to monitor the human body’s physiological response to exercise and also to measure the kinematic aspect of performance in some cases (Morris et al., 2009). Textile-based sensors are used to monitor the movements of an athlete naturally with integrated sensors attached to the parts of the body that need to be analysed.

Monitoring human motion using accelerometers attached to clothing has been the fundamental design in many research that has been carried out to measure sports movements (Bekdash et al., 2015; Fitzgerald et al., 2007; Pantelopoulos et al., 2010; Salazar et al., 2010). Farringdon et al. (1999) demonstrates two methods to measure human motion using textile-based sensors; first is by developing a sensor badge system using two ADXL05 accelerometers stitched to a chest band to detect the motion of the wearer. The developed sensor badge was successfully able to detect only five different motion of the wearer mainly sitting, standing, lying, walking and running. As a result, the researcher referred the first three movements as a simple exercise, where fewer data samples were needed to differentiate the motion being performed. However, the walking and running motion required a minimum of twenty samples per second to be represented. Second, a sensor jacket which aims to detect the posture and movement of the wearer using knitted conductive fabric. The illustration of the knitted stretch sensor is shown in Figure 2.10, where the resistivity increases when the fabric is stretched, and it is capable of being stretched over fifty percent of its original length.

![Knitted stretch sensor and the sensor jacket final design](image)

Figure 2.10: Knitted stretch sensor and the sensor jacket final design (Farringdon et al., 1999)
The sensor strips are stitched on top of a jacket in eleven predetermined positions mostly focusing on the shoulder and elbow joint as shown in Figure 2.10. The analogue output of each sensor is converted using analogue to digital converter because the output is used as input for the kinematic geometry model; where the mobility of the wearer is mathematically modelled. Although the developed system is capable of detecting human motion, further work is needed if this concept is to be adapted for multimodal human-computer interfaces. In another study, Salazar et al. (2010) expanded the idea of using sensor badge by Farringdon et al. (1999) by using multiple sensor badges connected which are referred to as body sensor network (BSN). The BSN system consists of two sensor badges that use a Freescale MMA7260QT accelerometer and an InvenSense IDG-300 gyroscope; these sensors are interconnected using conductive fabric.

The system was tested for usability in sports by conducting experiments, where tests were performed by measuring the motion of a human walking, running, playing tennis and swimming. Salazar et al. (2010) added the approach of using BSN in signal monitoring is gaining a new foothold in sports performance analysis with the numerous advances in integrated circuits (IC), wireless communications and textile technology. Previous studies have primarily focused on using conductive textile to integrate electronic sensors into wearable clothing. In particular, the usage of accelerometer and gyroscope which require mechanical plug-ins to position the sensor on the garment which is usually uncomfortable and complex (Shyr et al., 2014). Therefore, an alternative method of using fabric-based sensor is proposed by Jayaraman & Park (2005) as shown in Figure 2.11.

![Figure 2.11: Novel fabric-based sensor design (US6970731 B1, 2005)](image-url)
This concept eliminated the need to use adhesives and hard wiring to attach the sensors to the human body to monitor vital signs and electrical impulses of the wearer, as snap connector are used to transfer the electrical impulses received. Although, the usage of these micromechanical sensors are required to measure the angular acceleration and position. It is not appropriate for measuring biological aspects of the human body like a heartbeat, breathing rate, sweat composition or body fatigue level.

The number of research conducted using textile sensors has been increasing over the decade because they are comfortable to wear, flexible and stretchable (Carvalho et al., 2014, US6970731 B1, 2005; Shyr et al., 2014). Furthermore, they can be used daily for continued health monitoring. Having the same objective, Carvalho et al. (2014) conducted experiments by using fabric integrated electrodes to monitor the electrocardiographic (ECG) and electromyography (EMG) signals. Hence, Carvalho et al. (2014) used electrodes made of silver chloride electrode (Ag/AgCl) covered in knitted multi filament polyamide yarn which has a low resistance value and could withstand dimension modification. Figure 2.12 shows the developed electrodes attached to a t-shirt, where snap connectors are used to extract the electrical impulse when the sensor is in contact with the skin.

![Figure 2.12: Textile with (a) embedded electrodes and (b) snap connector (Carvalho et al., 2014)](image)

The resistivity value of the sensor seen in Figure 2.12 (a) changes every time the wearer breathes as this motion makes the knitted fabric sensor to expand and contract. Carvalho et al. (2014) stated that one of the advantages of using fabric-based sensors is the possibilities of reusing them with minimal maintenance. On the other hand, Shyr et al. (2014) developed an experimental textile strain sensor. This
sensor consists of two electrodes and a substrate covered in elastic conductive webbing, which works on the same principle as a textile sensor. The aim was to build a wearable gesture-sensing device to monitor a player’s elbow and knee flexion angles. Figure 2.13 shows the placement of the developed fabric strain sensor attached to the player’s body using woven fabric, referred to as steady fabric.

![Figure 2.13: The developed (a) fabric sensor for elbow (Shyr et al., 2014)](image)

Based on the experimental results, Shyr et al. (2014) state that a good linear relationship was obtained between the elastic conducting webbing resistance value and the flexion angle during the stretch-recovery cycle. So far, all the studies that have been discussed use the textile-based sensor to measure human motion, but they are all limited to measuring only one parameter. Morris et al. (2009) and Coyle et al. (2009) conducted a study on a full body system that can measure the physiological signals and body kinematics of an athlete by using textile-based wearable sensors. The developed whole body system is divided into three main sensor category. First, measuring the body fluids mainly sweat. Sweating is a good sign, but an important factor in athletic performance is rehydration (Morris et al., 2009). Therefore, an athlete’s dehydration level is measured by the difference in their sweat pH value.

Hence, Coyle et al. (2009) developed a waistband that can monitor in real-time the sweat activity produced by athletes as shown in Figure 2.14 (a). The pH value of sweat is determined by analysing the colour change using LED-based optical detection sensor. Coyle et al. (2009) mentioned that using the waistband to obtain useful physiological information has an advantage of being non-invasive and does not disturb the player's movement. Figure 2.14 (c) shows the experimental setup to test the wearable pH sensor, where the data obtained from the pH sensor is processed and transmitted wirelessly to a personal computer to display the sweat composition in real-time. Bromocresol purple (BCP) dye is used to exhibit a colour
change from yellow to purple, depending on the sweat pH level. Therefore, the LED optical detection is sampled every 0.2Hz to allows precise colour change detection.

Secondly, Morris et al. (2009) developed a chest band which is used to detect and monitor an athletes breathing pattern. This band integrates into clothing worn by athletes, where the data collected could indicate how well the athlete is handling particular types of exercise. The breathing pattern is determined by measuring the extension and contraction of the rib cage using stretchable Lycra PPy sensor, which is fabric based conducting polymer polypyrrole (PPy) that changes conductivity when stretched. The developed chest band with the sensor is shown in Figure 2.15, where the system can detect breathing patterns of the athletes in real time.

Figure 2.14: (a) the waistband with (b) integrated pH sensor pocket and (c) experimental set-up (Coyle et al., 2009)

Figure 2.15: Chest band to measure breathing rate (Morris et al., 2009)
Thirdly, Morris et al. (2009) proposed using fabric bend sensor to measure joint flexion angles, especially human hand joints. The sensors were made by attaching and stitching a few pieces of stretchable conductive fabric together. The developed fabric bend sensor works on the same principle as a stretchable fabric sensor, where the resistance value increases as it is bent or stretched (Carvalho et al., 2014, US6970731 B1, 2005; Pantelopoulos et al., 2010; Shyr et al., 2014). Figure 2.16 shows a glove integrated with the developed bend sensor which is designed for rehabilitation purposes, where it is used to detect patients finger movements after experiencing a stroke (Morris et al., 2009). The author mentioned that this approach could be developed further and be applied to evaluate any joint movements depending on the required sports movements for various sports.

![Figure 2.16: Full finger flexion (0), half extension (1) and full extension (2) (Morris et al., 2009)](image)

2.2.3 Flexion Based Monitoring System

A goniometer was the only available method to measure human joint angles during dynamic movements before the introduction of vision and sensor-based measuring device (Norkin & White, 2009). A goniometer is a type of instrument that measures angles between two corresponding objects, where it can be used to measure the flexion, abduction, extension and adduction of a human joint (Morrey, Askew, & Chao, 1981). In the 1980’s the human joints were measured using a ruler goniometer for many application such as medical and sports. Later in the 1990’s the usage of a digital goniometer was implemented. However, it was not until the 2000’s where measurements using sensors were taken.

Morrey et al. (1981) used a ruler goniometer to study the normal elbow motion required to perform fifteen activities of daily living on thirty-three healthy adults. The goniometer was attached to the subject's arm using velcro and was
required to perform the given task. However, one disadvantage was discovered during testing; the goniometer was bulky since it had two rulers pivoted together at the centre of an angle-measuring protractor. Therefore, researchers began searching for other methods to perform this measurement and started experimenting with stretchable fabric to measure joint angles (Gemperle et al., 1998, US6970731 B1, 2005). An example has been discussed previously, where Morris et al. (2009) used stretchable fabric to measure stroke patients finger flexion.

However, advancements in sensor technology have enabled newer and more advanced sensor with high precision capability to be developed; this contributed to the development of flex sensors. Flex sensors are fabricated from film sensor substrate which causes a mechanical stress on the conductive pattern that leads to change in electrical resistance (Saggio et al., 2016). The flex sensor has widely been used in many different types of research to control machines, artificial devices, and physical activity measurements. More importantly, flex sensors have played a major role in the development of many rehabilitation hardware for stroke patients (Borghetti, Sardini, & Serpelloni, 2014). A general idea of how flex sensors are used to measure finger flexion can be seen in the research done by Saggio (2011), which investigates the total number of sensors needed to measure the human hand motion successfully. Flex sensors have been used extensively in biomedical systems, and Saggio (2011) aims to build a data glove for rehabilitation purpose. Figure 2.17 shows the developed data glove with flex sensors integrated into the glove surface.

![Figure 2.17: Developed data glove (Saggio, 2011)](image)

Saggio (2011) mentioned that the experiment results demonstrated good performance in term of accuracy and repeatability of measures. The author also


Glove and Ball for Monitoring Hand Rehabilitation Therapy in Stroke Patients. 
*India Educators’ Conference (TIIEC), 2013 Texas Instruments*, 321–327.


Biomedicine (pp. 1–4). IEEE.


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