MARKERLESS MOTION CAPTURE SYSTEM VIA KINEMATIC ANALYSIS OF ANGULAR LOWER LIMB

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To my loving family, lectures and friends
May Allah bless abundantly and grant Jannatul Firdaus

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ABSTRACT

The introduction of markerless sensor technology in motion capture system offers a comparable alternative to the conventional systems by employing infrared-depth sensors and retaining the ability to acquire two (2D) and three-dimensional (3D) data on human movement. However, its accuracy is often questioned compared to the established technologies such as passive marker systems. Therefore, this study sets an alternative method to evaluate Kinect Xbox 360 markerless system accuracy based on two positioning coordinates of two pairs of sensors. Through this approach, the length of lower limb segments was measured in 2D and 3D on each motion frame while performing squat movement and compared with the actual segment length. Interestingly, all segment lengths in the 3D showed excellent accuracy with the actual length of the segment. The angle of knee joints was also evaluated to identify the types of squat movements. The same evaluation is also used for the accuracy of a passive marker system while capturing the turning kick motion. In addition, the velocity of the knee joint was also studied at each phase of movement to determine the speed and angular of the knee required to enable the subject's foot to reach the target. For validation purposes, simulations of all recorded motions were implemented to evaluate the squat and the phases of movement in a turning kick from a visual angle. Successfully, the study was able to compare the accuracy and precision of the system constructed using lower limb data relative to the passive marker system using actual lower limb data. The markerless gave a remarkable difference value between the highest and lowest percentage coefficients of variation with 3.90%, while the passive marker system gave 5.72%. It is suggested that the multi-camera markerless motion capture system used in this study be used only for applications that do not require a significant level of accuracy such as animations, gaming and recreational sports analyses.

ABSTRAK

Teknologi penderia tanpa penanda dalam sistem tangkapan gerakkan menawarkan alternatif yang setanding dengan sistem konvensional. Ia menggunakan penderia kedalaman inframerah dan mengekalkan keupayaan untuk memperoleh data pergerakkan manusia dalam dua dan tiga dimensi. Walaubagaimanapun, ketepatannya sering dipersoalkan jika dibandingkan dengan teknologi sedia ada seperti sistem penanda pasif. Maka, kajian ini menetapkan kaedah alternatif untuk menilai ketepatan sistem tanpa penanda Kinect Xbox 360 berdasarkan dua koordinat kedudukan bagi dua pasang penderia. Melalui pendekatan ini, panjang setiap segmen anggota bawah diukur dalam 2D dan 3D pada setiap kerangka semasa melakukan pergerakan jongkong dan dibandingkan dengan panjang segmen sebenar. Menariknya kesemua panjang segmen dalam 3D menunjukkan ketepatan yang baik. Sudut sendi lutut turut dinilai untuk mengenal pasti jenis pergerakan jongkong. Penilaian yang sama juga digunakan untuk menilai ketepatan sistem penanda pasif semasa gerakan sepakan pusing. Selain itu, halaju sendi lutut turut dikaji pada setiap fasa pergerakan untuk menentukan kelajuan dan sudut lutut yang diperlukan bagi membolehkan kaki subjek mencapai sasaran. Untuk tujuan pengesahan, simulasi semua gerakan yang dirakam dilaksanakan untuk menilai jongkong dan fasa pergerakan tendangan dari sudut visual. Kajian ini juga membandingkan ketepatan dan kejituan diantara sistem yang dibina dengan sistem penanda pasif menggunakan data anggota bawah. Sistem tanpa penanda memberikan nilai perbezaan yang luar biasa antara pekali peratusan variasi tertinggi dan terendah dengan 3.90%, manakala sistem penanda pasif memberikan 5.72%. Oleh itu, sistem tangkapan gerakan tanpa penanda berbilang kamera yang dibina dalam kajian ini dicadangkan hanya digunakan untuk aplikasi yang tidak memerlukan tahap ketepatan yang ketara seperti analisis animasi, permainan dan sukan rekreasi.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3D	-	Three dimensional
IR	-	Infrared
MoCap	-	Motion capture
Segment	-	Bone
SDK	-	Software development kit
RANSAC	-	Random sample consensus
CMOS	-	Complementary metal-oxide-semiconductor
RGB	-	Red, green, blue
C_1	-	Camera number 1
C_2	-	Camera number 2
C_3	-	Camera number 3
C_4	-	Camera number 4
Pair 1	-	Combination between camera number 1 and camera number 2
Pair 2	-	Combination between camera number 3 and camera number 4
Transverse plane	-	Top plane
Sagittal plane	-	Side Plane

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Motion capture or often called motion tracking or MoCap is defined as the algorithm for recording and converting a live motion event into usable mathematical terms. It is performed by tracking the number of critical points in space over time and merging them to obtain a three-dimensional (3D) depiction of the human body's movements (Wei et al., 2015). Also, it is a computerized method for monitoring and coding the motions of objects or living beings that have been developed over decades by applying various techniques and technologies. Therefore, experts believe that combining infrared (IR) technology with depth sensor in a system would be ideal for detecting an object's depth by measuring the time interval between the emission of light and the detection of backscattering light (Menolotto et al., 2020). As a result, every living movement in space can be mapped in the system's volume environment.

The development and configuration of MoCap systems have sparked great interest across various sectors. For instance, it assists clinical professionals such as doctors, nurses, and physiotherapists in decision-making (Kidziński et al., 2020), delivering effective services and consultations to patients, and evaluating whether a patient's motor healing process is effective or not. Additionally, MoCap is advantageous for sports applications since it can scientifically interpret players' physical movements to assess their performance, study their postural efficiency, and prevent injuries during training (Pueo & Jose, 2017). Meanwhile, in the industrial settings, MoCap is used in the entertainment industry, where actors wear a special suit with affixed markers and cameras to aid computers in detecting their movements and translating them to the screen to create a new character (Delbridge, 2016). Figure 1.1

shows an example of a MoCap application in the industry, where actor Andy Serkis wears an LED-inlaid costume to play the character of Caesar (King Kong) in Dawn of the Planet of the Apes.

Figure 1.1: Example of MoCap application in the entertainment industry (Perry, 2015).

The use of the MoCap application in various sectors necessitates the use of cutting-edge technology to improve the efficiency of capturing and analyzing the spatial-temporal structure of body motions. As a result, this system's operation is separated into two independent components: hardware and software. The commercial hardware available in the market can be marker-based or markerless and is used to track and record segment locomotion. Simultaneously, the software reviews and analyses data acquired via hardware and estimates subject movement positions.

However, the high cost (Gong et al., 2016) of specialized hardware and software, standard calibration procedures, uncomfortable markers, specialized clothing, and the costly installation and operating expenses of existing MoCap systems have considerably limited their usage. In addition, placing a marker on the human body leads to idle time since determining the position of human joints or bones requires knowledge.

An example of a MoCap system that employs markers is depicted in Figure 1.2. This system is known as a marker-based optical motion capture system. The markers are called retroreflective markers, and more than ten markers are attached to the subject's body.

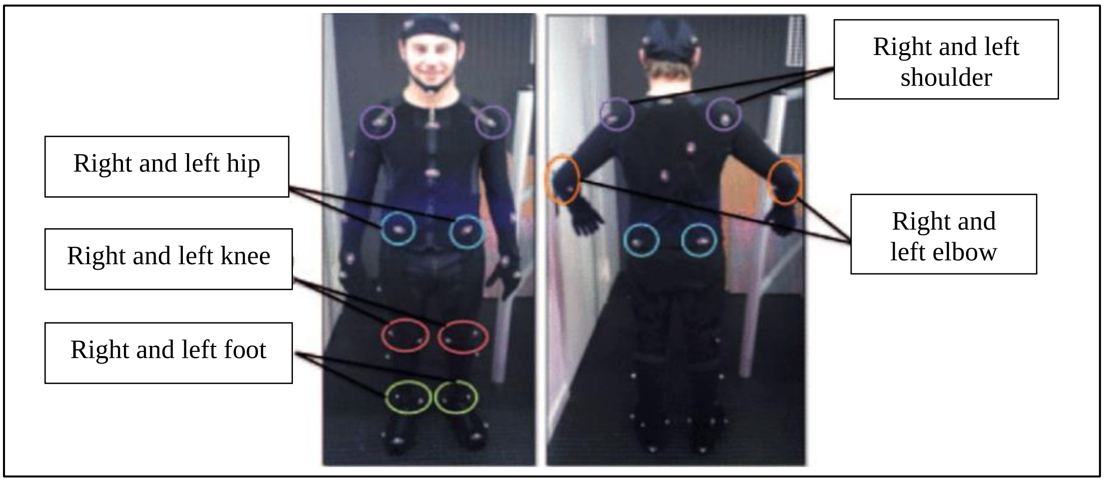

Figure 1.2: The details of marker arrangement on the subject's joint (Fernández-Baena et al., 2012).

Thus, this project aims to develop a markerless motion capture system by adapting current hardware and optimizing existing software. It will enable more effortless, user-friendly, time-efficient usage and facilitate a more relevant assessment of human movement in research and perhaps other fields of industrial training. Additionally, the motion analysis technique used in this study provides a mechanism for determining the accuracy of hardware collecting data on body segment movement and a framework for mathematical algorithms frequently used in biomechanical analysis.

1.1 Problem Statement

Motion capture systems have been widely used in biomechanical research as a fundamental technology for studying human physical behaviour. Therefore, researchers have adapted existing hardware to track human physical movements while performing activities. Unfortunately, controversy arises about whether the measurements tracked by the hardware are accurate or not. As a result, most researchers compare their hardware measurement data with standard gold data, which is often based on optical systems that employ markers to capture motion (Steinebach et al., 2020).

However, the optical motion capture is constrained by the presence of markers during motion tracking operations. Some users may experience discomfort throughout the recording procedure when the markers affixed to the skin adhere using doublesided adhesive (Shortland, 2020). Moreover, the motion capture technology that employs special clothing also causes discomfort to users. Special clothing, such as that depicted in Figure 1.3, is typically worn by the elderly who are unable to care for themselves.

Figure 1.3: A prototype of smart clothing (Guan et al., 2017).

To eliminate discomfort, this study used a markerless motion capture system in which infrared camera technology captures human movement. The cost of contemporary motion capture systems also plays a role in selecting this human locomotion capture system since established manufacturers like Vicon, Optitrack, Motion Analysis, Qualisys, and XSense charge a premium for their products.

In addition, this study was undertaken for the challenging and complex work of extracting anatomical tracking information, understanding it, and performing data analysis (Müller et al., 2017). Therefore, this study developed a new framework by combining existing marker-less motion capture sensors and analyzing the kinematic parameters of the observed motion. Also, the motion analysis of kinematic parameters will impact biomechanics researchers when accompanied by easy quantitative validation.

1.2 Objectives of Study

The main objectives of this study are:

i. To develop a framework to validate the accuracy of multi-depth camera motion capture system.

ii. To determine an angle lower limb biomechanics analysis of squat performance via the developed framework
iii. To determine the different accuracy of markerless motion capture with conventional optical motion capture

1.3 Scope of Study

The following are included in the scope of this study:

i. The Kinect Xbox 360 was chosen for its mobility and cost-effectiveness as the sample infrared sensor for capturing movement.
ii. Two pairs of sensors were employed simultaneously to verify the system's accuracy while capturing squat motions.
iii. A pair of sensors (Pair 1) was placed on the rear of the subject, and another pair of sensors (Pair 2) was placed on the front of the subject's front to verify the ideal sensor placement to record squat movement.
iv. The Xbox 360 Kinect sensors are connected to the Software Development Kit (SDK) v1.8 to record and track squat movement.
v. Since SDK v1.8 does not have consolidation features, SDK v2.0 is used to merge skeletal data for each sensor pair.
vi. The volunteer activity is half-squat since it is a motion that can monitor people's daily functions such as sitting, standing, and walking.
vii. The motion is repeated three times at the volunteer's own pace because the volunteer is a non-athlete.
viii. The segment lengths in the lower limb at both locations were analysed in each 2D and 3D plane to obtain the most accurate and consistent data.
ix. The most accurate results were determined by standard deviation, and then the knee angle was analysed using MATLAB software to determine the type of squat movement.
x. The same method was used to analyse the accuracy of the turning kick motion data recorded by the passive motion capture system.
xi. Analysis of angular displacement and angular velocity was performed through MATLAB to determine the knee speed when the subject's leg reached the target
xii. The movement of the turning kick was also analysed qualitatively to find out the phases of the kick performed by the subject.

xiii. Percentage of lower limb standard deviation obtained by the depth sensor system compared with passive motion capture data to determine the accuracy and precision of the two motion capture systems.

1.4 Significant of Study

Numerous study groups were able to use the same technique to assess the accuracy of MoCap in tracking motion, despite using different types of devices. Furthermore, optimizing the infrared sensor can simplify the setup process by eliminating the time required for a sophisticated equipment setup compared to a marker-based system.

In addition, the method developed can also simplify the task of researchers to conduct research based on their actual daily activities rather than focusing on researching a particular field.

The study also employed two sets of trace detection to demonstrate how the position of the sensor location affects the stability of the data recorded by the device.

1.5 Thesis Layout

Chapter 1 introduces the MoCap system and discusses the purpose of this study, including a problem statement and the study's objective, scope, and significance.

Chapter 2 is divided into four sections: biomechanics in kinesiology, mechanical systems, terminology, and technology employed in this research. The kinesiology section defines biomechanics and introduces the many types of mechanical systems pertinent to biomechanics. Meanwhile, the terminology section involves the basic terms used in this research, indicating the movement of the joints and joints on each axis and plane. Additionally, this chapter discussed the technology used in motion capture. The combination of all available knowledge results in the thorough understanding necessary for the work described in this study.

Chapter 3 discusses the components, formulae, equipment, and methods utilized to collect the research data. This chapter's primary objective is to demonstrate the system's behaviour and its appropriateness for real-world use. During the preliminary design stage, the primary needs for the software receiver and hardware must be identified. To begin, the receiver must have sufficient processing capacity to conduct a wide variety of mathematical algorithms, such as rigid transformation, because it must do substantial computations while receiving the coordinate axes of X, Y, and Z. Finally, the hardware must be capable of mapping and tracking skeletal joints and possess the flexibility for parallelization as well as subject move. Additionally, for a reader who is not familiar with the squat movement, there are also have a part that briefly explains the concepts of squat motion.

Chapter 4 discusses the experimental validation results for the suggested new framework's performance. Thus, the primary data obtained by the two sensor pairs were visualized in four different planes. This data was then evaluated in each plane to identify which pair of sensors was the most stable when capturing selected motions. Therefore, the most stable source data were selected for kinematic analysis. Additionally, this new framework was applied to existing data to assess the system's accuracy to record the turning kick motion, and a qualitative analysis could then be conducted. The coding of all mathematical algorithms is done in the IDE.

Finally, Chapter 5 discusses the conclusion like the suitable cameras positioned to acquire data during squat motion, and future recommendation where the knee angle speed data while performing the turning kick movement can be used as a reference by other athletes in the future. In addition, it also summarizes the precision of the system between markerless and maker-based.

CHAPTER 2

LITERATURE REVIEW

The work described in this thesis is centered on designing a framework that is suitable for MoCap analysis standards. This chapter will cover biomechanics in motion capture for software design and computer architecture for hardware applications. The combination of each field of specialization provides the necessary context to help the reader understand the work concept. The chapter introduces biomechanics under kinesiology and follows up with mechanical systems and terminology relevant to human motion. Then, the chapter progresses to computer architecture which is a discussion of the present ways for translating data collected via hardware recognition algorithms. Lastly, the chapter concludes by summarizing the chosen methods and technology in this study. This chapter will lead to a better understanding of the upcoming technical chapters.

2.1 Fields of Human Movement Study Based on the Discipline of Kinesiology

The term kinesiology refers to the study of the human movement. It associates the field of anatomy, physiology, physics, and geometry with human motion (Lippert, 2006). Table 2.1 shows the definition of sub-disciplines of kinesiology.

Table 2.1: Definition of sub-disciplines of kinesiology.

Sub-discipline	Definition
B	Biomechanics is the study of the human body in motion using concepts from mechanics and engineering. It is often defined as the discipline that explores

Table 2.1 (continued)

	the effect of internal and external forces on human and animal bodies in motion and at rest (Stergiou et al., 2017). There are numerous publications regarding human biomechanics included Sports Biomechanics, Clinical Biomechanics, and Computer Methods in Biomechanics and Biomechanical.
EP	Identifying the organ's function and mechanisms that support regular exercise and training, providing comprehensive treatment services related to analysis, improvement, and maintenance of physical and mental health, recovery from illnesses or disabilities, and providing professional and athlete advice on sports and training (Boone, 2015).
MD	Motor developmentalists study the process of motor behaviour changes from time to time, including typical trajectories of behaviour across the lifespan, the processes that underlie the differences, and factors that affect motor behaviour. Many factors that influence motor behaviour are the convergence of multiple factors related to living life, such as muscle strength, arousal, and experience. Another factor is the aimed goal, such as swinging at a baseball or optimizing on power. (Ulrich, 2007).
ML	Through instruction, practice, and/or experience, it is possible to change both the ability to produce movement performance and the actual movement performance in a reliable manner. (Fischman, 2007).
P	Pedagogy is defined as the science or profession of teaching. Also referred to as pedagogy or curriculum. It is the teaching of movement and sport in particular, based on sports pedagogy research (Tinning, 2008)
P-S	Psychosocial is defined as 'the influence of social factors on an individual's mind or behaviour, and the interrelation of behavioural and social factors' by the Oxford English Dictionary (Martikainen et al., 2002)

There are six significant disciplines of kinesiology; biomechanics (B), exercise physiology (EP), motor development (MD), motor learning (ML), pedagogy (P), and psychosocial (P-S). The studies of exercise are more likely to respond to physical activity based on the organism's function and the part of the mechanism involved during physical activity. Meanwhile, the motor development discipline will study changing motor behaviour from the results of the performance movements carried out in the motor learning discipline. Therefore, this study's focus is on biomechanical discipline as it directly studies the mechanical principles of the human body.

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