SELECTIVE JOINT MOTION RECOGNITION USING MULTI SENSOR FOR SALAT LEARNING

NOR AZRINI BINTI JAAFAR

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

School of Computing
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2022

DEDICATION

This thesis is dedicated to my late father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task could be accomplished if it is done one step at a time.

To my husband, thank you for being beside me all the time and going through this journey together. To my kids, thank you for being my source of energy and inspiration.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed to my understanding and thoughts. I particularly wish to express my sincere appreciation to my main supervisor, Associate Professor Dr. Nor Azman Ismail, for encouragement, guidance, critics, and friendship. I am also very thankful to my co-supervisor, Associate Professor Dr. Kamarul Azmi Jasmi, for his guidance, advice, and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to the Ministry of Higher Education (MoHE) and Universiti Teknologi Malaysia (UTM) for funding my PhD study. Librarians at UTM also deserve special thanks for their assistance in supplying the relevant works of literature.

My fellow postgraduate student should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance on various occasions. Their views and tips are useful, indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

Over the past few years, there has been significant attention given on motion recognition in computer vision as it has a wide range of potential applications that can be further developed. Hence, a wide variety of algorithms and techniques has been proposed to develop human motion recognition systems for the benefit of the human. Salat—an essential ritual in Muslim daily life which helps them be good Muslims—is not solely about the spiritual act, but it also involves the physical movements in which it has to be done according to its code of conduct. The existing motion recognition proposed for computing applications for salat movement is unsuitable as the movement in salat must be performed in accordance to the rules and procedures stipulated, the accuracy and sequence. In addition, tracking all skeleton joints does not contribute equally toward activity recognition as well as it is also computationally intensive. The current salat recognition focuses on recognizing main movements and it does not cover the whole cycle of salat activity. Besides, using a wearable sensor is not natural in performing salat since the user needs to give absolute concentration during salat activity. The research conducted was based on the intersections of technological development and Muslim spiritual practices. This study has been developed utilizing dual-sensor cameras and a special sensor prayer mat that has the ability to cooperate in recognizing salat movement and identifying the error in the movement. With the current technology in depth cameras and software development kits, human joint information is available to locate the joint position. Only important joints with the significant movement were selected to be tracked to perform real-time motion recognition. This selective joint algorithm is computationally efficient and offers good recognition accuracy in real-time. Once the features have been constructed, the Hidden Markov Model classifier was utilized to train and test the algorithm. The algorithm was tested on a purposely built dataset of depth videos recorded using a Kinect camera. This motion recognition system was designed based on the salat activity to recognize the user movement and his error rate, which will later be compared with the traditional tutor-based methodology. Subsequently, an evaluation comprising 25 participants was conducted utilizing usability testing methods. The experiment was conducted to evaluate the success score of the user's salat movement recognition and error rate. Besides, user experience and subjective satisfaction toward the proposed system have been considered to evaluate user acceptance. The results showed that the evaluation of the proposed system was significantly different from the traditional tutor-based method evaluation. Results indicated a significant difference ($p < 0.05$) in success score and user's error rate between the proposed system and traditional tutor-based methodology. This study also depicted that the proposed motion recognition system had successfully recognized salat movement and evaluated user error in salat activity, offering an alternative salat learning methodology. This motion identification system appears to offer an alternate learning process in a variety of study domains, not just salat movement activity.

ABSTRAK

Sejak beberapa tahun kebelakangan ini, terdapat perhatian penting diberikan pada pengecaman pergerakan dalam bidang visi komputer memandangkan ia mempunyai pelbagai aplikasi yang berpotensi untuk dibangunkan. Oleh itu, pelbagai jenis algoritma dan teknik telah dicadangkan untuk membangunkan sistem pengecaman pergerakan manusia untuk faedah manusia. Solat—suatu upacara penting dalam kehidupan seharian Muslim yang membantu mereka menjadi Muslim yang baik—bukan semata-mata tentang perbuatan rohani, tetapi ianya melibatkan pergerakan fizikal yang mana ia perlu dilakukan mengikut kod kelakuannya. Pengecaman pergerakan sedia ada yang dicadangkan untuk aplikasi pengkomputeran untuk pergerakan solat adalah tidak sesuai kerana pergerakan dalam solat mesti dilakukan mengikut peraturan dan prosedur yang ditetapkan, ketepatan dan urutannya. Tambahan pula, pengesanan semua sendi rangka tidak menyumbang secara sama rata ke arah pengecaman aktiviti dan ianya juga intensif dari segi pengiraan. Pengecaman solat sedia ada memberi tumpuan kepada mengenali pergerakan utama dan tidak meliputi keseluruhan kitaran aktiviti solat. Selain itu, menggunakan sensor boleh pakai adalah tidak menjadi kebiasaan semasa mengerjakan solat kerana pengguna perlu memberikan penumpuan sepenuhnya semasa aktiviti solat. Penyelidikan ini adalah berdasarkan persimpangan pembangunan teknologi dan amalan kerohanian Muslim. Kajian ini telah dibangunkan menggunakan kamera dwi-sensor dan sensor khas pada sejadah yang bekerjasama untuk mengenali pergerakan solat dan mengenal pasti kesilapan dalam pergerakan. Dengan teknologi semasa dalam kamera kedalaman dan kit pembangunan perisian, maklumat sendi manusia telah tersedia untuk mengesan kedudukan sendi. Hanya sendi yang penting dengan pergerakan ketara telah dipilih untuk melakukan pengecaman pergerakan masa nyata. Algoritma sendi terpilih ini cekap dari segi pengiraan dan menawarkan ketepatan pengecaman yang baik dalam masa nyata. Apabila ciri telah dibina, pengelas Model Markov Tersembunyi telah digunakan untuk melatih dan menguji algoritma. Algoritma telah diuji pada set data video kedalaman yang dirakam menggunakan kamera Kinect. Sistem pengecaman pergerakan ini direka bentuk berdasarkan aktiviti solat untuk mengenal pasti pergerakan pengguna dan kadar ralat pengguna, yang kemudiannya akan dibandingkan dengan kaedah tradisional yang menggunakan tutor. Seterusnya, penilaian terhadap 25 peserta telah dikendalikan menggunakan kaedah ujian kebolehgunaan. Ujikaji dijalankan untuk menilai markah kejayaan pengecaman pergerakan solat pengguna dan kadar ralat. Selain itu, pengalaman pengguna dan kepuasan subjektif terhadap sistem yang dicadangkan telah diambil kira untuk menilai penerimaan pengguna. Keputusan menunjukkan bahawa penilaian sistem yang dicadangkan mempunyai perbezaan ketara daripada penilaian kaedah tradisional berasaskan tutor. Keputusan menunjukkan terdapat perbezaan yang ketara ($p < 0.05$) dalam skor kejayaan dan kadar ralat pengguna di antara sistem yang dicadangkan dan kaedah tradisional berasaskan tutor. Dapatan kajian juga mendapati sistem pengecaman pergerakan yang dicadangkan berjaya mengecam pergerakan solat dan menilai kesilapan pengguna dalam aktiviti solat, dan ini secara tidak langsung, menawarkan kaedah alternatif pembelajaran solat. Sistem pengecaman pergerakan ini juga dilihat mampu menyediakan alternatif lain untuk kaedah pembelajaran dalam pelbagai domain kajian, tidaklah hanya terhad kepada aktiviti pergerakan solat sahaja.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
CAMSA	-	Continuously Adaptive Mean Shift Algorithm
CNN	-	Convolutional Neural Network
DRNN	-	Deep Recurrent Neural Networks
DTW	-	Dynamic Time Warping
EMG	-	electromyography
GR	-	Gesture Recognition
HCI	-	Human-Computer Interaction
HMM	-	Hidden Markov Model
HMR	-	Human Motion Recognition
IDE	-	integrated development environment
ISOMAP	-	isometric features mapping
KBS	-	Kem Bestari Solat
LDCRF	-	Latent-dynamic Conditional Random Field
LS-SVM	-	Least Squares Support Vector Machine
MOE	-	Ministry of Education
NN	-	Neural Network
NUI	-	Natural User Interface
RF	-	Random Forest
SDK	-	Standard Development Kit
SUS	-	Subjective Usability Scale
UEQ	-	User experience Questionnaire

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Motion recognition is an active research area among researchers worldwide because this topic can cover a wide range of applications, such as in sports (Fung *et al.*, 2014), health (Hoda *et al.*, 2017), surveillance, and security (Tzanidou, 2014). Much active research still explores the beauty of motion recognition. With the advent of advanced technology, motion recognition has been an exciting topic to discover. It makes work more accessible and fun to explore, especially when it involves learning. Computer and education have always been exciting topics to uncover and unleased. The assisted learning is one of the issues in computer and education research (Chien *et al.*, 2015). With assisted learning, it helps users or students have the ability to self-learning to improve their studies' quality. It can also reduce the burden on tutors or teachers and help students prepare before the classes. These will be life saviors in improving the education system.

Performing prayer correctly is a significant concern to all Muslims. In the Holy Quran, Muslims are obliged and required to perform prayer five times daily (Harun *et al.*, 2016). In Islam, prayer is known as salat. Salat is an Arabic or Quranic word for prayer, and it is foremost worship in Islam. Salat is a pillar of all acts of worship in Islam. As a Muslim, the primary responsibility is to perform salat correctly and fully concentrated. Salat must be done following Islamic Law's demands, which is pegged to the Quran and Sunnah. Performing prayer precisely is a significant concern to all Muslims. In the Holy Quran, it is written that Muslims are obliged and required to perform prayer five times daily.

A well-known motivational figure in Malaysia did a study, Dato' Dr Mohd Fadzilah Kamsah, stated that 80% of Muslims in Malaysia still do not perform salat five times daily. His survey obtained this percentage through talks and motivational programs conducted nationwide. According to him, among those who abandon to perform the salat are students, youth, factory workers, and merchants (Utusan Malaysia 2008, 23 Jun).

However, looking into the current scenario, there is neglect in performing salat by Muslims where they are not consistent in performing five times daily. (Suhaila *et al.*, 2018) found that some Muslims still considered performing salat as not essential and not prioritized to fulfil it. Due to lack of knowledge and understanding about the importance of salat, causing the imperfection in salat performance. Subsequently, when salat has been neglected, this exposed many social problems among Muslims, such as moral issues, drug issues, and abortion. Salat movement is a unique body language. Even though Muslims perform salat every day, they still cannot perform salat in perfect movements. Muslims often make many mistakes in salat and continue to do so for years before realizing their mistake (Salman, 2010). As a Muslim, learning and practising salat properly is important because proper salat will lead somebody to be a good Muslim.

It is important to have a strong fundamental in computer vision body of knowledge in order to understand activity recognition. Figure 1.1 shows the knowledge domain of activity recognition and understanding extracted from the Association for Computing Machinery computing classification system. Activity recognition and understanding fall under computing methodologies can be derived further into three categories: motion tracking, pose estimation, and motion recognition. This research is focused on motion recognition techniques throughout the process of problem formulation until the research contribution. This research is also an intersection with the Human-Computer Interaction (HCI) body of knowledge. The usability testing will be used to evaluate and validate research contributions.

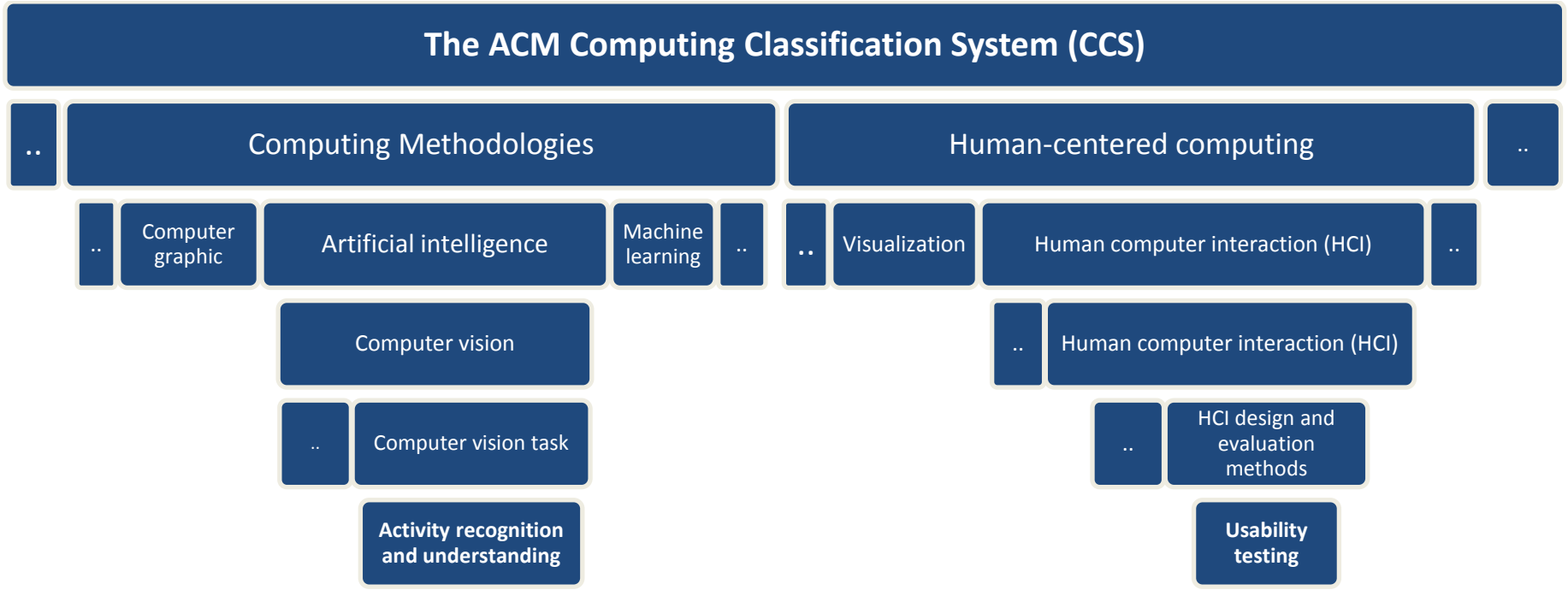

Figure 1.1 Body of knowledge of study

1.2 Problem Background

Human motion tracking is an important and challenging computer vision problem (Le *et al.*, 2013). When considering vision-based tracking for human-computer interaction, an interactive loop that includes several human motions is crucial. The complicated related system must operate in real-time, and acceptable low latency demands of human-computer interaction as feedback are needed (Fuhrmann *et al.*, 2013). Since a few years ago commercial marker-based motion capture system has existed. It can record the movement of people at high frequency with precise accuracy, which makes it an ideal tool for the film industry. This system requires special clothing and a controlled environment like a studio (Pohl and Hadjakos, 2010). However, markers and the corresponding special clothing are not always desirable or even applicable. As a result, such systems are complex, expensive, and difficult to maintain. Thus, it makes marker-less tracking applications are high demand.

Using a monocular or single camera is often challenged by problems such as occlusion and ambiguity. Marker-less human motion analysis from multi-view has been progressed rapidly in recent years (Colyer *et al.*, 2018). Multi-view motion analysis using multiple cameras can resolve occlusion and ambiguity problems. Most human motion analysis needs various perspectives to find a good view of the human body and ensure the movements are correct or accurate. Using motion recognition will allow users to interact with a computer naturally and have recognition in real-time. Thus, to have real-time motion recognition, a robust algorithm is proposed to have stable and less-computational but still able to get recognition works.

Receiving raw joint data from the sensor is challenging since there are noises and errors (Niu *et al.*, 2020). Tracking all joint data is computationally expensive and more complicated for real-time recognition. Track all joints did not promise high accuracy; a subset of joint tracking also provides the same accuracy with tracking all joints (Anjum *et al.*, 2017). The number of features is significant for the model to achieve a high accuracy metric. However, that is not the problem by creating a parsimonious recognition model. This concept focuses on creating a minimum feature model while maintaining high accuracy metrics.

As known as salat, Muslim prayer is one of the required acts in Muslim daily lives. Although they prayed every day, some did not notice the mistake. The current methodology in learning salat is still using the traditional method. As technology advances, the learning methodology should evolve from the conventional way with the computer. The traditional learning method used in the textbook as a medium for lessons seems less effective in attracting students' concentration (Zupanec *et al.*, 2013). Teachers or tutors mainly depend on their narration to teach in the classroom, partly supported by graphics, which do not motivate the students' interest. Those abstract carriers have linear characteristics, which are sometimes difficult for them to catch up with. When the students do not understand the teacher's lecture, some stay quiet and do not ask questions.

Human motion tracking and analysis have been exciting topics in computer vision because they can generate many potential applications. Humans express various desires, feelings, thoughts and facilitate communication on the level of emotion and ideas (Rwigema *et al.*, 2019). The invention of new technologies in computer science is very stimulating, parallel with human communication development. Apart from human-human communication, human's natural form of communication is with God. In Islam, the human body with specific movement has become part of communication between humans with Allah to fulfil the purpose of creation and existence. This relationship between Allah and humans is unique and can be achieved by performing the salat, Islam's fundamental obligation. Therefore, this mutual communication is considered as the instrument of elevation. Besides, Islam also encouraged using technology to manage the earth according to will and God's purpose (Mohd Khairi, 2018).

There are several ways humans can interact with the computer. Speech recognition was able for the user to interact with the computer by using voices. The touchscreen allows users to input the computer by touching it. With the latest technology, the user only needs to show simple gestures that can be used to input the computer (Kulshreshth *et al.*, 2013). Each method requires specific hardware so that the computer can receive information from the user. The method used to interact with the computer should be suitable for the user's task. HCI has become an evolving field

that attracts experts from various fields to improve the application of computer programs and the convenience of computer users. HCI is mostly related to learning and cognition, where the emerging approach to learning and problem solving is problem-based learning (Tan, 2011). Most studies on computer-assisted learning focus on the systems' technical parts and describe some novel components. However, these studies are rarely assessed regarding learning effectiveness or user acceptance and satisfaction (Nagy, 2018).

Existing salat research focuses on health and well being. The study found that performing salat with correct movement will ensure better health. The research focuses on finding the relationship between the salat movement and health (Harun *et al.*, 2016). The finding shows that performing a correct salat movement posture will improve a healthy body. This research stated that a perfect movement would bring improvement toward human health. It does not focus on enhancing the salat movement itself but on proving that good salat movement will lead to good health. The other salat research develops action recognition toward recognizing and estimating salat movement. Most of the study estimated based on the salat movement sequence. They do not recognize the movement but estimate the result based on the sequence. Motion recognition in salat activity still has unresolved issues such as learning or assisting the user to achieve the correct salat movement. This thesis proposed motion-based interaction for salat movement learning by using motion recognition technology and knowledge. To achieve this, assisted learning with technology can help users learn and improve movement.

1.3 Problem Statement

Various researchers in human motion recognition have developed several existing techniques and algorithms. Salat involves physical movement and focuses our minds on Allah. In performing salat, every Muslim should follow the manners and standards set of movement based on salat laws. Several existing research has been proposed to recognize human motion in salat activities (Al-Ghannam and Al-Dossari, 2016; Azizon Salleh *et al.*, 2019). However, the research used wearable sensors, which

the user does not desire. Existing research on motion recognition in the computing area was not suitable for salat activity as it mostly does not correspond to the nature of salat movement itself.

Motion recognition has strong potential to develop in the human-computer interaction field. However, existing databases on human motion are limited to daily activity (Guerra-Filho and Biswas, 2012). They do not cover all the important movements in salat activity. This study tries to improve existing salat research by enhancing salat motion patterns and vocabulary covering the whole salat activity. Even though salat movement research has been proposed, none of it is a motion-based system that supports real-time motion recognition and evaluation. This research attempts to contribute to the field and presents an algorithm to recognize salat activities and detect errors from the user. The main advantage of this research approach to activity recognition based on skeleton tracking is the selection of joins most relevant toward salat activity. This reduces the algorithm's computational complexity and enhances salat patterns and vocabulary datasets.

1.4 Research Question

The research question of this study are listed below:

(a) Does the current motion recognition algorithm allow the adoption of salat movements?
(b) How can Muslim's salat activities be assisted using motion recognition knowledge and technology?
(c) Will motion recognition technology be acceptable in an assistive system for Muslim salat activities?

1.5 Research Aim

This research aims to enhance user experience in salat learning through markerless motion recognition by proposing a selective joint algorithm for motion recognition and applying it to salat activity as an alternative method to assist Muslim salat learning.

1.5.1 Research Objectives

The objectives of the research are :

(a) To construct markerless motion recognition for salat movement by proposing a selective joint position algorithm
(b) To enhance existing salat motion pattern and vocabulary by adding all the important movements in the salat cycle
(c) To integrate the proposed algorithm into salat learning and evaluate its performance, user experience, and acceptability

1.6 Research Scope

This research's scope has been determined to align with the aim and objectives to carry out this research. Among them are as follow:

(a) this research will only follow salat rules and guidelines under Shafie Mazhab, which is dominant in Malaysia's Islamic thought, where this research was done.
(b) This research is based on human motion recognition and analysis for salat movement.

(c) This thesis focuses only on salat activity movements, which do not include recitation in salat, as recitation should focus on the speech recognition process.

(d) This research covers two cycles of raka'ah in salat activity, which is enough to cover all salat movement activity as a whole.

(e) The salat movement speed was counted at least 3-second delay from each movement to fulfil salat law

(f) This research only covers the adult motion database to prove the proposed algorithm; no child data was used.

(g) For female database, this study does not cover females in telekung, which is not the requirement to fulfill to perform salat, as long as they cover their body

(h) A fully functional real-time motion recognition was developed and used in the evaluation stage.

(i) This research focuses on to single user at one time to optimize the evaluation of the proposed prototype

(j) Evaluation of the proposed prototype is specific to measuring the ability motion recognition and user error rate in salat movement

1.7 Significant of Research

The research is combining motion technology into Islamic educational tools. The proposed interaction contributes to human-computer interaction and the educational technology domain. Learning to perform salat properly is very important as Muslims do it in their daily lives. Learning performing salat through technology could solve their quality issue as adults are shy to ask and learn from others. This makes them continue making some mistakes for years. Based on this study, this research's outcomes can contribute to the current unexplored motion recognition area, such as salat movement. The proposed algorithm can also be used in other motion recognition areas and as a learning tool for other motion movements.

1.8 Organization of Thesis

This thesis is structured into six chapters. Chapter 1 introduce the background and problem of this work. The aim and objectives to be accomplished by this research are also given, along with the scope. Chapter 2 discusses the literature review, an overview of the previous research relevant to this work. Chapter 2 describes the history of motion research and its state of the art. It also discusses the salat ontology and its learning methodology. A related issue to user interaction and learning technology is highlighted as well.

Chapter 3 presents the adopted research methodology, the research nature, and the whole research design. This chapter includes an overview of the research procedures and methods used to design human motion recognition and analysis for salat learning. Chapter 4 discusses insight into problem formulation using observation and expert interviews. The process of development for the proposed prototype also will be highlighted.

Chapter 5 details the experiments designed to evaluate the proposed prototype's usability and performance compared with traditional learning methodology. The results for each study were analyzed, and the finding will be discussed in detail. Finally, Chapter 6 concludes the thesis by discussing the overall achievements and implications of the research. This chapter also discusses the limitation and suggestions for future work in this domain.

REFERENCES

Abdul Manaf, S. Z., Mohamad Zaid, A. S., Din, R., Hamdan, A., Mat Salleh, N. S., Kamsin, I. F., Abdul Karim, A. and Lubis, M. A. (2015) 'Aplikasi Mudah Alih Panduan Solat dan Pengunaannya', *Ulum Islamiyyah Journal*, 16, pp. 43–61.

Ahmad, N. A. and Razak, F. H. A. (2013) 'On the Emergence of Techno-Spiritual: The Concept and Current Issues', *Computer and Mathematical Sciences Graduates National Colloquium 2013*, pp. 1–8.

Ahmad, N., Han, L., Iqbal, K., Ahmad, R., Abid, M. A. and Iqbal, N. (2019) 'SARM: Salah activities recognition model based on Smartphone', *Electronics (Switzerland)*, 8(8), pp. 1–24.

Al-Ghannam, R. and Al-Dossari, H. (2016) 'Prayer Activity Monitoring and Recognition Using Acceleration Features with Mobile Phone', *Arabian Journal for Science and Engineering*, 41(12), pp. 4967–4979.

Alabbasi, H., Gradinaru, A., Moldoveanu, F., & Moldoveanu, A. (2016) 'Virtual Sports Training System Using Kinect V2 Sensor', *University Politehnica Of Bucharest Scientific Bulletin Series C-Electrical Engineering And Computer Science*, 78(4), pp. 17-30

Alias, A. and Aziz, N. A. A. (2010) 'Implementing multimedia and simulation in developing computerized blood circulation and bodily movement during obligatory prayers (SolatSim)', in *ICCTD 2010 - 2010 2nd International Conference on Computer Technology and Development, Proceedings*, pp. 735–738.

Anjum, M. L., Rosa, S., & Bona, B. (2017). 'Tracking a subset of skeleton joints: an effective approach towards complex human activity recognition'. *Journal of Robotics*.

Azizon Salleh, Huzaimah Ismail, Kamariah Yussof, Azizah Zakaria and Ahmad Faizar Jaafar (2019) 'Inovasi " Solat Alert Software " (SAS) sebagai Satu Kaedah Menggalakkan Pengguna Komputer Menunaikan Solat di Awal Waktu (Solat Alert Software as a Method of Encouraging Computer User to Perform', *Jurnal Inovasi Malaysia*, pp. 51–60.

Bangor, A., Staff, T., Kortum, P., Miller, J. and Staff, T. (2009) 'Determining What Individual SUS Scores Mean : Adding an Adjective Rating Scale', *Journal of usability studies*, 4(3), pp. 114–123.

Berger, K. (2014) 'A state of the art report on multiple RGB-D sensor research and on publicly available RGB-D datasets', in *Computer Vision and Machine Learning with RGB-D Sensors* (pp. 27-44).

Blackburn, J. and Ribeiro, E. (2007) 'Human motion recognition using Isomap and dynamic time warping', in *Workshop on Human Motion* (pp. 285-298).

Celebi, S., Aydin, A. S., Temiz, T. T. and Arici, T. (2013) 'Gesture recognition using skeleton data with weighted dynamic time warping', in *VISAPP 2013 - Proceedings of the International Conference on Computer Vision Theory and Applications*, 1, pp. 620–625.

Chan, J. C. P., Leung, H., Tang, J. K. T. and Komura, T. (2011) 'A virtual reality dance training system using motion capture technology', *IEEE Transactions on Learning Technologies*, 4(2), pp. 187–195.

Chen, S., Maeda, Y. and Takahashi, Y. (2012) 'Music conductor gesture recognized interactive music generation system', in *The 6th International Conference on Soft Computing and Intelligent Systems, and The 13th International Symposium on Advanced Intelligence Systems*. IEEE, pp. 840–845.

Chien, K., Tsai, C., Chen, H., Chang, W. and Chen, S. (2015) 'Computers & Education Learning differences and eye fi xation patterns in virtual and physical science laboratories', *Computers & Education*. Elsevier Ltd, 82, pp. 191–201.

Colyer, S. L., Evans, M., Cosker, D. P. and Salo, A. I. T. (2018) 'A Review of the Evolution of Vision-Based Motion Analysis and the Integration of Advanced Computer Vision Methods Towards Developing a Markerless System', *Sports Medicine - Open*.

Ding, I. J. and Chang, C. W. (2016) 'An adaptive hidden Markov model-based gesture recognition approach using Kinect to simplify large-scale video data processing for humanoid robot imitation', *Multimedia Tools and Applications*, 75(23), pp. 15537–15551.

Dubois, A., Dib, A. and Charpillet, F. (2011) 'Using HMMs for discriminating mobile from static objects in a 3D occupancy grid', in *Proceedings - International Conference on Tools with Artificial Intelligence, ICTAI*, pp. 170–176.

E. Cutting, J. and T. Kozlowski, L. (1977) ‘Recognizing friends by their walk: Gait perception without familiarity cues.pdf’, *Bulletin Psychonometric Society*, pp. 353–356.

El-Hoseiny, M. H. and Shaban, E. (2009) ‘Muslim prayer actions recognition’, *2009 International Conference on Computer and Electrical Engineering, ICCEE 2009*, 1, pp. 460–465.

Elmezain, M. and Al-Hamadi, A. (2018) ‘Vision-based human activity recognition using LDCRFs’, *International Arab Journal of Information Technology*, 15(3), pp. 389–395.

Essid, S., Lin, X., Gowing, M., Kordelas, G., Aksay, A., Kelly, P., Fillon, T., Zhang, Q., Dielmann, A., Kitanovski, V., Tournemenne, R., Masurelle, A., Izquierdo, E., Connor, N. E. O., Daras, P. and Richard, G. (2013) ‘A multi-modal dance corpus for research into interaction between humans in virtual environments’, *Multimodal User Interfaces*, pp. 157–170.

Fanti, C., Zelnik-Manor, L. and Perona, P. (2005) ‘Hybrid Models for Human Motion Recognition’, in *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR’05)*. IEEE, pp. 1166–1173.

Fuhrmann, A., Kretz, J. and Burwik, P. (2013) ‘Multi Sensor Tracking for Live Sound Transformation’, *Proceedings of the International Conference on New Interfaces for Musical Expression*, (Figure 1), pp. 358–362.

Fung, S. K., Sundaraj, K., Ahamed, N. U., Kiang, L. C., Nadarajah, S., Sahayadhas, A., Ali, M. A., Islam, M. A. and Palaniappan, R. (2014) ‘Hybrid markerless tracking of complex articulated motion in golf swings’, *Journal of Bodywork and Movement Therapies*, 18(2), pp. 220–227.

Guerra-Filho, G. and Biswas, A. (2012) ‘The human motion database: A cognitive and parametric sampling of human motion’, *Image and Vision Computing*. Elsevier B.V., 30(3), pp. 251–261.

Hachaj, T. and Ogiela, M. R. (2016) ‘Human actions recognition on multimedia hardware using angle-based and coordinate-based features and multivariate continuous hidden Markov model classifier’, *Multimedia Tools and Applications*. Multimedia Tools and Applications, 75(23), pp. 16265–16285.

Hamzah, N., Abd Halim, N. D., Hassan, M. H. and Ariffin, A. (2019) ‘Android application for children to learn basic solat’, *International Journal of Interactive Mobile Technologies*, 13(7), pp. 69–79.

Harun, H., Nasir, N. F. M. and Salleh, A. F. (2016) 'The study of EMG signals during sitting postures in Muslim prayer', *IECBES 2016 - IEEE-EMBS Conference on Biomedical Engineering and Sciences*. IEEE, pp. 722–726.

Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004) 'Design Science In Information Systems Research', in *MIS Quarterly*, pp. 75–105.

Hevner Alan, R. (2007) 'A Three Cycle View of Design Science Research', *Scandinavian Journal of Information Systems*, 19(2), pp. 87–92.

Hoda, M., Hoda, Y., Hafidh, B. and El Saddik, A. (2017a) 'Predicting muscle forces measurements from kinematics data using kinect in stroke rehabilitation', *Multimedia Tools and Applications*. Multimedia Tools and Applications, pp. 1–19.

Hou, S., Galata, A., Caillette, F., Thacker, N. and Bromiley, P. (2007) 'Real-time Body Tracking Using a Gaussian Process Latent Variable Model', *IEEE 11th International Conference on Computer Vision (ICCV 2007)*, pp. 1–8.

Hsiao, H.-S. and Chen, J.-C. (2016) 'Using a gesture interactive game-based learning approach to improve preschool children's learning performance and motor skills', *Computers & Education*, 95, pp. 151–162.

Ibrahim, F. and Ahmad, S. a. (2012) 'Assessment of upper body muscle activity during salat and stretching exercise: A pilot study', *Proceedings - IEEE-EMBS International Conference on Biomedical and Health Informatics: Global Grand Challenge of Health Informatics, BHI 2012*, 25(Bhi), pp. 412–415.

Ibrahim, F. and Ahmad, S. A. (2012) 'Investigation of Electromyographic Activity during Salat and Stretching Exercise', in 2012 IEEE-EMBS Conference on Biomedical Engineering and Sciences (pp. 335-338).

Ismail, J., Md Noor, N. L. and Rahim Wan Mohd Isa, W. A. (2014) 'Addressing cognitive impairment among elderly people: A techno-spiritual perspective', in *2014 the 5th International Conference on Information and Communication Technology for the Muslim World, ICT4M 2014*.

Ismail, J., Noor, N. L. M., Abdul, W., Wan, R. and Isa, M. (2015) 'Smart Prayer Mat: A Textile-Based Pressure Sensor to Assist Elderly with Cognitive Impairment in Praying Activity', *Proceedings of the 5th International Conference on Computing and Informatics*, (170), pp. 241–246.

Jiang, M., Kong, J., Bebis, G. and Huo, H. (2015) 'Informative joints based human action recognition using skeleton contexts', *Signal Processing : Image Communication*. Elsevier, 33, pp. 29–40.

Johansson, G. (1973). 'Visual perception of biological motion and a model for its analysis'. *Perception & psychophysics*, 14(2), pp. 201-211.

Kale, G. V. and Patil, V. H. (2016) 'A Study of Vision based Human Motion Recognition and Analysis', *International Journal of Ambient Computing and Intelligence*, 7(2), pp. 75–92.

Kay, J., & Kummerfeld, B. (2010). 'Tackling HCI challenges of creating personalised, pervasive learning ecosystems', in *European Conference on Technology Enhanced Learning*, pp. 1-16.

Khalid, N., Jaafar, H. and Kasbun, R. (2015) 'Developing a Mobile Learning Application Framework of "Jamak Qasar Apps" using ADDIE Approach', *Australian Journal of Basic and Applied Sciences*, 9(19), pp. 40–44.

Koppula, H. S., Gupta, R. and Saxena, A. (2013) 'Learning human activities and object affordances from RGB-D videos', *The International Journal of Robotics Research*, 32(8), pp. 951–970.

Kulshreshth, A., Zorn, C. and LaViola Jr., J. J. (2013) 'Poster: Real-time markerless kinect based finger tracking and hand gesture recognition for HCI', *IEEE Symposium on 3D User Interface 2013, 3DUI 2013 - Proceedings*, pp. 187–188.

Laugwitz, B., Held, T. and Schrepp, M. (2008) 'Construction and Evaluation of a User Experience Questionnaire', *HCI and Usability for Education and Work*, pp. 63–76.

Le, T. L., Nguyen, M. Q. and Nguyen, T. T. M. (2013) 'Human posture recognition using human skeleton provided by Kinect', in *2013 International Conference on Computing, Management and Telecommunications, ComManTel 2013*.

Leite, L. and Orvalho, V. (2012) 'Shape Your Body: Control a Virtual Silhouette Using Body Motion', *Proceedings of the 2012 ACM Annual Conference Extended Abstracts on Human Factors in Computing Systems Extended Abstracts - CHI EA '12*, pp. 1913–1918.

Lun, R. and Zhao, W. (2015) 'A Survey of Applications and Human Motion Recognition with Microsoft Kinect', *International Journal of Pattern Recognition and Artificial Intelligence*, 29(05), 1555008.

Lv, F., and Nevatia, R. (2006) ‘Recognition and segmentation of 3-d human action using HMM and multi-class adaboost’, in *European conference on computer vision,* pp. 359-372.

Macefield, R. (2009) ‘How To Specify the Participant Group Size for Usability Studies : A Practitioner's Guide’, *Journal of Usability Studies*, 5(1), pp. 34–45.

Mamat, M. S., Hassan, S. N. S. and Ab. Halim Tamuri (2009) ‘Amalan Ibadat Harian dan Sumbangannya kepada Kecerdasan Emosi Remaja’, *Journal of Islamic and Arabic Education*, 1(1), pp. 29–40.

Mohd Ali, S. W., Mohamed Yusof, H., Yusof, R., Talib, R., W Ramli, W. M. A. A., Sulaiman, S., Zakaria, M. A., Suhadi, A. and Mozi, A. M. (2020) ‘Monopoli Solat : Interactive Learning Methods for Prayer Recitations’, 1(November), pp. 53–61.

Mohd Khairi, S. (2018) ‘Keberkesanan Aplikasi Multimedia dalam Pengajaran dan Pembelajaran Ibadah Solat’, *International Journal of Civilizational Studies and human Sciences*, 1(4), pp. 50–60.

Murad, A. and Pyun, J. Y. (2017) ‘Deep recurrent neural networks for human activity recognition’, *Sensors (Switzerland)*, 17(11).

Nagy, J. T. (2018) ‘Evaluation of online video usage and learning satisfaction: An extension of the technology acceptance model’, *International Review of Research in Open and Distance Learning*, 19(1), pp. 160–185.

Nguyen, V. A., Le, T. H. and Nguyen, T. T. (2016) ‘Single Camera Based Fall Detection Using Motion and Human Shape Features’, *Proceedings of the Seventh Symposium on Information and Communication Technology*, pp. 339–344.

Niu, J., Wang, X., Wang, D., & Ran, L. (2020) ‘A Novel Method of Human Joint Prediction in an Occlusion Scene by Using Low-Cost Motion Capture Technique’. *Sensors*, 20(4), pp. 1119.

Ocepek, U., Bosnić, Z., Šerbec, I. N., & Rugelj, J. (2013) ‘Exploring the relation between learning style models and preferred multimedia types’, in *Computers & Education*, 69, pp. 343-355.

Olson, K. E., Brien, M. A. O., Rogers, W. A. and Charness, N. (2011) ‘Diffusion of Technology: Frequency of use for Younger and Older Adults’, *Ageing International*, (March), pp. 123–145.

Patsadu, O., Watanapa, B., Dajpratham, P. and Nukoolkit, C. (2018) 'Fall Motion Detection with Fall Severity Level Estimation by Mining Kinect 3D Data Stream', *International Arab Journal of Information Technology*, 15(3), pp. 378–388.

Pérez, M., Thomaschewski, J., Schrepp, M. and Gonçalves, R. (2014) 'ScienceDirect Efficient Measurement of the User Experience . A Portuguese Version', 27(34), pp. 491–498.

Piyathilaka, L. and Kodagoda, S. (2013) 'Gaussian mixture based HMM for human daily activity recognition using 3D skeleton features', in *Proceedings of the 2013 IEEE 8th Conference on Industrial Electronics and Applications, ICIEA 2013*, pp. 567–572.

Plouffe, G. and Cretu, A. M. (2016) 'Static and dynamic hand gesture recognition in depth data using dynamic time warping', *IEEE Transactions on Instrumentation and Measurement*, 65(2), pp. 305–316.

Pohl, H. and Hadjakos, A. (2010) 'Dance pattern recognition using dynamic time warping', *Proceedings of the 7th Sound and Music Computing Conference, SMC 2010*, p. 24.

Rashid, O., Al-Hamadi, A. and Michaelis, B. (2009) 'A framework for the integration of gesture and posture recognition using HMM and SVM', *Proceedings - 2009 IEEE International Conference on Intelligent Computing and Intelligent Systems, ICIS 2009*, 4, pp. 572–577.

Reza, M. F., Urakami, Y. and Mano, Y. (2002) 'Evaluation of a new physical exercise taken from salat (prayer) as a short-duration and frequent physical activity in the rehabilitation of geriatric and disabled patients', *Annals of Saudi Medicine*, 22(January), pp. 177–180.

Rodrigues, D. G., Grenader, E., Nos, F. da S., Dall'Agnol, M. de S., Hansen, T. E. and Weibel, N. (2013) 'MotionDraw', in *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13*. New York, New York, USA: ACM Press, p. 1197.

Rosmani, A. F., Zainuddin, N. A., Ahmad, S. Z. and Ramli, S. Z. (2015) 'Bio Terapi Solat: 3D Integration in Solat Technique for Therapeutic Means', in *Lecture Notes in Electrical Engineering*, pp. 1001–1011.

Rozan, M. R., Mohd Sidik, M. K., Sunar, M. S. and Omar, A. H. (2015) 'KIHECT©: Reliability of Hand-Eye Coordination among Rugby Players Using Consumer

Depth Camera', in Phon-Amnuaisuk, S. and Au, T. W. (eds) *Advances in Intelligent Systems and Computing*. Cham: Springer International Publishing (Advances in Intelligent Systems and Computing), pp. 201–210.

Rwigema, J., Choi, H. R. and Kim, T. (2019) 'A differential evolution approach to optimize weights of dynamic time warping for multi-sensor based gesture recognition', *Sensors (Switzerland)*, 19(5), pp. 1–16.

Salman, S. M. H. (2010) *Common mistakes regarding prayer*.

Santoso, H. B., Nurrohmah, I., Fadhilah, S. and Goodridge, W. H. (2017) 'Evaluating and Redesigning the Self-Monitoring Tool', 7(1), pp. 228–234.

Saputra, M. R. U., Widyawan, Putra, G. D. and Santosa, I. P. (2012) 'Indoor human tracking application using multiple depth-cameras', *International Conference on Advanced Computer Science and Information Systems*, pp. 3–8.

Satapathy, S. C. and Das, S. (2016) 'Preface', *Smart Innovation, Systems and Technologies*, 50(January), pp. v–vi.

Satta, R., Pala, F., Fumera, G. and Roli, F. (2013) 'Real-time appearance-based person re-identification over multiple Kinect™ cameras', in *VISAPP 2013 - Proceedings of the International Conference on Computer Vision Theory and Applications*, pp. 407–410.

Schrepp, M. (2015) 'User Experience Questionnaire Handbook', pp. 1–11.

Schrepp, M., Hinderks, A. and Thomaschewski, J. (2014) 'Applying the user experience questionnaire (UEQ) in different evaluation scenarios', *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 8517 LNCS(PART 1), pp. 383–392.

Schrepp, M., Hinderks, A., Thomaschewski, J. and Germany, S. A. P. A. G. (2017) 'Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S)', 3, pp. 103–108.

Sedgwick, P. and Greenwood, N. (2015) 'Understanding the hawthorne effect', *BMJ (Online)*, 351(September), pp. 1–3.

Sheu, F. R. and Chen, N. S. (2014) 'Taking a signal: A review of gesture-based computing research in education', *Computers and Education*, 78, pp. 268–277.

Suhaila, N., Suhaily, M. S., Siti Syuhada, A. R., Ahmad A'toa', M. and Azri Rizal, M. R. (2018) 'Pendidikan Awal Solat dalam Kalangan Remaja di Negeri

Selangor', *Proceeding of the 5th International Conference on Management and Muamalah (ICoMM 2018)*, 2018(ICoMM).

Suhid, A. and Abdul Mutalib, L. (2009) 'Tinjauan Terhadap Pelaksanaan Kem Bestari Solat', *Journal of Islamic and Arabic Education*, 1(1), pp. 15–28.

Tan, O.-S. (2011) 'Problem-based learning approach to human computer interaction', *World Academy of Science, Engineering and Technology*, 76, pp. 462–465.

Tzanidou, G. (2014) 'Carried baggage detection and recognition in video surveillance with foreground segmentation'. (Doctoral dissertation, Loughborough University).

Villaroman, N., Rowe, D. and Swan, B. (2011) 'Teaching natural user interaction using OpenNI and the Microsoft Kinect sensor', in *Proceedings of the 2011 conference on Information technology education - SIGITE '11*. New York, New York, USA: ACM Press, p. 227.

Wang, J., Chen, Y., Hao, S., Peng, X. and Hu, L. (2019) 'Deep learning for sensor-based activity recognition: A survey', *Pattern Recognition Letters*, 119, pp. 3–11.

Wu, M. Y., Chen, T. Y., Chen, K. Y. and Fu, L. C. (2016) 'Daily activity recognition using the informative features from skeletal and depth data', *Proceedings - IEEE International Conference on Robotics and Automation*. IEEE, 2016-June, pp. 1628–1633.

Wu, P. F., Huang, M. J. and Chang, N. W. (2013) 'The learning experience of fine art by somatosensory game device', *Proceedings - 2013 5th International Conference on Service Science and Innovation, ICSSI 2013*. IEEE, pp. 108–114.

Wyche, S. P. (2008) 'Investigating Design for Global Techno-Spiritual Practices', *ACM SIGCHI Conf. on Computer Supported Cooperative Work*, pp. 5–6.

Xu, W. and Lee, E. (2012) 'Continuous Gesture Recognition System Using Improved HMM Algorithm Based on 2D and 3D Space', *International Journal of Multimedia and Ubiquitous Engineering*, 7(2), pp. 335–340.

Yamato, J., Ohya, J. and Ishii, K. (1992) 'Recognising Human Actions in Time-sequential Images using HMMs', *Proceedings, Second International Conference on Computer Vision,* pp. 379–385.

Yeung, K., Kwok, T. and Wang, C. C. L. (2013) 'Improved Skeleton Tracking by Duplex Kinects : A Practical Approach for Real-Time Applications', *Journal of Computing and Information Science in Engineering*, 13(14).

Zeeshan, M. (2018) 'Remote activity guidance for the elderly utilizing light projection', *University of Oulu Graduate School; University of Oulu, Faculty of Information Technology and Electrical Engineering; Nara Institute of Science and Technology, Graduate School of Information Science*, (Acta Univ. Oul. A 722,).

Zhang, C. and Tian, Y. (2012) 'RGB-D Camera-based Daily Living Activity Recognition', *Journal of Computer Vision and Image Processing*, 2, p. 12.

Zhang, H., Reardon, C. and Parker, L. E. (2013) 'Real-time multiple human perception with color-depth cameras on a mobile robot', *IEEE Transactions on Cybernetics*, 43(5), pp. 1429–1441.

Zhang, L., Sturm, J., Cremers, D. and Lee, D. (2012) 'Real-time human motion tracking using multiple depth cameras', *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 2389–2395.

Zhang, M. and Sawchuk, A. A. (2013) 'Human daily activity recognition with sparse representation using wearable sensors', *IEEE Journal of Biomedical and Health Informatics*, 17(3), pp. 553–560.

Zhao, W., Feng, H., Lun, R., Espy, D. D. and Reinthal, M. A. (2014) 'A Kinect-based rehabilitation exercise monitoring and guidance system', *Proceedings of the IEEE International Conference on Software Engineering and Service Sciences, ICSESS*. IEEE, pp. 762–765.

Zhu, Y. and Fujimura, K. (2010) 'A Bayesian Framework for Human Body Pose Tracking from Depth Image Sequences', *Sensors*, 10(5), pp. 5280–5293.

Zupanec, V., Miljanovic, T. and Pribicevic, T. (2013) 'Effectiveness of computer-assisted learning in biology teaching in primary schools in Serbia', *Zbornik Instituta za pedagoska istrazivanja*, 45(2), pp. 422–444.

.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Jaafar, N.A.**, Ismail, N.A., & Yusoff, Y.A. (2021). Usability Study of Enhanced Salat Learning Approach using Motion Recognition System. International Arab Journal of Information Technology.
2. **Jaafar, N.A.**, Ismail, N.A., Jasmi, K.A., & Yusoff, Y.A. (2019). Optimal dual cameras setup for motion recognition in salat activity. International Arab Journal of Information Technology, 16, 1082-1089.

Indexed Journal

1. **Jaafar, N.A.**, Ismail, N.A., & Yusoff, Y.A. (2015). An investigation of motion tracking for solat movement with dual sensor approach. ARPN Journal of engineering and applied sciences, 10, 17981-17986.

Indexed Conference Proceedings

1. **Jaafar, N. A.**, Ismail, N. A., & Yusoff, Y. A. (2020). A New Approach in Islamic Learning: Performance Evaluation of Motion Recognition System for Salat Movement. In 2020 21st International Arab Conference on Information Technology (ACIT) (pp. 1-6). IEEE.

(Patent Filing) Patent

1. Motion Recognition and Monitoring system for Salat Movement.
   Filing No: PI 2018701425
   Filing Date: 10-04-2018