UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

AUTOMATED POSTURAL ANGLE CLASSIFICATION USING MICROSOFT KINECT FOR ERGONOMICS ASSESSMENT

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AUTOMATED POSTURAL ANGLE CLASSIFICATION USING MICROSOFT KINECT FOR ERGONOMICS ASSESSMENT

TAREK MHD MOATAZ ALBAWAB

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in Manufacturing Engineering

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DECLARATION

I declare that this thesis entitled "Automated Postural Angle Classification Using Microsoft Kinect for Ergonomics Assessment**"** is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature	:	....
Supervisor Name	:	DR. NADIAH BINTI AHMAD
Date	:	....

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DEDICATION

I would like to present my work to those who did not stop their daily support since I was born, my dear Father, my kindness Mother, and my treasured brothers and sister they never hesitate to provide me all the facilities to push me forward as much as they can. This work is a simple and a humble reply to their much goodness. I would like to take this opportunity to express my gratefulness to my uncle Ghassan and his children who believed in me and supported me at my most difficult time to get my degrees and achieve the best in my career. Last but not least, I would like to express the gratitude to all of my teachers, lecturers, and friends who advised me and gave me the courage to drive my career the perfect way it should be. Thanks to you all, much love.

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ABSTRACT

Musculoskeletal injury is a common cause in manual material handling activities, where workers are exposed to repetitive picking and placing of materials, that therefore may lead to dangerous injuries if incorrect postures are made. It is the duty of factories to take care of the health conditions of their employees, and ensure the workplace is ergonomically designed. However, it is a difficult task to assess the work postures in a large number of employees all the time due to cost, lack of equipment, and lack of experience. The aim of this study is to formulate an ergonomic model to identify and classify body part motion angle ranges for upper limb postural analysis, to develop an automated real-time upper limb postural angle and classification system, and to evaluate the developed postural angle classification system using 30 participants in a lab setting and five ergonomic experts opinions. The chosen experts are individuals with experiences in ergonomics field working as academic researchers, consultancy agents, and industry management positions in Malaysia. Formulating the postural classification model applied the concepts of traffic light to categorise the work postures, where upper limb postures were classified into three classifications with mathematical models to count the number and percentage of each classification occurrence for each posture. The postural classification model was then integrated with a developed C# based software and a Microsoft Kinect sensor using heuristic approaches to do an automated real-time upper limb postural angle classification system. The developed postural classification was validated for 12 static postures, and 4 dynamic postures among 30 participants in a lab setting using Jamar goniometer (Sammons Preston Roylan, USA), a computerised protractor tool in ErgoFellow v3.0, and the statistical analysis used the root mean square error (RMSE). The evaluation was further explored by taking the ergonomic experts' opinions through semi-structured interviews to note the needful, usefulness, applicability, effectiveness, and the details provided for the workplace. The results of validation revealed that the static postures was 7.52 RMSE, dynamic postures was 21.93 RMSE, and combined static and dynamic results was 14.48 RMSE. The study shows better mean RMSE results than Plantard et al. (2017) study by 15.6% in static phase analysis, but larger mean RMSE in dynamic analysis which might be due to the method of capturing the reference angles. The study concluded that despite the acceptable RMSE results presented by the developed system, the software architecture and detection techniques require further improvement and development for better angle measurement accuracy with added parameters for ergonomics assessment.

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ABSTRAK

Gangguan pada otot berangka adalah kecederaan fizikal yang disebabkan oleh aktiviti pengendalian manual seperti mengangkat dan mencapai bahan-bahan dalam keadaan postur kerja yang tidak selamat yang boleh menyebabkan kecederaan merbahaya pada otot. Adalah menjadi tugas majikan untuk menjaga kesihatan pekerja-pekerja mereka, dan memastikan tempat kerja direka secara ergonomik. Walau bagaimanapun, adalah satu tugasan yang mencabar bagi pengamal ergonomik untuk menilai postur kerja apabila melibatkan ramai pekerja di sepanjang masa disebabkan oleh kos, kekurangan peralatan yang sesuai dan kekurangan pengalaman. Objektif kajian ini adalah untuk merangkakan satu model ergonomik untuk mengenal pasti dan mengklasifikasikan julat sudut bahagian atas badan, untuk membangunkan satu sistem penilaian dan klasifikasi postur badan yang automatik dan masa nyata, dan untuk menilai sistem penilaian dan klasifikasi postur badan yang telah dibangunkan melibatkan 30 peserta untuk eksperimen makmal dan lima pakar ergonomik. Pakar terlibat adalah individu yang berpengalaman dalam bidang ergonomik yang berkerja sebagai penyelidik akademik, ajen konsultansi, dan penjawat jawatan pengurusan dalam industri di Malaysia. Kajian ini telah merumuskan model klasifikasi postur menggunakan konsep lampu isyarat yang mengkategorikan postur bahagian atas badan dalam tiga klasifikasi menggunakan model matematik untuk mengira bilangan dan peratusan kejadian untuk setiap postur. Model klasifikasi postural kemudian diintegrasikan dengan perisian berasaskan C # dan penderia Microsoft Kinect menggunakan pendekatan heuristik untuk membangunkan sistem klasifikasi sudut postur bahagian atas otot yang automatik dan masa nyata. Sistem penilaian dan klasifikasi postur badan yang dibangunkan ini telah disahkan berdasarkan 12 postur statik, dan 4 postur dinamik di kalangan 30 peserta eksperimen di dalam makmal menggunakan Jamar goniometer (Sammons Preston Roylan, Amerika Syarikat), alat protektif berkomputer di ErgoFellow v3.0, dan analisis statistik ralat punca min kuasa dua (RMSE). Pengesahan ke atas penilaian dan klasifikasi postur badan ini terus diterokai dengan mengambil kira pendapat ahli ergonomik melalui wawancara separa berstruktur untuk menentukan keperluan, kebolehgunaan, keberkesanan, dan butiran yang diperlukan untuk penilaian ergonomik di tempat kerja. Hasil pengesahan mendedahkan bahawa postur statik adalah 7.52 RMSE, postur dinamik adalah 21.93 RMSE, dan gabungan statik dan dinamik adalah 14.48 RMSE. Kajian menunjukkan hasil RMSE lebih baik daripada kajian Plantard et al. (2017) sebanyak 15.6% dalam analisis fasa statik, tetapi lebih besar RMSE dalam analisis dinamik yang mungkin disebabkan oleh kaedah menangkap sudut rujukan. Kajian ini menyimpulkan bahawa walaupun keputusan RMSE ini berada di tahap boleh diterima, teknik dan kaedah pengesanan yang digunapakai oleh sistem penilaian dan klasifikasi postur badan yang dibangunkan ini memerlukan penyelidikan dan pembangunan yang selanjutnya untuk ketepatan pengukuran sudut yang lebih baik dengan parameter tambahan untuk penilaian ergonomik.

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LIST OF ABBREVIATIONS

A	-	Acceptable postural angle classification
AoM	-	Angle of Motion
CMC	-	Coefficient of Multiple Correlation
CV	-	Coefficient of Variation
CVME	-	Coefficient of Variation of Method Error
DOE	-	Design of Experiment
E	-	Excessive postural angle classification
EF	-	Elbow Flexion
eq.	-	Mathematical Equation
I	-	Investigate postural angle classification
IR	-	Infrared sensor
ICC	-	Intraclass correlation coefficient
IMU	-	Inertial Measurement Unit
j	-	joint or body part motion
K	-	Kinect
LEF	-	Left Elbow Flexion
LOA	-	Limit of Agreement
LUAA	-	Left Upper Arm Abduction
LUAF	-	Left Upper Arm Flexion

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M	-	Moderate postural angle classification
MBS	-	Marker Based System
MIS	-	Minimally Invasive Surgery
MLS	-	Marker-Less System
MoCAP	-	Motion Capturing System
N	-	Neutral postural angle classification
NF	-	Neck Flexion
NLLF	-	Neck Left Lateral Flexion
NRLF	-	Neck Right Lateral Flexion
OLP	-	Ordinary Least Product
REF	-	Right Elbow Flexion
RGB-D	-	RGB camera with Depth sensing
RMSE	-	Root Mean Square Error
ROM	-	Range of Motion
RUAA	-	Right Upper Arm Abduction
RUAF	-	Right Upper Arm Flexion
SOP	-	Standard Operating Procedure
TF	-	Trunk Flexion
TLLF	-	Trunk Left Lateral Flexion
TRLF	-	Trunk Right Lateral Flexion
U	-	Urgent postural angle classification
UAF	-	Upper Arm Flexion
UI	-	User Interface
WMSD	-	Work related Musculoskeletal Disorder

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LIST OF PUBLICATIONS

JOURNAL:

1. Albawab, T. M. M., Halim, I., Ahmad, N., Umar, R.Z.R., Mohamed, M.S.S., Abdullais, F., Basari, A.S.H., Bakar, M., Saptari, A., 2019, 'Upper Limb Joints and Motions Sampling System Using Kinect Camera', *Journal of Advanced Manufacturing Technology*, 12(2), pp. 147–158.

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CHAPTER 1

INTRODUCTION

1.1 Background

Work-related musculoskeletal disorders (WMSDs) are common injuries in a workplace environment which affect the various anatomical sites of the human body including muscles, joints, and nerves. As stated in the annual report of 2017 in Health and Safety Executive (HSE) in the UK, a total of 45% of disorders are from upper limbs or neck, followed by 38% from backs, and 17% from lower limbs' joints. Awkward postures are one of the risk factors that mostly cause WMSDs. It is highlighted that manual materials handling, repetitive motion in awkward or strenuous postures are the main causes of these disorders (UK Department of Health and Safety Executive, 2017). Marcum et al. (2017) reported the WMSDs from the year 1999 to 2013 in different sectors of the industry, and it is found that overexertion due to manual handling and poor postures are the most prevalent causes of these WMSDs. Lifting, pulling and repetitive works were the highest proportion of the overall overexertion reported. Wang et al. (2016) did a review on WMSDs among workers in construction sites in the US from the year 1992 to 2014, and it is noted that the US managed to reduce the WMSDs by 60% in 2014 as compared to the past historical data, and the most musculoskeletal injuries were due to overexertion, poor postures, and repetitive motions.

Wilson et al. (2000) stated ergonomics is the only science that ensures the technology and workplace are suited for human performance. The paper further

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emphasised the importance of ergonomics science in our daily life and defined how ergonomics would enhance the quality of work and human development.

From the point of human care and development, various assessment models and tools have been developed to assess the exposure of workers to injury risks with the goal of preventing WMSDs. And perhaps one of the very first assessment tools that are made as a measure for human development at work is the work done by Karhu et al. (1977) with his paper “Correcting working postures in industry: A practical method for analysis”. The paper introduced a practical reference for future assessments called the Ovako Working Posture Analysing System (OWAS).

Karhu et al. (1977) made the assessment to be as an observational method to evaluate the human postural working performance in industry and set the measures to know which and what to redesign and enhance in the workplace. This tool was the inspiration for future assessment tools, and one of it was the work done by Mcatamney et al. (1993) in his assessment tool called Rapid Upper Limb Assessment (RULA).

RULA is designed to assess the human upper limb postures by making two categorisations “A” and “B” for postural angles, postural support, muscle use, and force or load exertion. The two categorisations “A” and “B” seperate arm and wrist from the neck, trunk, and leg analysis. And the final results of both category assessment are tabulated in “C” category, and combined to make an abstracted decision for the whole work done in four categorial scoring as: “acceptable”, “further investigation and change may be needed”, “further investigation and change soon”, and “investigate and implement change”. With the clarity that the assessment gave, it became so popular in the 21st century, and many trials were made to implement this assessment with computerised methods. However, the identification of postural movement is very challenging, since human posture is very dynamic with high movement degrees of freedom, and various body types and topologies.

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Moreover, the traditional practices usually only consider the worst case postural scenario in the ergonomics assessment, in which it reduces the quality of ergonomics effectiveness in industry.

There have been efforts to do detection of human postural motions using computerised methods to facilitate the analysis of human postures and get as much information as possible on the effect of workplace design on human postures, despite the observation challenges such as occlusion and environmental effects on electronics (Karhu et al., 1977; Mcatamney et al., 1993; Lehrmann et al., 2014; Mohamed, 2015). The interest of studying human postural motions appeared since ages, and perhaps it starts to be a highly researched topic when the power of computers started to exist in human life. Since the late 1970s, researchers have set their lives to find optimised ways to study the human motions in a real-time using computerised methods (Mohamed, 2015; Elmadany et al., 2018; Negin et al., 2018). Cristani et al. (2013) discussed the aspects of the analysis of human activity for computer vision based systems. Aspects can be concluded as physical, poses and postures, and environmental characteristics. Designing an automated real-time postural analysis system contributes to agile decision making for workplace assessment to reduce the human risk factors, and it provides a better electronic documentation of each individual to monitor performances over time (Wilson, 2000; Mohamed, 2015).

In 2010, a new, innovative, and cost-effective technology came into sight, with its ability to do high-speed human motion analysis. This technology combines the power of depth sensing with the two-dimensional RGB cameras to create a three-dimensional spatial analysis of the scenes. This RGB-D camera is called Kinect. And since its release, researchers showed a significant interest to use it for solving the dream of a real-time human motion analysis (Han et al., 2013; Shotton et al., 2013). Kinect provides a simplified tool to enable a software developer to track the skeletal motions related to its

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joints (Cruz et al., 2012). According to author's reviews of various usage of Kinect with ergonomics assessments, it is found that papers experimented on ergonomics assessment tools with Kinect were: Rapid Upper Limb Assessment (RULA), Ovako Workplace Assessment (OWAS), and Rapid Entire Body Assessment (REBA).

The focus of this research is to provide a software design model to study the kinematics of human motion in industry. This research then apply the ergonomics assessment principles to evaluate the postural movement of workers in the industry for the purpose of determining the risk level exposed in the workplace. The study evaluates the upper limb postural analysis, by categorising sets of angle ranges for the upper limb on the basis of earlier published research studies, especially the researches done by Bao et al. (2009) and Juul-Kristesen et al. (1997). In order to study the human postural movement, first, it is important to set the definition of body part motions in relation to body joints for this software development. Providing an abstracted definition of body part motions relation will enable a better understanding of the human postural motion and better integration and implementation with other assessment tools. The scope of this study is more to action recognition and analysis for ergonomics science.

1.2 Problem statement

WMSDs are still presenting a significant negative effect on industries and countries Marcum et al. (2017). The negative effects as reported by the latest UK's HSE for 2017/18 show that 14.9 billion euros were wasted for work-related injuries, 0.5 million people suffer from WMSDs, and 31.2 million days were wasted due to working days lost (UK Department of Health and Safety Executive, 2018). Making the working environment fit the human body needs changes in system designs and approaches, together with

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developing profession and discipline. System designs and approaches should not only be based on financial costs, but also on how to boost the safety and health of the human body in the workplace. Giving the care on human development in the industry will contribute to a better image of companies, and boost the performance and productivity (Dul et al., 2012).

Despite the movement towards Industry 4.0 that emphasises automation, the human workers existence is still vital as most mass production industries are assembly work-based, and in this, the human is still more capable than any machine (Hecklau et al., 2016; Pfeiffer, 2016). Ergonomics has to be at the center of any design or development involving human, and it is the role of ergonomics scientists to provide a tool that will empower the use of the ergonomics science in the industry. Finding solutions to empower ergonomists to do assessments in a more feasible and economical way is needed.

Ergonomists encounter challenges in assessing the workplace design and workers' performance. The challenges include not being able to make detailed reports of the whole work duration, all population in the industry, and the full working postures with all of its dimensions. Current assessments tend to make use of only a sample of working time and worker population which only gives abstracted knowledge of the scenes, while depending on observational methods for making decisions. These abstracted observational methods lacks of detailed reports on what body part motions are most affected, as the current assessments tend to make the ergonomics decision based on many parameters specified by the ergonomics assessment tool. Moreover, the tools used are tedious and time-consuming, as they are done manually with a specified time and workers' population in the industry (Kilbom, 1994; Bao et al., 2009; Takala et al., 2010; Abd Rahman, 2011).

Therefore, there is a need for a tool that allows for a more comprehensive analysis of postures and can present the distribution of postural dynamics throughout the work duration. There is a research gap of having a computerised system that is able to be used

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