BIOMECHANICAL EVALUATION OF SPINAL LOADINGS DURING OIL-PALM PLANTATION TASKS

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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DEDICATION

This FYP thesis is dedicated to my parents

I am certainly proud of my accomplishments in life, but not as proud as I am to be your son. Thanks for always supporting me in everything I choose to do.

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ACKNOWLEDGEMENT

All praises are to Allah, the Most Gracious and the Most Merciful

I am using this opportunity to express my deepest gratitude to my supportive supervisor Dr. Mohamad Ikhwan Zaini bin Ridzwan who, despite being extraordinarily busy with his duties, still took time out to give constant support and guidance. The successful completion of this research would be far from possible without his continuous encouragement.

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LIST OF ABBREVIATIONS

FFB/FFBs	Fresh Fruit Bunch/Bunches
3DSSPP	3-Dimension Static Strength Prediction Software
WMSDs	Work-related Musculoskeletal Disorders
IMU	Inertial Motion Unit
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment
OWAS	Ovako Working posture Assessment System
DOSM	Department of Statistics Malaysia
GDP	Gross Domestic Product
USM	Universiti Sains Malaysia
NIOSH	National Institute of Occupational Safety and Health
6DOF	Six axis Degree of Freedom
DAQ	Data Acquisition
SCU	Signal Conditioning Unit
DHM	Digital Human Modelling

LIST OF APPENDICES

BIOMECHANICAL EVALUATION OF SPINAL LOADINGS DURING OIL-PALM PLANTATION TASKS

ABSTRAK

Walaupun kesan gangguan *muskuloskeletal* berkaitan kerja (WMSD) melibatkan penuaian kelapa sawit telah didokumenkan dengan baik, kajian biomekanikalnya yang memfokuskan pada daya dihasilkan pada tulang belakang kurang difahami. Oleh itu, kajian ini bertujuan untuk membandingkan postur kerja dan beban tulang belakang L5-S1 semasa tugas utama perladangan kelapa sawit. Sepuluh individu telah didaftarkan dalam kajian ini dan diminta untuk melakukan tiga tugas utama. Kinematik seluruh badan telah dirakam menggunakan sensor Unit Gerakan Inersia (UGI)(IMU) berkomputer canggih untuk menghasilkan avatar digital dan sistem pemarkahan REBA automatik. Daya tindak balas diperoleh menggunakan plat daya, dan daya tangan akan diukur menggunakan sel beban yang dipasang pada alat pemotong. Dengan data tersebut, penilaian biomekanikal akan dilakukan untuk meramal daya mampatan tulang belakang dan beban ricih pada L5-S1 menggunakan perisian *3D Static Strength Prediction Programme* (3DSSPP). Mengangkat menggunakan besi pencucuk boleh mengurangkan daya mampatan pada L5-S1, selain menunjukkan bahawa ketinggian angkatan mempengaruhi daya mampatan dan ricih tetapi tidak mempunyai perbezaan yang ketara dalam skor REBA. Tugasan mencantas pelepah menggunakan sabit atau pahat kedua-duanya mencatatkan skor REBA puncak tertinggi iaitu 12. Kedua-dua sabit intervensi dan konvensional menghasilkan ricih melebihi had yang dibenarkan NIOSH.

BIOMECHANICAL EVALUATION OF SPINAL LOADINGS DURING OIL-PALM PLANTATION TASKS

ABSTRACT

While the immediate adverse effects of work-related musculoskeletal disorders (WMSDs) related to oil palm harvesting have been well documented, its biomechanical study focusing on lumbar spinal forces is poorly understood. This study therefore aimed at comparing work postures and L5-S1 spinal loads during main oil-palm plantation tasks. Ten healthy, pain-free individuals were enrolled in this study and asked to complete three main tasks: 1) FFB loading using manual hand lifting and loading spike, 2) Fronds pruning using a chisel and 3) Fronds pruning using conventional and intervention sickle. The whole-body kinematics were recorded using a cutting-edge computerised Inertial Motion Unit (IMU) sensor to drive a digital motion captured avatar and automatic REBA scoring system. The ground reaction force will be acquired using a force plate, and the hand force will be measured using a load cell that attached to the cutting tools. With that data, a biomechanical evaluation will be done to predict the spinal compression forces and shear load at L5-S1 using 3D Static Strength Prediction Program (3DSSPP) software. Lifting using a loading spike could reduce the compression force on L5-S1, and it also shows that the lifting height does affect the compression and shear but has no significant difference in the REBA score. The fronds pruning tasks using sickle or chisel both recorded the highest peak REBA score of 12 (very high level). Both intervention and conventional sickle produce shear above the NIOSH allowable limit.

CHAPTER 1

INTRODUCTION

1.1 Background Study

The oil palm industry is an important agricultural commodity that has become the backbone of Malaysia's economy. In 2021, Malaysia's oil palm estates had an average FFB of 15.47 tonnes/hectare, whereas Selangor yielded 19.20 tonnes/hectare alone [1]. This industry, as reported by the Department of Statistics Malaysia (DOSM), majorly contributed 37.7% to the Gross Domestic Product (GDP) through the agriculture sector in 2020 [2]. The same report also stated that the production of fresh fruit bunches (FFBs) increased by 64.6 thousand tonnes (0.7 per cent) compared to the previous year. Even during the pandemic, Malaysia still maintained the highest FFBs production, accounting for 39 per cent and 44 per cent of the world's palm oil production and exports, respectively[3]. Besides, Malaysian palm oil, listed among the world's largest producers, contributed 11 per cent of the world's edible oil and fat production with 27 per cent of export trade score.

Even with all these facts, oil palm workers still perform various manual energy-intensive activities with different work postures to carry out field operations. In the pruning process, the worker must first cut the layer of crown-canopy arrangement palm fronds, followed by the harvesting process, which is harvesting FFB, pruning fronds, loading FFBs, and collecting loose fruits (LFs). Pruning and harvesting tasks in the oil palm industry commonly use the same cutting tools, the chisel and sickle, with the same technique. Chisel (Figure 1-2 (a)) is usually used for the tree with a height lower than 3m since it uses the pushing-momentum-cutting technique as in Figure 1-1(b). This approach required the worker to thrust the chisel with sufficient energy to cut off the frond. For sickle (Figure 1-2 (b)) is attached to a long pole and used on a tree with a challenging height to reach by chisel. The harvester must be tough enough to lift the pole since the length of the pole itself may be up to 20m depending on the tree's height. During this harvesting operation, the method applied is positioning the sickle above the frond and then driving it down with forceful exertion, which is very challenging. Pruning must be done before harvesting since that frond layer will restrict the cutting tool from reaching the FFB.

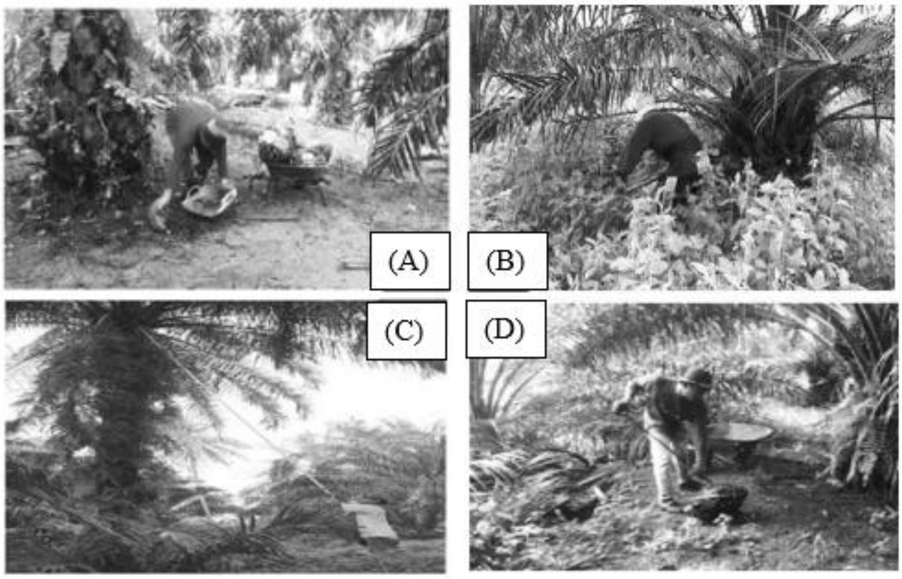


Figure 1-1 (a) Collecting loose fruits (LFs), (b) Canopy arrangement of oil palm trees affecting pruning posture using a chisel, (c) Pruning/harvesting task using a sickle pole with head tilted upward and both hands above the shoulder, (d) lifting FFB using loading spike into a wheelbarrow. Photo from [4]

(a) (b)

Figure 1-2 (a) Chisel with sharp end, (b) Conventional sickle that attached to a long pole

After pruning and harvesting, the worker collects the FFBs using a sharp metal spike (Figure 3-1) called the loading spike that will be used to strike the FFB, lift it using a technique and throw it up into the wheelbarrow or the lorry. The weight of the FFBs ranges from 20 kg to 40 kg [4]–[6]. All of this involves heavy lifting tasks, pushing and pulling, with awkward postures, which exposes many types of work-related musculoskeletal disorders (WMSDs) and injuries [7].

Several intervention devices have been developed, such as Cantas Evo by Malaysian Palm Oil Board (MPOB). However, this technology adoption implementation was not all successful [8]. There is currently a low level of acceptance and limited application of harvesting technology. Frequency breakdown, heavy machine, and high vibration are among the feedback from the harvester [9]. Even though this kind of intervention statistically increases harvesting productivity, the harvester could not handle the machine for a prolonged time as they need to stop from time to time during operation to rest and maintain. The high vibration occurs, leading to hand-arm vibration syndrome (HAVS). Besides, the machinery could not deal with the unstructured, uncertain and varying environment, such as the geographical landscape, of the oil palm plantation, making the harvester prefer the conventional method more. Therefore, the technology should be integrated with ergonomic elements that focus on design and more on ergonomic features.

1.2 Problem Statement

The oil palm industry is one of the most significant resources contributing to Malaysia's economy [2], [3]. Besides this fact, this industry still relies heavily on manual labour for the tasks such as FFBs harvesting, collecting and frond trimming. Those processes involve workers performing various types of repetitive physical work in most extreme and awkward body positions, exposing them to different kinds of work-related musculoskeletal disorders (WMSDs) [7]. Previous studies [10]– [16] have found that most oil palm plantation workers experienced excessive pain in both the lower and upper back. This area involves spinal load, which induces vertebral stress and causes various back disorders. However, none of the studies quantifies how much force is exerted on the lumbar spine during related tasks. This research will fill the gap by predicting the compression and shear forces exerted on L5-S1 during collecting FFBs and harvesting or pruning. This finding is crucial to supporting healthcare professionals in implementing more effective preventative injury measures and promoting a safer workplace. Given the significance of the contribution of this field to economic growth, it is vital to research a way to facilitate and improve the harvesting process of oil palm. For that, a postural study to evaluate their working posture must be carried out. However, several articles [6], [14], [17], [18] have already measured and analysed some related working postures. However, their methodology approach is traditionally based on a survey, camera-based and manual visual observation, limiting the data that could be obtained for total utilisation. In this study, cutting-edge technology will be used to fill in the research gap. The working posture when loading the FFBs into the different heights and when pruning fronds at different heights will be evaluated by utilising full 6 Degree of freedom (6DOF) computerised IMU-based motion capture. The data will be used to generate the ergonomic risk using the REBA scoring method. The ground reaction force will be acquired using a force plate, and the hand force will be measured using a load cell that attached to the cutting tools. With that data, a biomechanical evaluation will be done to predict the spinal compression forces and shear load at L5-S1 using 3DSPSS software. The findings emphasise the data and insight that are beneficial to provide reference material for ergonomic interventions in improving the working condition and MSDs risk in the oil palm industry.

1.3 Research Objective

The objectives of this study are to:

1. Evaluate work postures during FFB loading using manual hand lifting compared with a loading spike.
2. Evaluate and compare work postures during pruning using chisel and sickle: conventional and intervention type.
3. Estimate spinal compression and shear loads on L5/S1 for all tasks using 3DSSPP software.

1.4 Scope of Research

Whilst the immediate adverse effects of WMSDs related to oil palm harvesting have been well documented, its biomechanical study focusing on spinal forces is poorly understood. This study uses the ergonomic REBA scoring to evaluate work posture and predicts L5/S1 compression and shear forces during FFBs collecting and harvesting/pruning tasks. By combining the pilot study from last year, the scope of this study involves ten subjects between the ages of 22 and 43 among the Universiti Sains Malaysia (USM) Engineering Campus's students and staff. This recruitment period will last for a maximum of 2 semesters (1 year) and end when either ten subjects have been recruited or one year has passed. Each subject will be asked to sign the consent form before participating in this study. Out of 10, only two subjects have experience in this area. The whole-body posture evaluation will be discussed using the REBA method. Other well-known ergonomic assessment tools such as Rapid Upper Body Assessment (RULA) or Ovako Working posture Assessment System (OWAS) are not within the scope of research. The ground reaction force and the hand load also will be measured using a force plate and load cell, respectively. The joint angle data will be taken using an Xsens motion tracker attached to the subject's body. The data collected will be synced to predict the L5-S1 compression and shear load using 3DSSPP software.

Two series of experiments were held on the USM engineering campus. One in the USM Vibration lab to study the effect of lifting the FFBs into different heights, and another in the USM School of Chemical engineering's compound to study the effect of harvesting/pruning using different cutting tools at different heights. The framework of this study starts with participant selection, cutting tools, and field preparation. It continues with the wearable motion capture sensor, force plate and load cell setup and calibration. The data collected was the subject's anthropometry, ground reaction force (GRF), hand force and entire body's joint angle. After the post-experiment data processing, those data will be used to predict the L5-S1 compression and shear load using 3DSSPP software.

1.5 Thesis Organization

This thesis comprises five chapters: introduction, literature review, methodology, results & discussions, and conclusion with future works recommendations. Chapter 1 starts with a brief description of palm harvesting, the WMSDs in palm harvesting, and the limitations of the current literature and methods in determining them. The objectives and the scopes of this research are then highlighted. This chapter ends with the significance of the study. Chapter 2 discusses ideas, facts, flow, and information about this study. This chapter consists of five subsections: Risks of work-related musculoskeletal disorder (WMSDs), postural analysis, ergonomic assessment tools and biomechanical evaluation. In each subsection, the facts and findings from previous studies are discussed. Chapter 3 explains in detail the methodology applied in this study. The first subsection highlights participants' inclusion criteria, anthropology, and basic information. Within the field setup, the arrangement of equipment and the preparation of cutting tools is explained. Brief explanations are presented regarding the placement, setup, and calibration of the Xsens motion capture, force plate, and load cell.

The data analysis subsection discusses the approaches to analysing the data from all trials to meet the study's objectives and the signal processing for all sensors. Finally, the statistical analysis consists of descriptive and inferential analysis are described. Chapter 4 presents and discusses the results related to the study's objectives. The result for the REBA score is reported at the beginning of this chapter. The chapter continues by analysing the L5-S1 compression and shear for each task. This chapter ends with a discussion on the effect of trunk flexion angle during lifting and load effects. Chapter 5 presents the conclusion of the findings. The chapter ends with some suggestions and strategies for future research to improve the quality of the proposed technique.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews and compares articles that related to this study's methodology with existing literature in the oil palm plantation industry. The main contents of the chapter are about the work-related musculoskeletal disorder (WMSD), postural analysis, ergonomic assessment tool and biomechanical spinal load, especially in the L5-S1 spinal cord. The chapter ends with a summary of the reviewed literature.

2.2 Risks of work-related musculoskeletal disorder (WMSDs) among oil palm workers.

The effects of work-related musculoskeletal disorder (WMSD) on body posture have been vastly studied in recent years. Multiple industries have been deliberate such as among computer-intensive office workers [19], manufacturing industry workers [20] and agriculture workers [21]. Taking agriculture workers, which consist of rice farmers, vegetable growers and greenhouse workers, as an example, which is closely related to this study's theme, show prevalence of musculoskeletal symptoms and risk factors highest at low back (75.1%), knees (62.1%), and upper back (61.55%) [21].

In the palm oil industry, studies from Malaysia reported that the oil palm harvesting workers have an extraordinarily high 12-month prevalence of MSDs ranging from 86 to 99 per cent [10]– [12]. The high prevalence of MSD indicates the association with a hazardous task in the past. It also revealed that the oil palm harvesting worker had suffered unpleasant MSDs over the past week [10]. A study of 25 oil palm workers shows that the working posture of 61% of them is at high-risk level and 39%t very high-risk level [22]. A result from the modified Nordic musculoskeletal questionnaire (NMQ) revealed that the workers experienced frequent pain in the shoulder, with a maximum prevalence of 60%, followed by upper back, 52% and neck, 48%. Two studies with larger respondent [11][23], using the same type of survey among 70 - 88 oil palm workers, shows that 87.1 - 99% of them have the highest pain level in the lower back, followed by at upper back (85 - 94.3%). This is also supported by recent studies in Thailand that reported the same trend where lower back pain has the highest prevalence, followed by shoulder and neck [15], [16]. Even with all these support studies as evidence, to date, still, none of the literature focuses on quantifying the load exerted at the worker’s spinal loading.

2.3 Postural analysis

Most papers discussing oil palm-related activities use on-site observation, face-to-face interviews, and video recording methods to measure the posture and joint angle. The on-site observation method consists of several researchers observing the real-time worker’s posture and trying to evaluate the possible MSD associated with activity, as has been done by [17] and [11]. This kind of study usually comes together with modified NMQ and face-to-face interviews to gain feedback to support the conclusion. For picture or video recording based, manually sketching the line on the subject's body photo or, with the help of software to retrieve the postural angle as in Figure 2-1 was the method done by [6], [17] and [14]. Problems with this method are regarding the angle measurement's accuracy since it is based only on one side view where the camera angle was taken. Also, it is very troublesome to do it one by one for many work postures or subjects.

(a) (b)

(c)

Figure 2-1 (a) Sketched line on subject's body to measure the joint angle [6], (b) Measuring trunk flexion using Ergo Fellow 2.0 software[14], (c) The lumbar flexion angles were visually estimated using an electronic protractor[24]

To evaluate manual tasks in real-time, an innovative ergonomic assessment system must be implemented to suit the industrial environment. One of the solutions is to implement a wearable inertial measurement unit (IMU) in this kind of study to retrieve more reliable data. IMU accurately record the angular velocity and linear acceleration of the body segments to which they are attached, allowing them to estimate joint angles and body posture in real-time. Its ability to collect data wirelessly and in a compact device would be an advantage to the new methodology implemented in this study. This called direct measurement method has been widely implemented in most recent ergonomics studies such as in dentistry [25], office workers [26] and rehabilitation [27]. Every example stated here uses IMU sensors from Xsens Technologies (Enschede, The Netherlands). They all provided good feedback regarding the validity and reliability of this product's body segment position and joint angles measurement. The data from Xsens IMU could be interpreted into a 3D modelling avatar using Xsens MVN software to fully access 360-degree views from any direction and angles.

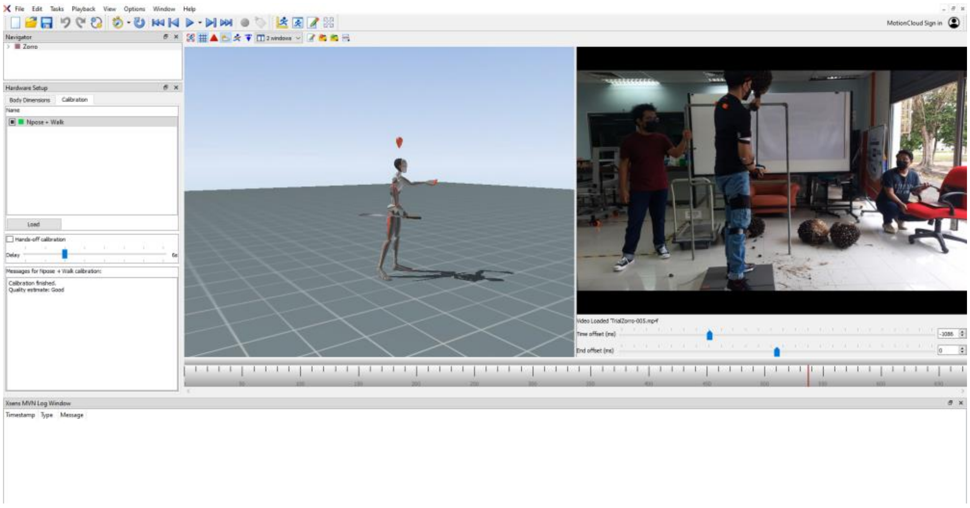


Figure 2-2 Xsens MVN motion tracker system’s interface for 3D real-time human motion measurement

By record, only [28] and [29] have applied IMU sensors to measure joint motion during FFB harvesting and loose fruit (LF) collecting. However, both papers did not discuss about FFB loading activity. The limitation is that both papers only measure the upper body part for the harvesting task, not for all-body posture. It is limited to (L&R), elbow (L&R) and back joint. For LF collecting, only the lower body segment, which is the back, hip (L&R) and knee (L&R), were measured. This fails to relate to the overall working posture; hence no proper ergonomic assessment tool such as REBA can be or has been discussed based on the interpreted data.

IMUs sensors from Xsens Technologies, The Netherlands, called Xsens Motion Tracker Awinda (MTw), has proven validity and repeatability [25]– [27], [30]– [32]. Two comparison studies between Xsens and optoelectronic systems for whole body motion revealed that Xsens has a high level of accuracy in producing a reliable and consistent result when assisting the kinematic measurement of human motion in a real-world working environment [33], [34]. A study compared Xsens and another commercial IMU, Noraxon MyoMOTION Research Pro shows no significant difference between these two brands, and both demonstrated acceptable concurrent validity for the tasks assessed [35]. As a result, an accurate entire body parts motion posture measurement could be developed to provide high-resolution joint angle measurements required to calculate the effective REBA score [32].

2.4 Ergonomic assessment tools

Many observational approaches have been developed to identify risk factors for musculoskeletal diseases (MSDs). Still, the most significant technique cited in most related literature is RULA, REBA and OWAS [36]. Joshi and Deshpande [37] comparing 39 ergonomic studies, revealed that, among 18 observational methods, the most frequently compared technique was REBA (69%), followed by the RULA (64%), Strain Index (36%), and OWAS (33%). Despite that, minimal studies related to oil palm plantation implementing either of these three methods [7]. Most of the studies are questionnaires and surveys based, which are traditional types of measurement.

In the oil palm industry, only [12] is using the OWAS method, stating that posture while lifting the FFBs needs immediate corrective action. The most recent paper

[21] uses the RULA method, which revealed a mean RULA grand score of 6.7 out of a maximum of 7.0 during chisel pruning activity. This finding correlates with the oldest papers back in 2014 [38] which also stated scored 7 out of 7 for the same task.

For REBA, the most recent study in 2019 [6] shows that posture during FFBs lifting using loading spike into lorries (3m to 5m) has the highest score at 11, which falls under the level of 'very high' categories as a reference to the Table 2-1 below.

Table 2-1 REBA score and associate risk action

REBA Score	Risk level	Action
1	Negligible	No necessary
2-3	Low	May be necessary
4-7	Medium	Necessary
8-10	High	Necessary soon
11-15	Very High	Necessary now

Even though it is the most recent study, they still use the manual REBA scoring sheet method, where the postural data was manually estimated based on observation and video recording. The same methodology was used in 2016 [22]. The paper reported that lifting using a loading spike into the wheelbarrow also led to a REBA Score of 11. In 2013 [18], one literature reported that posture while lifting the FFB manually by hand into the wheelbarrow had a REBA score of 10. The same literature stated that posture during harvesting/pruning using a chisel and sickle could be as high as 13.

However, in 2016, another paper had implemented Ergo Fellow 2.0 software to retrieve the joint angle data [14]. It is the most modern REBA evaluation method ever used in related literature. Their finding reported that lifting FFB using a loading spike into the lorry scored higher at 12. However, this software measures the angle base on a photo taken during observation, so the data retrieved only could be evaluated in a 2D perspective. The user is also required to draw the reference line manually based on the subject's photo, as shown in Figure 2-1. This method will require lots of time to evaluate multiple postures, especially for different subjects. A more accessible and more reliable method to retrieve the data could be implemented by utilising the IMU technology, as explained in Section 2.3.

To fill in the research gap, an auomatic REBA scoring method based on IMU data will be implemented using Xsens Postural Assessment V1.1.1, which can automatically calculate the REBA score for 60 frames per second based on data generated from Xsens MTw IMU. As a result, multiple postures with different subjects could be studied to produce reliable and insightful data.

2.5 Digital human modelling (DHM) and biomechanical evaluation

The digital human modelling (DHM) technique provides an efficient solution to simulate ergonomic issues in the workplace. Musculoskeletal workload could be evaluated by integrating biomechanical models with the DHM system. Plenty of related software available could render realistic avatars to visualize work tasks. A comparison study [39] has compared several commercially available software tools for ergonomics and biomechanics study summarised in Figure 2-3.

In oil palm plantation research, only two papers have utilised 3D biomechanical modelling for postures observation and spinal evaluation. Syah et al. (2014) [38] create a 3D modelling using CATIA software to integrate the anthropometric measurement to produce a RULA result of the postural analysis. The first study that created an upper extremity musculoskeletal model of the oil palm harvesting motion was done by [29] using OpenSim software to provide information about the dynamics of the joints and muscles. However, none of the study simulated the force exerted on the spinal loading.

Software Features and Costs	MotionView	ProAnalyst Professional	MaxTRAQ 2D	Visual3D Professional	MaxPRO	SIMM	ProAnalyst 3-D Professional	3DSSPP	Jack	Ergowatch	AnyBody
2D Analysis	X	X	X	X	X	X	X	X	X	X	X
3D Analysis				X	X	X	X	X	X		X
Camera Required	X	X	X		X	X	X		OPT		OPT
Allows Import of video files			X		X						
Multiple Cameras				X	X	X	X		OPT		OPT
High Speed or High Resolution Cameras		X		X		X	X		OPT		OPT
Calibration Equipment				X	X	X	X		OPT		OPT
Limited to	X										
Existing MoCap Required				X		X			OPT		OPT
Muscle Data						X					X
System Cost	$1180	$9595	$695	$15995	$4995	N/A	$14995	$1495	$2400	$1500	N/A

Figure 2-3 Comparison between several software tools for occupational biomechanics and ergonomic study [39]

From Table 2.3, the University of Michigan 3-dimensional static strength prediction program (3DSSPP) software is among the most user-friendly digital biomechanical modelling software available. The occupational biomechanical and mathematical model of 3DSSPP has been previously discussed in the literature [40], [41]. This computerized biomechanical model predicts spinal compressive force at the L5-S1 spinal disk for a static working posture in three dimensions using anthropometry, hand load, and posture angle data. Many kinds of literature have applied this software to evaluate spinal compression and shear, such as for airline baggage handling [42], manual waste collectors[24] and among health care workers in hospitals [43], [44].

2.6 L5-S1 spinal intervertebral disk

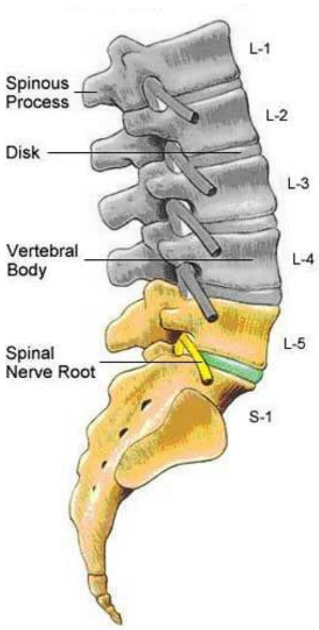


Figure 2-4 Location of L5-S1 on spinal disk

The L5-S1, which is located at the base of the vertebral column, is frequently under severe biomechanical stress, which increases the loads and the risk of injury. Common problems include Slipped disc, facet joint pain, spondylolysis, and spondylolisthesis[45]. The spine's tolerance to anterior shear loads is far lower than the spine's tolerance to compression before tissue damage occurs. Cadaver studies have revealed that the ultimate shear strength of a complete lumbar spine motion segment is around 2,000 N [46], while the maximum compressive strength can be greater than 10,000 N [47]. The spine's natural characteristic is that the compression forces are substantially more extensive than the shear forces when performing lifting activity[48],

[49]. To prevent low-back disorders, NIOSH recommends L5/S1 disc compression force should not exceed 3400 Newtons (N) during any single job activity[50]. Based one study that analyses and comparing data on USS of human lumbar spines, it appears that shear loads of 1000 N would be acceptable for 90% of the working age population for infrequent loading (≤ 100 loadings/day), while shear loads of 700 N would be tolerable for up to 1000 loadings/day [51].

2.7 Chapter summary

Based on the review on MSDs, several industries are associated with the occurrence of MSDs, especially in the agriculture sector. In the oil palm industry, while the world is modernizing, they are still implementing traditional ergonomic assessment tools and questionnaires to identify the risk variables related to MSDs. Most literature reported that the lower back, neck, and shoulder are the most frequent fatigue. Besides, no literature discusses forces exerted on spinal loading. Because of that, observational techniques must be further assessed using robust technology for direct measurement. Wearable motion capture is the perfect method to capture human kinematic data in real-time. Several methods for human modelling and biomechanical evaluation have been stated with 3DSSPP was selected for this study. L5-S1 characteristic also have been discussed including the NIOSH compression and shear limit on those disks.

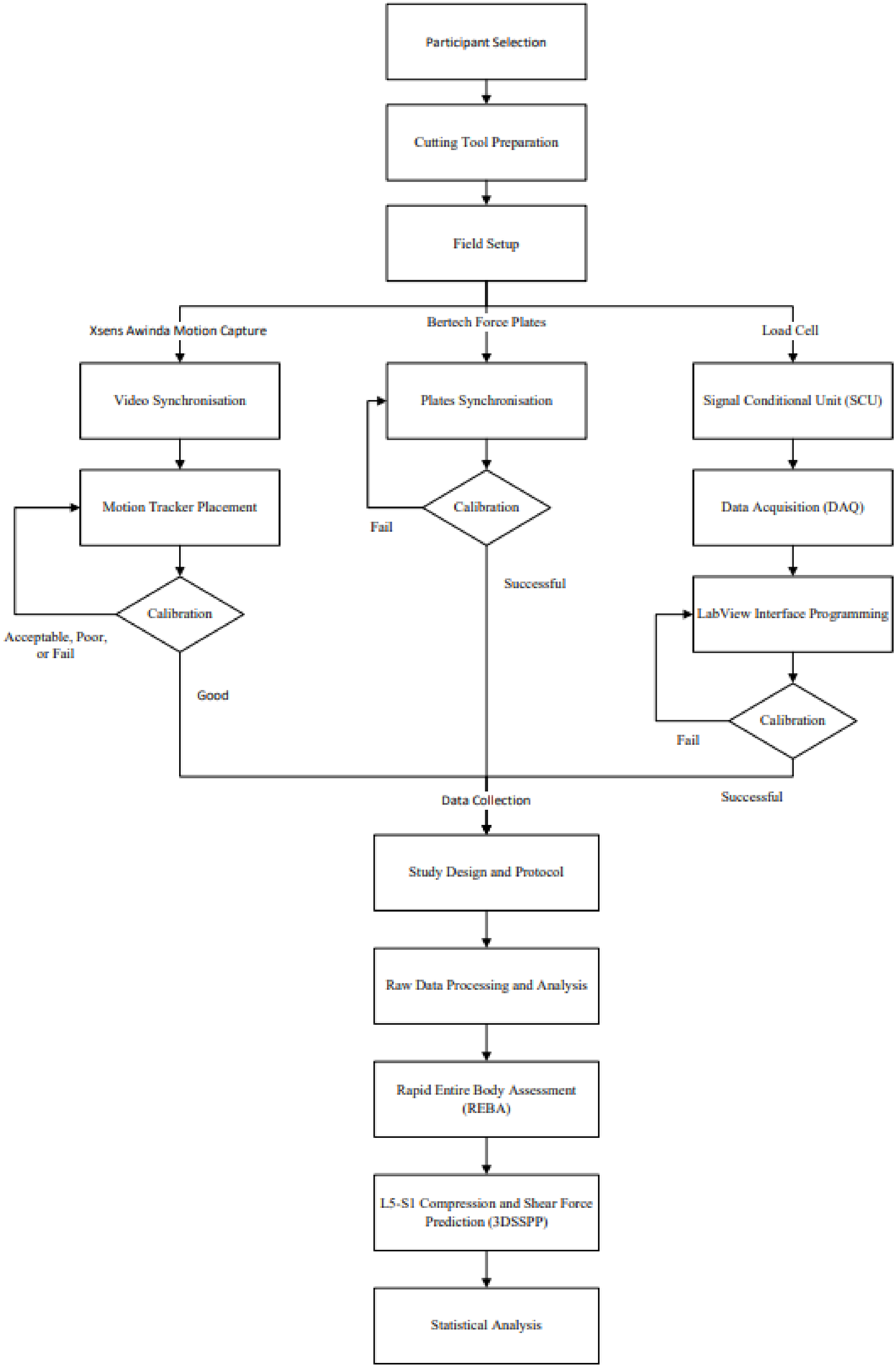
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter details the experiment's study flow and explanation of the whole study setup and protocol. This involving field layout synchronization, including all hardware setup, sensor calibration and software used throughout the study. The hardwares sensor used are wireless Xsens wearable motion trackers, force plates and load cells. The tools including FFBs, loading spike, chisel, intervention sickle and conventional sickle. The software includes Xsens MVN, Xsens Postural Assessment, 3DSSPP, Sigmaplot 14 and Microsoft Excel. The experimental setup and the methodology for each task are clarified.

3.2 Experiment flow



3.3 Participant

Eight male participants were recruited for this study that met all the inclusion criteria. Data from the pilot test consisted of two subjects were combined in this study to make a total of 10 subjects. Only two subjects have experience working in oil palm plantation. However, most of the subjects already had prior knowledge and idea about the process. Besides, videos on pruning and harvesting activities have been provided beforehand, followed by practical training before the actual trial. All subjects agree willingly to comply with all aspects of this study protocol as stated in Appendix A by signing that consent form. The guideline and regulation were approved by Human Research Ethics Committee Universiti Sains Malaysia (USM) (JEPeM) – code number 21100665. The demographic and basic information of subjects is shown in Table 3.1.

Table 3-1 The demographic and basic information of the subjects

Subjects	Age (Year)	Height (cm)	Weight (kg)	BMI	Experience
S1	22	171	65.11	22.27	No
S2	22	163	45.16	17.00	No
S3	22	166	59.25	21.50	No
S4	22	164	46.73	17.37	No
S5	22	172	60.03	20.29	(10h/w)
S6	22	170	65.52	22.67	No
S7	22	168	66.03	23.39	No
S8	22	164	48.08	17.88	No
S9	44	171	69.10	23.63	No
S10	43	165	84.50	31.94	(10h/w)
Mean (SD)	26.3 (9.07)	167.4 (3.40)	60.95 (12.04)	21.79 (4.35)	-

3.4 Field Setup

This study has done two separate FFB lifting and pruning experiments. The FFB lifting experiment was conducted in Vibration Lab, USM, to eliminate the issues related to weather, power supply and internet connection. Five FFBs with different weights were prepared beforehand, and their weight was stated in Table 3-1. The pruning experiment was conducted on the USM Engineering Campus, Nibong Tebal, beside the School of Chemical Engineering, to get real-life action data. Two oil palm trees that meet the required criteria have been chosen for this experiment.

3.4.1 Lifting the FFB experiment's field setup and flow

For FFBs collecting, standard practices among the oil palm workers are using manual hand lifting or loading spike. Because of that, these two methods have been chosen for evaluation in this study. A one-meter-long metal loading spike with a handle was used for this experiment, as shown in Figure 3-1.

Figure 3-1 loading spike with handle (length 1m)

In this experiment, the height of the FFBs to be lifted and the weight of the FFB was manipulated. The height was made variable because the worker in oil palm plantations needs to uplift the FFBs into either wheelbarrow, lorry, or pickup truck which requires different lifting heights. The heights employed in this study are 0.5m, 0.8m and 1.6m. The weight and size of FFBs also varied as in Figure 3-2 and Table 3-2.

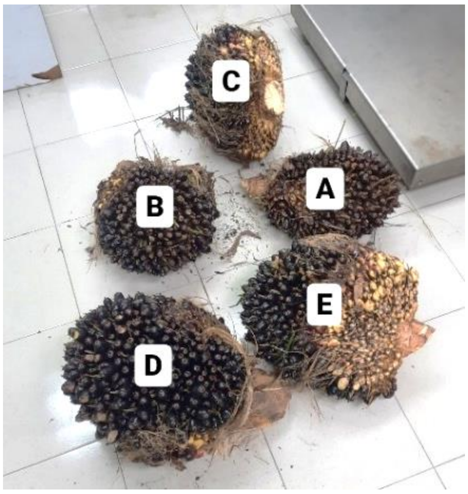


Figure 3-2 The FFBs used in the harvesting experiment with the assigned alphabet

The FFBs were classified with the alphabet for a more straightforward representation of their weight. FFB A indicated the lightest, and end with FFB E which is the heaviest. Since the FFBs have become detached, watery and lose their weight after a week, the mean weight was used for more simple clarification.

Table 3-2 Classification of FFBs' weight along two weeks of the experiment and from the pilot study.

FFBS	Weight week 1 (kg)	Weight week 2 (kg)	Pilot study (kg)	Mean (kg)	Std. Dev
A	6.17	5.65	6.11	5.98	0.28
B	8.67	7.94	9.36	8.66	0.71
C	11.13	10.21	10.13	10.49	0.56
D	12.10	11.16	11.02	11.43	0.59
E	13.38	12.59	12.97	12.98	0.40

This experiment was divided into four different main tasks, and every main tasks has divided into four subtasks. The details for main tasks were listed in Table 3-3. The details four subtasks were: neutral standing (NS), lifting (start) (LS), lifting (while) (LW), and loading (LO). The manual hand lifting and loading spike lifting have different techniques, so separated tables have been made to describe the working postures of each subtask.

Table 3-3 Description for four tasks during FFB lifting experiment.

Task	Task description
Task 1A	Manual hand lifting FFB into the wheelbarrow (0.5)
Task 1B	Lifting FFB using a loading spike into the wheelbarrow (0.5m)
Task 1C	Lifting FFB using a loading spike to a height of 0.8m
Task 1D	Lifting FFB using a loading spike to a height of 1.6m

Table 3-4 Descriptions of the working postures for each subtask during manual hand lifting into the wheelbarrow.

Subtask	Symbol	Description
Neutral Standing	NS	Standing up straight with an empty hand
Lifting (Start)	LS	Squatting to start lifting the FFB.
Lifting (While)	LW	Half-squatting position while holding the FFB.
Loading	LO	Twisting the body to place the FFB into the wheelbarrow at the subject's side.