Master of Science in Engineering

An Early Stage Development of Posture Model: To Prevent Work-Related Musculoskeletal Disorders on Construction Sites

by

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Abstract

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Aging of skilled construction workers has been a major problem throughout most of the developed countries including Korea. Physically demanding and repetitive work tasks have caused these aging workers in the construction industry to become more vulnerable to work-related musculoskeletal injuries; the disorders often lead to decrease in worker's productivity. As a result, more and more Korean companies started to pay attention to health, safety and environment. Thus, this study introduces a posture model called the M2B2P model in order to robustly model

brickmason's postures and three-dimensional (3D) geometries of workspace obstacles allowing "virtual" representations of the construction worker's real work site environment. The 3D posture model can be further used for many applications by construction managers and safety managers to help manage recurring illnesses. Current construction site environment denote the utmost opportunity to ergonomically improve workspaces, which reduce risk of work-related musculoskeletal disorders of the workers.

To investigate solution to this recurring problem, this study proposes a state-of-the-art model titled The M2B2P model that is based on the MBPP model from the previous literature. The previous 2D model is modified to 3D model along with other modification in terms of improved representation of construction worker and better representation of the actual construction site environment.

The objective of this research is to help reduce the risks of work-related musculoskeletal disorders of construction workers by accurately identifying awkward postures and repetitive work – major causes for work-related musculoskeletal disorders. Using the Modified Memory Based Posture Planning (M2B2P) model, the 3D visualization of postures enables safety managers to easily identify potential awkward posture problems. Therefore, the suggested model will allow safety mangers to focus more on primary prevention of work-related musculoskeletal disorders, which can be significantly reduced.

The results of the M2B2P model show promising future application such as health monitoring system of construction workers. As discussed above, in this study we will only introduce the model development stage out of overall framework and test this model by running simple simulation representing average Korean brickmason. Although this is an early stage research study, there is a high anticipation that the result of this study will improve the health of construction workers.

Keywords: Brickmason, Ergonomic Design, Human Performance, Posture Analysis, Work-Related Musculoskeletal Disorder, Worker Behavior

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Chapter 1. Introduction

This chapter introduces the importance of ergonomics in construction industry and current efforts of applications in safety management. To solve the current problems, in this study research objectives are established. Then, more detailed research process is introduced to attain the objectives of this study.

1.1 Research Background and Objective

Today, developed countries throughout the world including Korea are facing a rapid aging of workers. In the U.S. construction industry, the median worker age was 37.9 years old in 2000 and 40.4 years old in 2010 (Schwatka et al. 2011). Due to the fact that construction job often requires labor intensive work, aging construction workers are easily prone to disease such as Work-Related Musculoskeletal Disorders (WRMSD). In Korea, over the past decade, WRMSD has always been prevalent as shown in Figure 1-1 below.

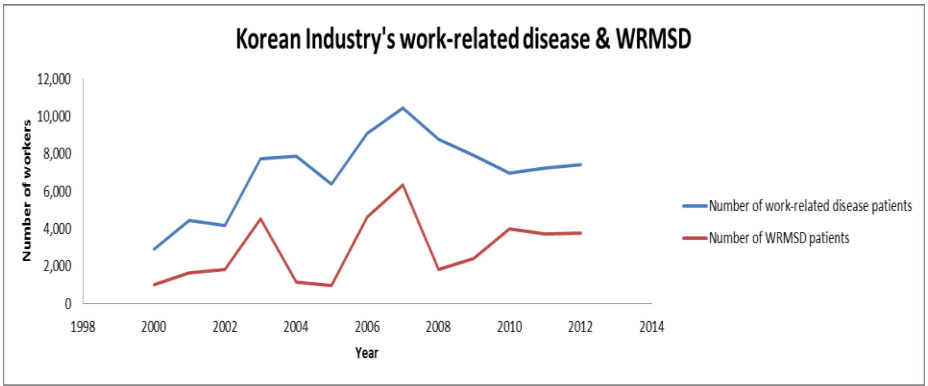

Figure 1-1. Korean Industry's work-related disease and WRMSD relationship (reinterpreted from KOSHA data)

Unfortunately, WRMSD often cause chronic pain and functional loss, enforce heavy costs on society and worst case scenario, it reduce productivity of workers (Boschman et al. 2012).

However, these problem receives much less attention from workers and safety managers than other common fatal injuries (i.e. falls, struck by object, electrocutions, and caught-in/between) [Occupational Safety and Health (OSHA) 2012]. In fact, back injury and back pain is one of the most common WRMSD. Thus, in this study, we will investigate primarily on back pains of construction workers. According to the center for disease control and prevention, back symptoms are among the top ten reasons for medical visits. For 55% of back injury cases: 1) operators, fabricators, and laborers (38%); and 2) precision production, craft and repair (17%). Moreover, previously researched data from the scientific studies of primary and secondary interventions indicated that low back pain can be reduced by the following:

- Engineering controls (i.e. ergonomic workplace redesign)
- Administrative controls (i.e. changing work schedules and workloads)
- Programs designed to modify individual factors (i.e. employee exercise)
- Combination of these approaches

In this study, focus is on engineering control method, namely redesigning ergonomic workspace. Ergonomics is the science of fitting workspace conditions and job demands of the capability of the working population. The objective of ergonomics is to alleviate stress and reduce injuries associated with the overused of muscles, bad postures, and repeated tasks [Center for Disease Control and Prevention (CDC) 2013].

Previously, (Han et al. 2013), (Seo et al. 2013) and (Cheng et al. 2012) has focused on some aspects of ergonomics that can be applied to construction. However, the following gap still remains:

- Deficiency of actual construction worker′s motion capture database
- Deficiency of integrated monitoring system and real-time posture data for analyzing an awkward posture of real workers
- Deficiency of interest regarding the need to better manage work-related musculoskeletal disorders of the workers systematically.

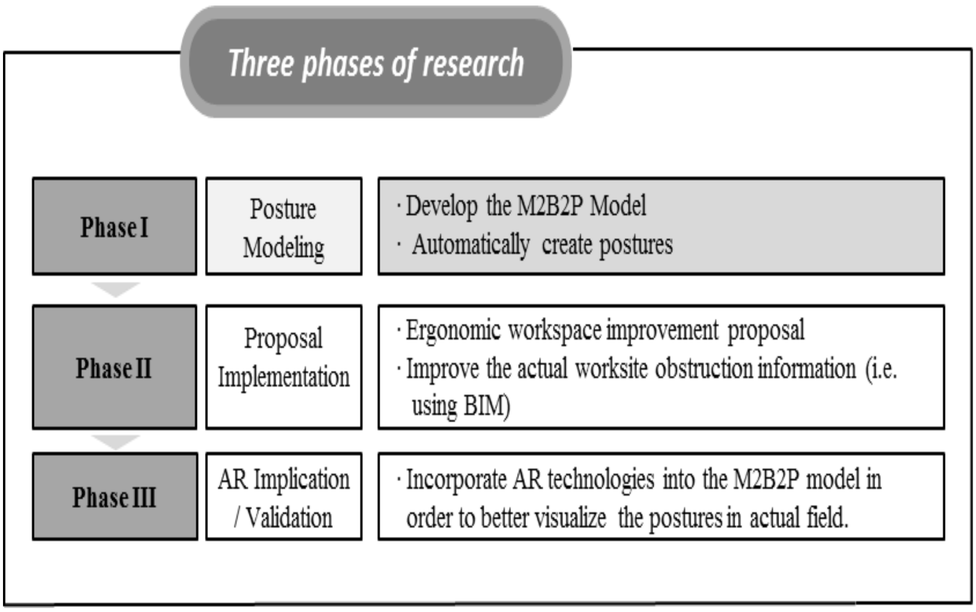

Figure 2-2. Three phases needed to achieve the long-term goal of this research (Phase I is introduced only)

To address the problem above, the author set an ambitious long-term plans with three specific tasks that needs to be accomplished, which are shown in Figure 1-2 : (1) Develop the M2B2P model in order to automatically generate postures of construction workers. (2) Propose for improvements on construction worker's typical workspace and investigate a method to improve the real-life worksite obstruction information in the model and (3) Validate and evaluate the M2B2P model by integrating Augmented Reality (AR) in order to establish the prototype of real-time posture monitoring system of the construction workers.

1.2 Research Scope and Process

There are various types of construction workers in the field, however, in this study, scope of the research is limited to indoor workers; especially brickmason is investigated for two primary reasons: (1) The M2B2P model introduced in later chapter utilize motion capture device called Microsoft Kinect sensor for windows that uses infrared camera, which gives more accurate motion capture results indoors. (2) From the various indoor workers, brickmason was selected since their everyday job tasks involve frequent bending in a relatively constraint workspace.

The Research process shown in Figure 1 is as following:

(1) Research Problems are identified from thorough literature review in multidisciplinary field (i.e. industrial engineering, public health and

construction) and work-related musculoskeletal disorder risk factors of construction workers are verified from preliminary survey. Survey was conducted in 5 different construction sites, involving 300 workers with a response rate of over 50%.

(2) The M2B2P Model will require construction worker information (i.e. physical information, job type and repetitive motion frequency) and construction workspace information (i.e. obstruction location and object location)

(3) In order to accurately portray real-life worker in the model, real-life worker's everyday job will be recorded using Observer XT and motion will be captured using Microsoft Kinect for Windows to help build a database to detect awkward postures.

(4) The M2B2P model for generating postures during work is developed using MATLAB programming with improving the weakness of prior two dimensional model into three dimensional model.

(5) Lastly, through 'case-study', the M2B2P model is tested for its validity and worker's behavior is discussed.

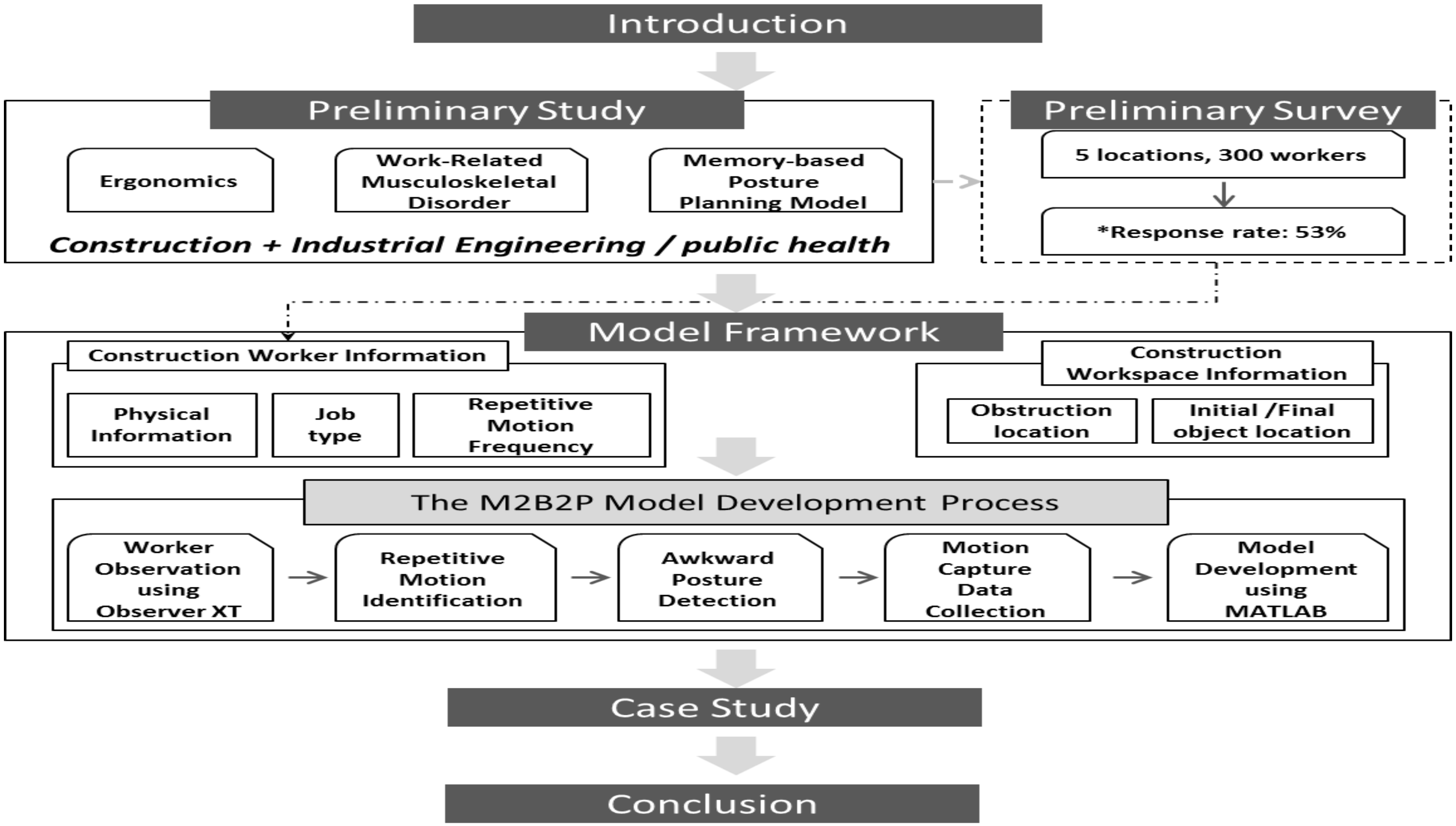

Figure 1-3. Research Process

Chapter 2. Preliminary Study

This chapter begins with the investigation of ergonomics in safety management field of construction. Due to the multidisciplinary characteristic of the research problem, related topics from industrial engineering and public health will be introduced – literatures on posture analysis and work-related musculoskeletal will be thoroughly reviewed.

2.1 Definition

2.1.1 Ergonomics and Construction

Ergonomics is the study of fitting workplace conditions and job demands to the capability of the workers. The objective of ergonomics is to alleviate stress and reduce injuries or disorders commonly associated with the overuse of muscles, awkward postures and repetitive tasks [Center for Disease Control and Prevention (CDC) 2013].

Previously, a number of researchers in construction sector have investigated ergonomics. For instance, ergonomic measures (i.e. trestles, bricklaying scaffolds, mast climbing work platforms, and cranes) for bricklayers were studied (van der Modlen et al. 2004). Despite these efforts, construction industry is still one of the largest contributors of work-related musculoskeletal disorders, which means that there is still a room for improvement in managing these recurring illnesses.

Since, bricklaying has shown to present significant ergonomic risks to workers, the focus of this study will be primarily on brickmasons. The prevalence of back pain among brick layers ranged from 40% to 60% [Stumer et al., 1997; Rothenbackher et al., 1997b; Luijsterburg et al., 2005]. Typically, bricklayers lift an average of about 87 to 262 bricks per hour [van der Molen et al., 2004; Hartmann and Fleischer, 2005] and average bricklayer makes 912 trunk flexion with more than 20° and 842 flexion with more than 60 °, approximately 105-130 times per hour (Vink et al., 2002; van der Modlen et al., 2004). Also, awkward postures of kneeling or squatting during work are frequently observed. Moreover, bending occurs during 10-53% of the working time (Lujisterburg et al., 2005)

2.1.2 Ergonomics Risk Factors

Construction industry is traditionally a dynamic and hazardous industry. There are many factors which can be taken into consideration for controlling ergonomic risk factors on construction site. Ergonomic risk factors are defined as actions or conditions that increase the likelihood of injuries to the human musculoskeletal system. Prolonged exposure to ergonomic risk factors can cause WRMSD (Inyang et al., 2013). Also, various ergonomic methods for risk exposure assessment were reviewed by G.C. David (2005). However, it is difficult to define the relationship between risk factor exposures and the level of WRMSD risk.

As mentioned earlier, common ergonomic risk factors are defined as (1) awkward postures, (2) force, (3) repetition, (4) vibration, (5) static loading, (6) contact stress and (7) extreme temperature (Jaffar et al., 2011).

In this study, primary focus is on studying awkward postures and repetitive work task. In a relatively limited workspace, brickmason is determined to be an appropriate subject in the model since they are easily exposed to the above mentioned ergonomic risk factors. Details about the model will be explained in later chapters.

2.1.3 Ergonomics Posture Classification

There is no single 'ideal' posture. Yet, some postures are ergonomically more desirable than others. For example, NIOSH provided a posture guideline for lifting as shown in Figure 2.

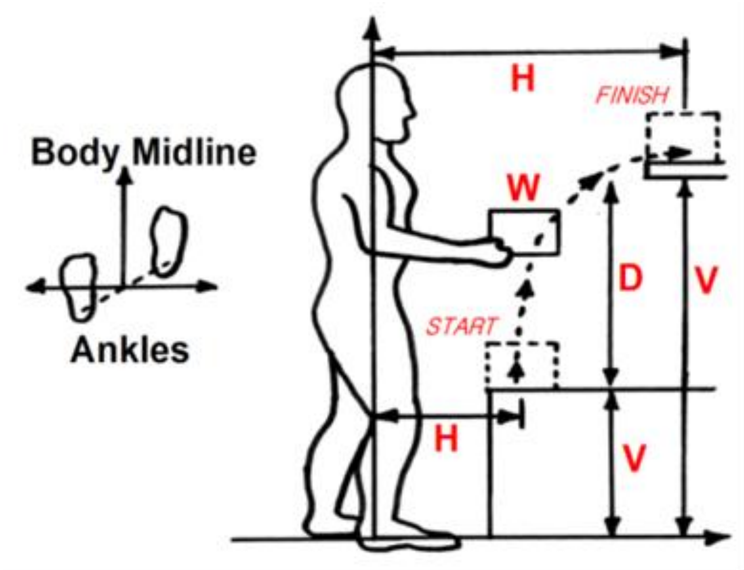

Figure 2-1. Lifting task design parameters(reinterpreted from NIOSH)

In 1991, NIOSH revised the lifting equation in order to prevent or reduce the occurrence of lifting-related low back pain (LBP) among workers (Walters et al., 1993). The RNLE consists of two primary products shown in formula 1 and 2 below:

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \tag{1}$$

$$\text{And } LI = \frac{Load\ Weight}{Recommended\ Weight\ Limit} = \frac{L}{RWL} \tag{2}$$

Where LC = load constant, HM = horizontal multiplier, VM = vertical multiplier, DM = distance multiplier, AM = asymmetric multiplier, FM = frequency multiplier and CM = coupling multiplier

Load weight (L) = weight of the object lifted (lbs or kg)

Also, Ovako Working Analyzing System (OWAS) provided some guideline for ergonomic assessment. However, this was not validated for construction workers. Recently, there was an attempt to classify various postures of construction workers (Ray and Teizer, 2012). Also, Burgress-Limerick reviewed various postures for lifting techniques as explained below:

(1) Overhead work

Overhead work involves those activities in which a worker is required to reach up and raise an arm or both above the shoulder level. This kind of overhead work will put stress on shoulders and neck which will eventually lead to serious muscle and joint injuries.

(2) Stoop to lift load

Lifting load from a low level is often described as stooped posture. In this posture, knee joints are almost fully extended and the hip joints and vertebral column are flexed to reach the load. Task involving frequent or stooping postures over an extended period of time can result in back spasms and sprain. Construction workers have ranked the prolonged stooping posture as one of the most problematic posture during work (Rogers and Granata, 2006).

(3) Squat to lift load

Another common lifting posture is squatted posture. In this posture, knee joints are fully flexed and the trunk is held as vertical as possible. Full squat posture reduced stability leading to the possibility of injury due to unexpected perturbations (NIOSH, 1981).

(4) Bending

Bending forward will cause muscles to work harder and the ligaments flex and stretch. The discs get squeezed which can cause back pain. Twisting body while bending puts even more pressure on the discs and more stress on the cartilage and ligaments, especially when person is exerting force to lift, push or pull objects (Alberts and Estill, 2007)

2.2 Memory Based Posture Planning Model

Previously, there were many research conducted on computational models that simulate human reach posture or motions. For instance, the objective of ergonomics model is to facilitate computer-aided ergonomic design of workspace by accurately simulating human behaviors in virtual environment (Hsiang and Ayoub, 1994; Zhang and Chaffin, 2000).

In 2006, the Memory Based Posture Planning (MBPP) model was developed by Park and his colleagues to plan reach postures that can avoid obstructions using 2D five segment human model. For a given figure in the model, the task space is partitioned into many square-like regions called 'cells' – each cell is linked to a memory that stores various alternative postures for reaching the cell. For instance, when a posture planning problem is given in terms of a target and an obstruction configuration, the model carefully examines postures that belongs to the corresponding cell and eventually selects collision-free postures and modifies it to exactly meet the hand target acquisition constraint.

Mathematically, the constraints can be stated as shown in formula 3 to 6 below:

$$F(\theta, L) = E \qquad (3)$$

$$P(\theta, C) = \sum_{k=1}^{K} potential(S_k(\theta), C) = 0 \qquad (4)$$

$$L_j \leq \theta_j \leq U \quad \text{for all } j(j=1,...,J) \qquad (5)$$

$$X_{com}(\theta, L) \in Bo \qquad (6)$$

Also, the MBPP model inherited two critical ideas from the previous reach and grasp model (Rosenbaum et al. 1999, Vaughan et al. 2001): usage of stored postures and hybrid posture search scheme that combines both global and local searches.

2.3 Literature Review

With the recent improvement in computer-aided visualization technology, several researchers have investigated on integrating visualization method to ergonomics in construction. Seo et al. (2003) proposed a motion capture approach to obtain worker's posture information. In this method, quasi-static biomechanical analysis of worker was performed in a ladder climbing case study with 3D SSPP. Also, Motion data was collected using the Microsoft Kinect depth sensor.

On the other hand, by fusing data from real-time location trackers and physiological status monitors, Cheng et al. (2003) attempted to identify and locate unsafe postures of construction workers that can lead to WRMSD. The goal of this research was to identify subject's working behaviors (i.e. bending and lifting) dealing with heavy loads. In this study, subject's squatting posture was classified as 'safe' compared to stooping posture as 'unsafe' However, Burgress-Limerick (2001) showed that there is no justification for advocating a squatting posture for lifting technique since it cannot be utilized in many situations. Also, while compression is highly influence by load moment, lifting speed, and acceleration, lumbar curvature had little influence.

It is apparent that there is a close relationship between behavior of unsafe worker and unsafe working conditions, contributing to construction accidents.

The risk of construction accidents could be reduced by successfully detecting and separating unsafe behaviors from related unsafe working conditions (Chi et al. 2012). Also, previous research has shown that ergonomic hazards can be controlled by safe workplace design (Hinze and Wiegrand, 1992)

2.4 Preliminary Survey

There are various types of construction workers who are equally vulnerable to WRMSD. As shown in Table2-1 below, preliminary survey is conducted on 5 different construction site locations – includes from SME construction companies to major construction companies (The detailed survey questionnaire can be referred to the Appendix A).

Out of 300 initial survey participants, 92 surveys were conducted by brickmasons. Not surprisingly, majority of brickmasons who participated in this survey indicated that they have experienced lower/upper back pain in the past 6 months of their work. Thus, this shows that brickmasons are group of workers who are vulnerable with high risk of developing WRMSDs.

The purpose of this survey is to help select the scope of research from identifying the subject out of various construction worker job types and deduct the WRMSD symptoms to be focused for the model development in later chapters.

Table 2-1. Different Types of Survey Participants by various construction sites

Construction Site	Site Type	Number of Survey Participants							
		Total	Brickmason	Electrician	Mechanical	Carpenter	Steel Worker	Windows Installation	etc
Daewoo E&C Office/Apt construction Site	Office/ Apt	111	43	21	18	9	7	8	5
Hyundai E&C Apt construction site	Apt	64	19	15	9	7	4	6	4
Doosan E&C Apt construction site	Apt	41	9	5	8	7	3	6	3
LH Apt construction site	Apt	65	17	9	13	7	5	8	6
Seoul National University Campus Construction Sites	Campus Facility	19	4	3	3	2	3	2	2

Korea Occupational Safety and Health Agency (KOSHA) introduced a manual on managing work-related musculoskeletal disorders; however, as shown in Figure 2-2. Almost 80% of survey respondents are unaware of the existence of this manual published by KOSHA.

As shown in Figure 2-3 below, the result of survey indicates that majority of construction workers show high prevalence on developing upper/lower back problems. Moreover, as indicated in Figure 2-4, out of 92 brickmason surveyed, majority of brickmason experienced lower back pain Thus, in this study the primary focus will be on brickmason who shows high risk of developing back problems due to his/her job characteristics.

Although, many construction workers are easily vulnerable to develop work-related musculoskeletal disorders, majority of the workers show hesitant behavior in terms of how to reduce the risk of developing such illnesses.

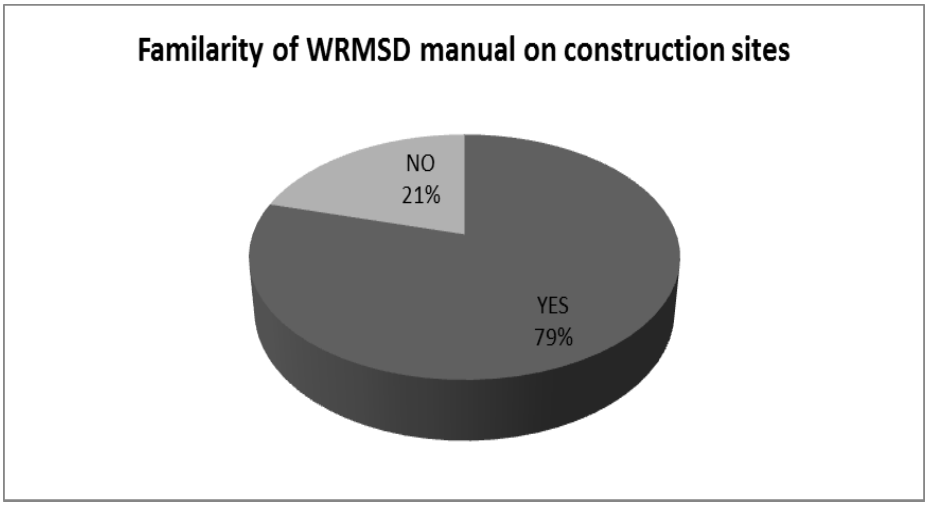

Figure 2-2. Survey results of brickmason

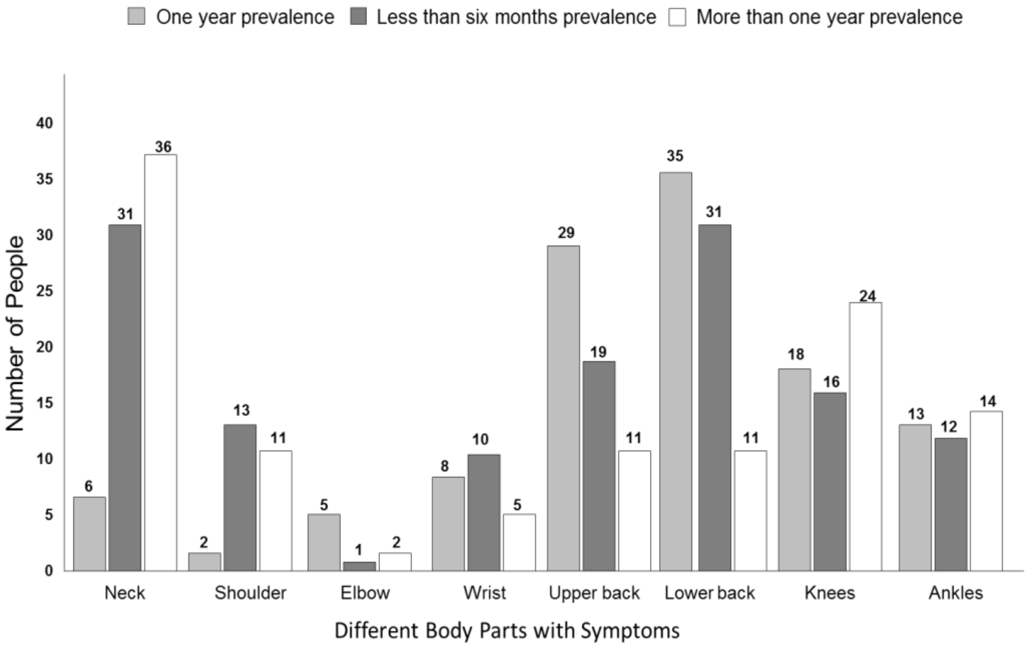

Figure 2-3. Survey results of construction workers

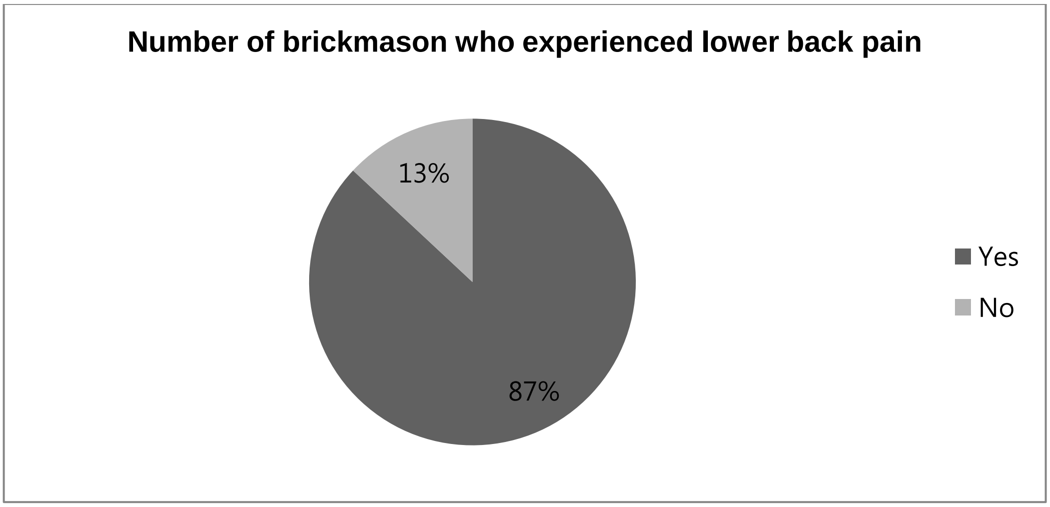

Figure 2-4. Survey results of brickmason

More detailed questionnaire can be referred to the appendix

2.5 Summary

This chapter reviews previous literatures on ergonomics as shown in Table 2-1 below. Mainly, out of various types of literatures, topics on ergonomics in construction, ergonomics risk factors and ergonomics posture classification is thoroughly reviewed. Traditionally, ergonomics is a field studied by Industrial Engineering and public health sectors. Since, construction workers are equally vulnerable to work-related musculoskeletal disorders, more and more construction researchers are paying attention to possible applications of ergonomics to construction worker's workspace environment. Moreover, two detailed literatures are reviewed: the RNLE and the MBPP model.

After gathering valuable insights from these previous literatures, following requirements will be considered for a state-of-the art model to be developed in later chapter.

(1) Brickmason is selected for the model since their job task requires frequent bending of lower back in a constraint workspace. Moreover, repetitive work for prolong hours are another contributing factor for risk of developing work-related musculoskeletal disorders.

(2) Computer-aided visualization tool will be needed in order to better detect awkward postures, which is often difficult to identify with a naked-eye.

(3) The model will be based on the previous MBPP model except that it will modify to better represent construction site workspace. Also, the model will be in three dimensions in order to accurately represent real-life worker.

Table 2-2. Previous Literatures on Ergonomics Reviewed

Classification	Detailed Classification	Study Subjects	Key Contents	Authors	Applicability
Ergonomics in Construction	Ergonomic Measures	Bricklayer	- Studied various tools (i.e. trestles, scaffolds, etc.) to help improve work site condition	van der Modlen et al. (2004)	Δ
	Work-related Musculoskelatal Disorders	Bricklayer	− Investigation of prevalence of back pain among bricklayers	Stumer et al. (1997); Luijsterburg et al. (2005)	●
	Awkward Postures	Bricklayer	− Investigation of number of repetitive work and awkward postures	Vink et al. (2002) van der Modlen et al. (2004)	●
Ergonomics Risk Factors	workplace risk factors	Overall construction workers	- Overview of the most significant ergonomic risk factors in construction industry	Jaffar et al.(2011)	●
	Ergonomic Methods for risk assessment	Forestry workers, retail, manufacturing workers ,etc.	- Overview of the range of methods that have been developed for the risk exposure assessments	G.C. David (2005)	×
	Impact of Ergonomic Risks on Productivity	Residential construction workers	- Developed a framework for assessing the ergonomic risk of residential construction tasks	Inyang (2013)	×
Ergonomics Posture Classification	Real-time posture analysis	Construction worker	- Attempt to classify various postures of construction workers	Ray and Teizer (2012)	Δ
	Postural Index	Volunteers	-Postural index to define the postures adopted at the start of lifting	Burgress-Limerick	Δ

●: consideration Δ: partial consideration ×: no consideration

Chapter 3. The Modified Memory Based Posture Planning (M2B2P) Model

In this chapter, the overview of posture model framework is introduced in order to build the state-of-the-art M2B2P model. The purpose of the M2B2P model is to help identify awkward postures, which is one of the main causes of work-related musculoskeletal disorders. In order to build an accurate model that can represent a real-life brickmason, this model is based on motion captured data using Microsoft Kinect for Windows.

3.1 Posture Modeling Framework

Awkward postures can often strain worker's body parts and it can result in fatigue, injuries or even permanent disabilities for severe cases (Ray and Teizer, 2012). Based on the previous literature reviews, the overview framework of the proposed modeling process for identifying an awkward posture is shown in Figure 3-1.

First, observation of construction labor activities from actual construction site and injury records by site surveys, workspace and tasks will be selected. Second, based on this information 3D posture modeling will be developed. In this early stage research, integrating BIM layout will be left out for further study. However, this will make improve the accuracy of the model. Third, worker's current task will be evaluated by ergonomic analysis using NIOSH lifting equation and the 3D posture model developed. Forth, based on this model and evaluation, ergonomic workspace improvement can be

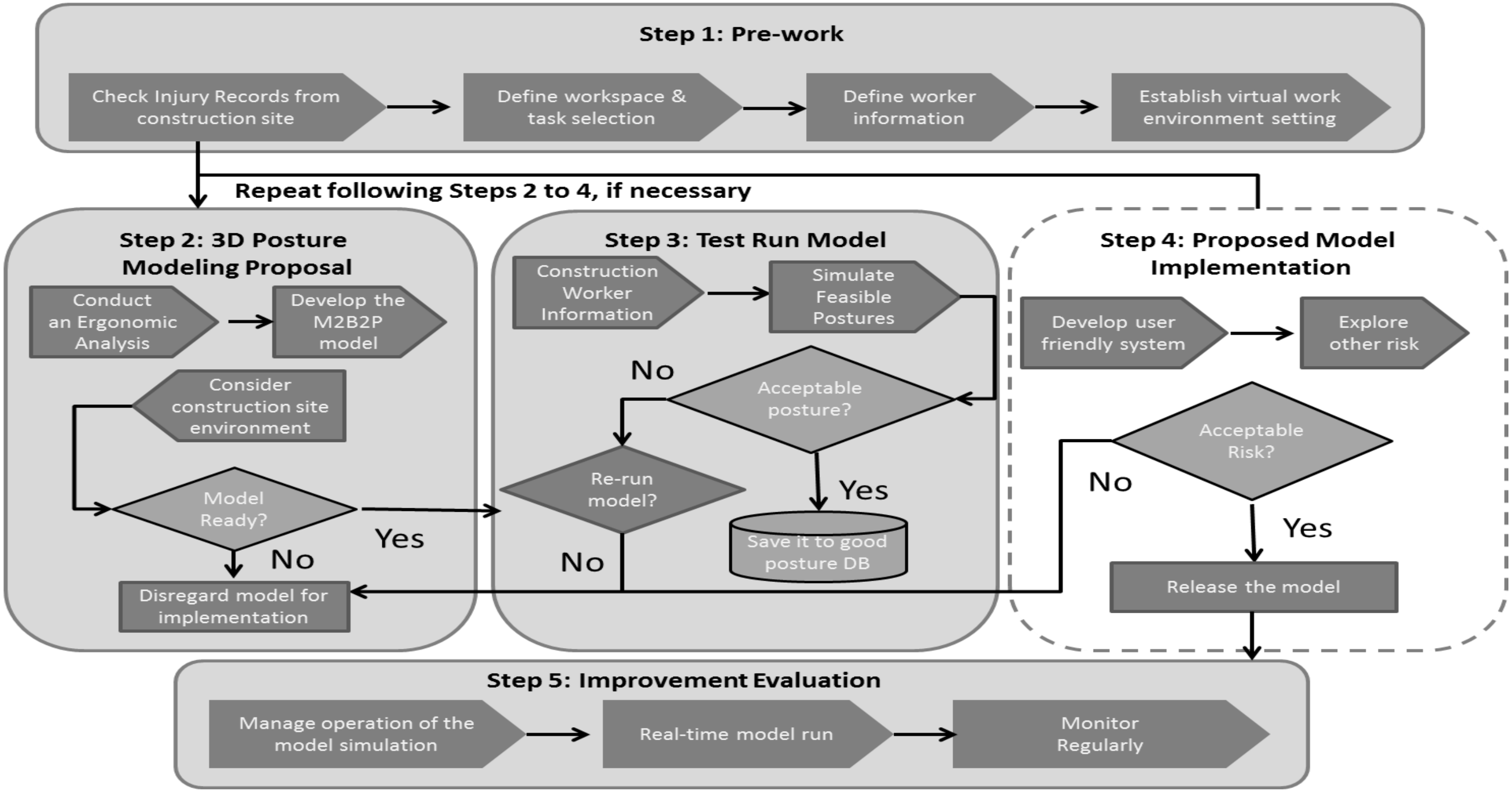

Figure 3-1 Overview Framework of ergonomic workspace improvement using the M2B2P model

recommended and the improvement will be evaluated. At this stage, construction manager or safety managers can implement the proposed ergonomic improvements.

3.1.1. Motion Capture Observation

The proposed posture model framework is developed with MATLAB programming, Microsoft Kinect for Windows and video recordings of construction workers’ job activities. The algorithms which output feasible postures are coded with MATLAB. Also, motion data for brick laying activities is collected. This motion data is recorded and extracted using a single Microsoft Kinect sensor and the iPiSoft Motion Capture solution. Sample depth information measured using Kinect sensor is shown in Figure 3-2. This method was previously validated by Han et al. (2012).

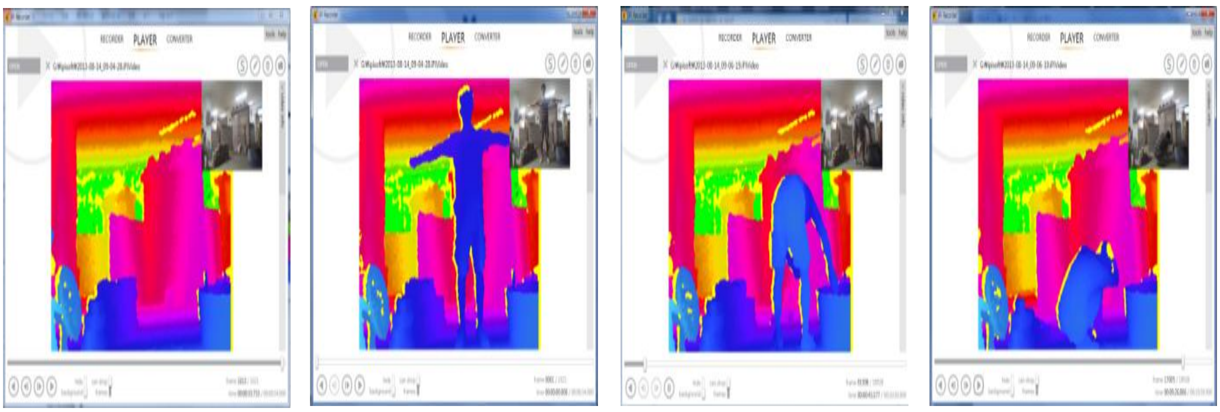

Figure 3-2 Depth information of brickmason measured with Microsoft Kinect for windows

3.1.2. Observer XT

The Observer XT is a professional and user friendly software packages for the collection, analysis and presentation of an observational data (Noldus, 2014). The major strength of this software is that both behavior and physiological responses can be studied using Observer XT. The analysis of data often begin with visualizing event log, one or more videos, and physiological data streams as shown in Figure 3-3 below.

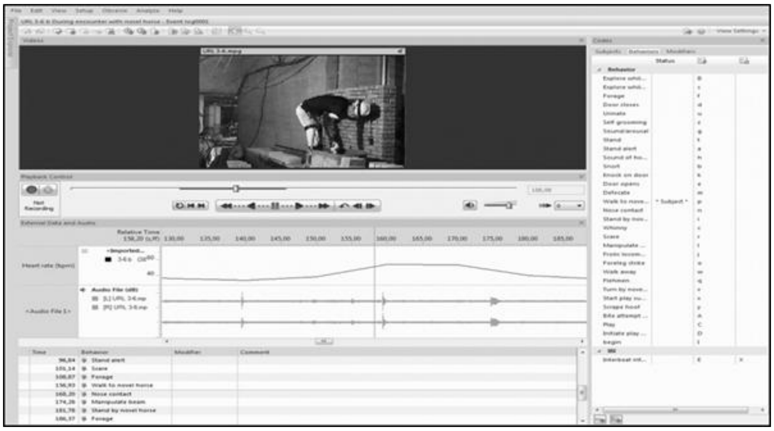

Figure 3-3 Visualization event log from the Observer XT 8.0

The physiological data is acquired using sensors and it can be imported to software where it is visualized along with the video. The pre-recorded video of brickmason is analyzed according to a coding scheme that is designed by the user and this can help determine what the user can do with the data at later stage of further studies.

As mentioned earlier, in this study primary focus will be on developing the 3D posture model and testing with a simple real-life case study on brickmason.

3.2 Model Development Process

Computer-aided model that simulate human reach postures and motions have been widely researched in the fields of kinesiology and ergonomics. Correspondingly, ergonomics model aim to facilitate computer-aided design that can help identify ergonomic problems and safety hazards virtually (Zhang and Chaffin, 2000; Park et al. 2004).

As shown in Figure 3-4 below, the development process of the M2B2P model in this study is based on observation of brickmason on construction sites. This model implements MATLAB programming language. In this model, three inputs are considered: (1) Physical information of worker, (2) object location and (3) obstruction information.

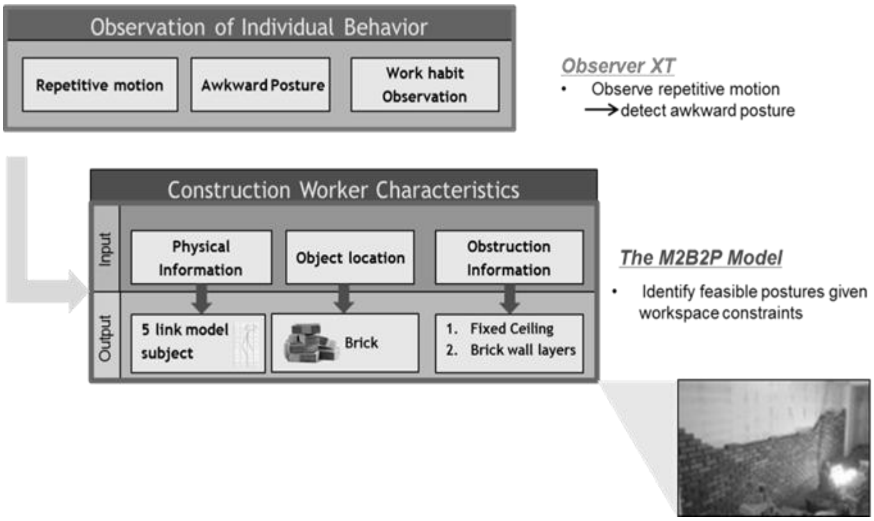

Figure 3-4. Model Development Process

Given a research posture planning problem, this model is developed based on the previous MBPP model in order to find the feasible set of postures of construction worker. This ability to find the entire range of feasible posture is very useful for ergonomics study and safer workspace design. However, this model had the following limitations: (1) Real-life posture is more complex than the 5 link human model used in this model (2) Real-life obstructions are more complex-shaped than in this model. In order to better fit the construction site environment, the MBPP model was modified. The M2B2P model represents better posture of real construction worker compared to the previous version.

In this study, the model is tested for simple indoor construction site (i.e. apartment construction site). As shown in Figure 3-5 below, brickmason working on bricklaying to build walls is represented in the M2B2P model. However, further investigation is needed to possibly integrating BIM in order to improve an actual workspace condition of workers represented in this model. At this current stage, obstruction and obstacle is represented in a simple geometric primitive shape.

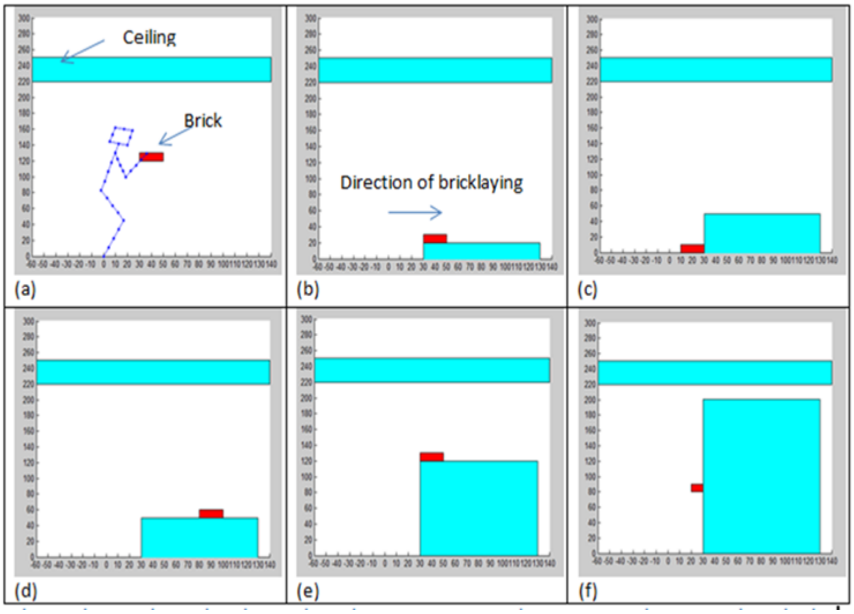

Figure 3-5 Six obstruction configuration representing indoor construction site in the M2B2P model

3.3 Posture Planning Example

3.3.1. Kinematic human linkages

Based on the observation of brickmason on construction sites, a kinematic linkage system representing the upper 5 percentile of Korean brickmason (180 cm tall) is used in the M2B2P model. The linkage is based on the kinematic linkage structure shown in Figure 3-6 below.

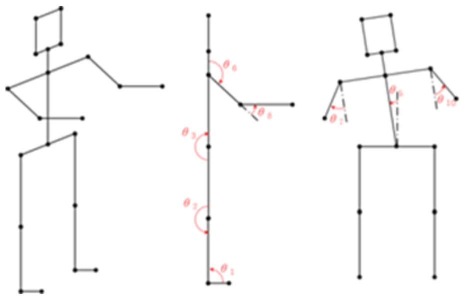

Figure 3-6. A simple kinematic linkage model representing human body in the sagittal plane

In this model, 11 degree of freedom is sufficient in the linkage structure. Although, in reality, human body is consisted of higher number in degrees of freedom, human motions can be sufficiently denoted with small number of driving dimensions since the motion are coordinated (Han et al. 2013).

For the link lengths in the system, it is based on the Drillis and Contini's (1966) proportion of stature data. Previous studies used anthropometric data representing the U.S. population, however, there should be further investigation on finding a way to better interpret Korean anthropometric data. Recently, organization such as Size Korea [1] built anthropometric data specifically for Korean population.

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1 Size Korea is a symbolic name that represents 'Korean anthropometric data business'. As a national business, it utilizes the latest technology such as dynamic and three dimensional measurements.

3.3.2. Sagittal-plane

The term "Sagittal" refers to that set of planes perpendicular to the front of the body and on the other hand "Symmetric" refers to action in which bothpoi des of the body perform equal motions (Martin and Chaffin, 1972). As shown in Figure 3-7 below, the sagittal plane is a vertical plane that passes through anterior to posterior which results in dividing human body into havles.

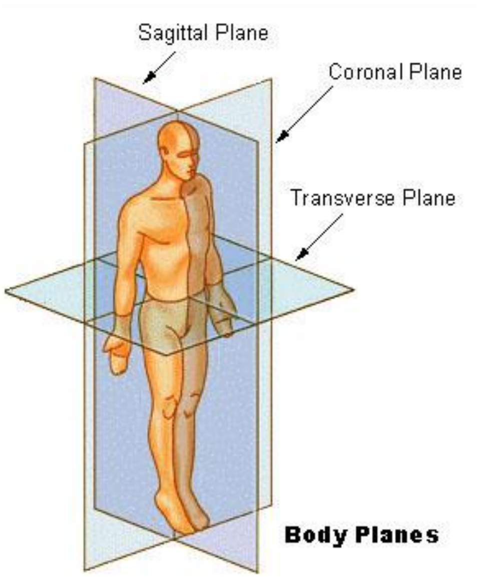

Figure 3-7 Sagittal plane and body plane.

In the M2B2P model, the sagittal-plane is divided into a set of 10 cm × 10 cm × 10 cm cube shaped cells in order to better represent the three dimensional environment as shown in Figure 3-8 below. Only one posture is shown for clarity of illustration.

The term 'cell' is referred to both a region in the task space and its association with posture memory. Postures stored in a cell are assumed to

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http://sizekorea.kats.go.kr/

repute physiological and physical constraints (i.e. joint range of motion and static body balance constraint).

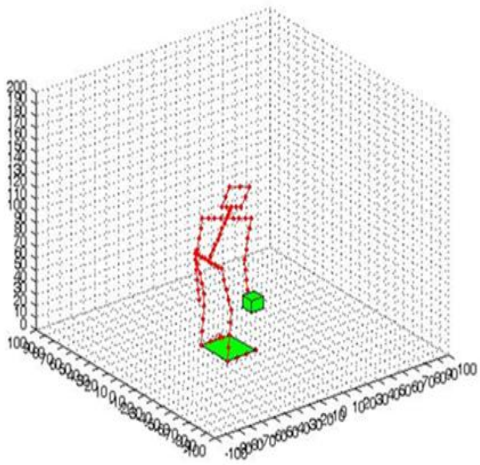

Figure 3-8 Partitioning of the 3-D task space into cube shaped cells.

3.3.3. Random posture generation

Given the constraint of obstacles in the model, there are infinite possible postures that can be easily modeled using random posture generation technique. However, it is still challenging job to predict the exact posture of a real-life worker. Despite these underlying challenges, a total of 1.0×10^6 feasible postures is randomly generated in this study in order to improve the accuracy of predicting feasible postures. Among the randomly generated postures, a total of 19,521 postures were stored in a cell. (See Table 2 for details). Detailed process of random posture generation technique is shown in Figure 3-9 below.

In this process, first randomly generate posture in terms of θ_g that satisfies the joint range of motion constraints. This constraint will be randomly tested to check if it rather falls under corresponding lower and upper limit of the joint ROM. Second, out of these randomly generated postures, feasibility will be determined by checking the static balance constraint. During this process if a similar posture already exists in the corresponding cell to be stored, it will be discarded and automatically go back to step 1 in the process. Lastly, for the remaining postures, it will be registered in the corresponding cell. If these cells are full, then the process will terminate. Otherwise, it will continue back to step 1 of the process.

Overall cell construction process took about 6 hours for the human figure representation when running a MATLAB program on a laptop computer with an Intel Core i7 CPU.

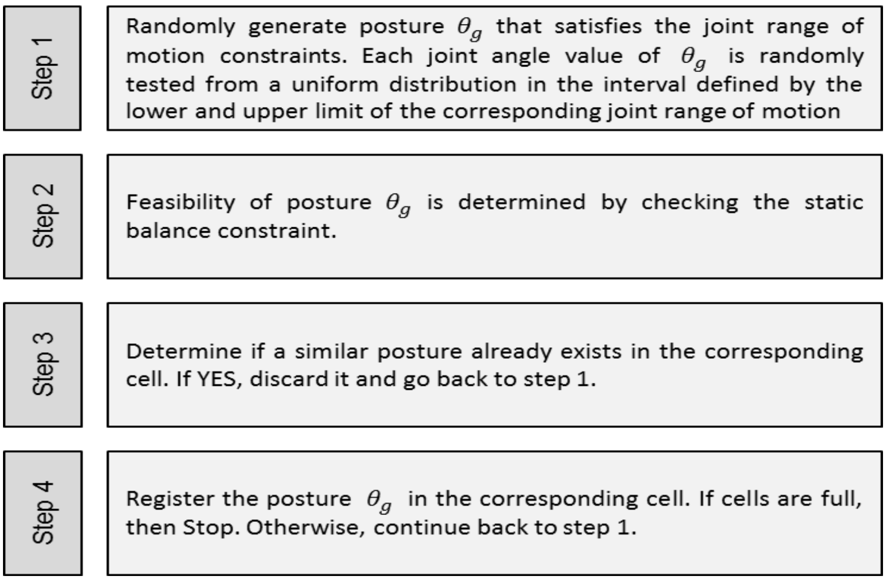

Figure 3-9 The random posture generation and registration process for

constructing cell contents

Table 3-1. Results of the Random posture generation

Number of test run	Total Feasible posture randomly generated	Number of postures stored in a cell
1	67,920	11,632
…	…	…
50	510,094	12,545
51	637,212	12,499
…	…	…
100	791,673	14,155
101	803,632	15,791
…	…	…
150	942,369	11,778
151	975,258	17,023
…	…	…
200	1×10^6	19,521

3.3.4. Obstruction Representation

Geometric primitive objects are used to represent obstructions in the given task space. In this model, there are two obstructions represented: (1) ceiling and (2) wall being built. Assuming that workspace of the brickmason is an indoor construction site, ceiling will be always assumed to be present.

A geometric primitive object can be specified by its particular location in the task space and relevant dimensions. For example, a 3-D box can be specified by its center position **c**, width **W**, height **H** and base **B** as shown in Figure 3-10 below.

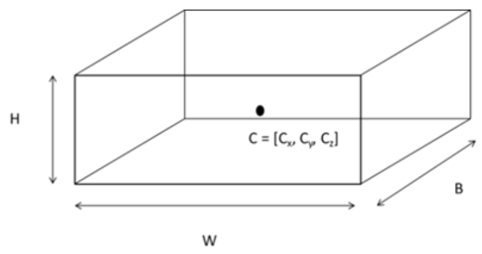

Figure 3-10 Example of geometric primitive object: a 3-D box

Moreover, a geometric primitive object is modelled as an artificial potential field for collision detection (Badler et al. 1994). The potential energy generated by this object is greatest at the center of the object and it decreases to zero on the surface or exterior of the surface (Park et al. 2006). For example, for any given point S=(S_x S_y S_z) in the 3D task space, the potential energy generated by a box object that are defined with c, W,B and H) can be mathematically expressed as below:

Potential(S, c, W, B,H)

$$= \begin{cases} 0 & \text{if } |S_x-c_x| \geq W/2 \text{ or } |S_y-c_y| \geq B/2 \text{ or } |S_z-c_z| \geq H/2 \\ (W/2-|S_x-C_x|)^2 + (B/2-|S_y-c_y|)^2 + (H/2-|S_z-c_z|^2 & \text{else} \end{cases} \quad \text{--------} \ (3)$$

This equation 7 is implemented from Park et al 2006 and Badler et al. 1994. The equation was improved to represent the 3D environment investigated in this study. The potential field modeling above enables collision detection between a geometric primitive object and a point object.

It can be simply classified into two groups: collision-free and collision. If a subject is outside of a geometric object or on the surface, it is defined as collision free and the potential energy generated by the primitive object is zero. On the other hand, if it is in collision, the potential energy is always positive.

3.4 Pseudo code of the M2B2P model

There are several ways to develop a program. Computer Scientist often uses an informal mixture of programming language and ordinary language called pseudo code (Malik, 2007).

Although the M2B2P model is based on the previous MBPP model, it has major differences in objectives that there are many differences in the algorithms. In order to help readers understand the basic mechanism behind the M2B2P model's algorithm, the pseudocode of the model is shown below in Figure 3-11. Full version of the code can be referred to the appendix.

```
close all;
clear all;
tic
weight = 70*9.81; % 설문에 참여한 조적공 평균 몸무게(kg)
stature = 180; % 설문에 참여한 조적공 상위 5% 키 (cm)
load = 0*9.81; % 작업에 쓰이는 벽돌의 무게 (kg)

num_trials=500000;

num_registered_L_posture = 0;
num_registered_R_posture = 0;
rec =[];

thresh = 40;

method=0;

X_tar = 20; Y_tar = -40;
Z_tar = 80;

L_tar = 10;
W_tar = 10;
H_tar = 10;
```

Figure 3-11 Example of pseudo code of the M2B2P model

In this sample pseudo code, information such as worker's stature, object location and object size, etc. are entered in the model. Based on the general information provided, the model will run and generate feasible set of postures for brickmason. Then, it can be noted that the postures produced will be different based on the location of the object and presence of obstacles in the virtual environment.

3.5 Summary

In this chapter, prior to developing the state-of-the-art M2B2P model, overview of framework for the posture modeling is introduced. In this framework, the latest motion capture technology using the Microsoft Kinect Sensor is introduced along with observation tool utilizing the Observer XT software. Based on the framework, in this study the main focus is to develop a robust posture prediction modeling called the M2B2P model.

The objective of the M2B2P model is to help identify awkward posture of indoor construction workers who are easily vulnerable to risk of developing work-related musculoskeletal disorders.

Chapter 4. Case Study

In the previous chapters, the state-of-the art M2B2P model is developed with an anticipation that it will help detect awkward postures of construction workers. The objective of this chapter is to investigate and test-run the M2B2P model by implementing brickmason as a subject in the model. Simple profile of real-life brickmason is shown in Table 4-1 below.

Table 4-1. Outline of case study subject information

Classification	Contents
Profession	Brickmason
Site Type	Apartment construction (Indoor)
Work experience	20 years
Object Information	Brick size (7.62 cm × 7.62 cm × 27.94 cm)
Physical Information	180 cm, average body type
Observation of job activities	 (Typical day job of Brickmason)

. Observation of everyday brickmason clearly shows that their workspace is in poor quality in terms of ergonomics perspective. Frequent bending and repetitive job task often cause awkward postures and seriously increase the risk of developing work-related musculoskeletal disorders.

4.1 3D representation of brickmason posture modeling

4.1.1 Overview

A brickmason with 20 years of experience representing ‘skilled labor’ is recruited for this case study. The subject is limited to indoor worker since during the motion capture process, Microsoft Kinect is used and its depth sensor, which is an infrared camera, works best in indoor environment. Also, out of many different types of construction workers, previous studies clearly showed that brickmason is easily vulnerable to WRMSD, especially lower back pain. Thus, after a series of observation as shown in Figure 4-1 below, it is detected that brickmason handles about 213 bricks per hour and bending occurred about 50% of working time.

Figure 4-1 Observation of brickmason during brick laying task

Poor workspace often leads to unavoidable awkward postures during construction work. This indicates that there is a room for improvements on construction sites to actively apply ergonomic design in workspace. However, in order to adopt ergonomic design on construction sites, the initial step is to develop the M2B2P model.

4.1.2 Posture modeling example

This model is used to pan target range postures for several brick locations and obstruction configuration typically representing everyday workspace environment of brickmason.

As shown in the example below, a 7.62 cm × 7.62cm × 27.94cm oversize brick is considered (For simplicity of calculation in the model, 8 cm × 8 cm × 30 cm is considered). A total of six obstruction configurations representing an indoor construction site (i.e. apartment construction site), including no obstruction condition is considered in Figure 4-2 below.

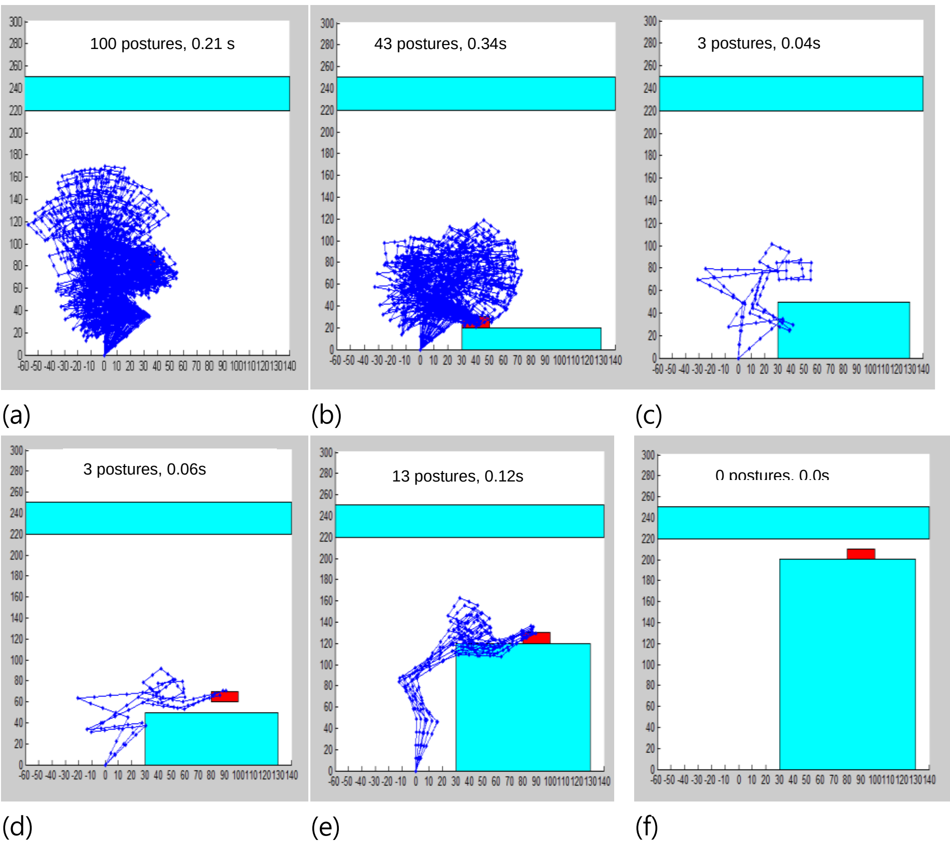

Figure 4-2 Brickmason constructing mason wall is represented in the model (a) No Obstruction (b) a single floor of the wall (c) increasing floor of the wall (d) model showing awkward posture (e) stable posture showed during wall height

similar to worker (f) extreme case

For each obstruction configuration, postures are planned for male brickmason with a height of 180cm. Then, an awkward posture is identified by modeling feasible set of postures for a brickmason. Also, this model tested some extreme cases where the height of a wall reaching near the ceiling. In actual construction site, workers often use trestles and bricklaying scaffolds to help minimize bending or ergonomically ‘unsafe’ activities.

4.2 Case Study Results and Discussion

4.2.1. Brickmason Case Study Results

The M2B2P model planned collision-free target reach postures for all 6 example posture planning problems. The model found a wide range of feasible postures for the ‘no obstruction’ and the less restricting configuration.

The posture planning results are shown in Figure 4-3 below. The number of feasible reach postures found and the time required to plan and display the posture are shown for each example in Table 4-2 below.

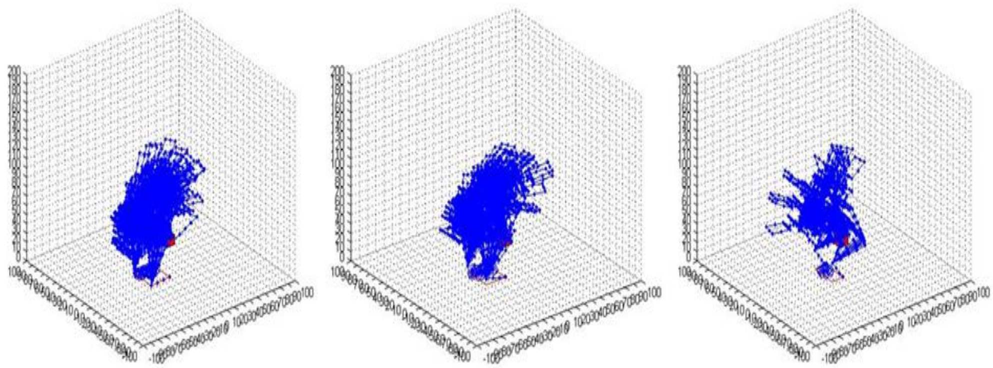

Figure 4-3 Posture planning example results

Table 4-2 Brickmason Case Study Results

Classification	Number of Postures stored	Time Duration
Case I	53	1.67s
Case II	46	1.91s
Case III	22	1.35s

Notice that time duration for all three cases are all relatively fast, which proves that this model can robustly pick out variety of postures that one can possibly generate in short period of time.

4.2.2 Discussion

As mentioned in earlier chapters, the M2B2P model inherited a key idea from an earlier memory based model by Park and his colleagues, mainly using geometric primitive object and energy potential method to represent the virtual task space.

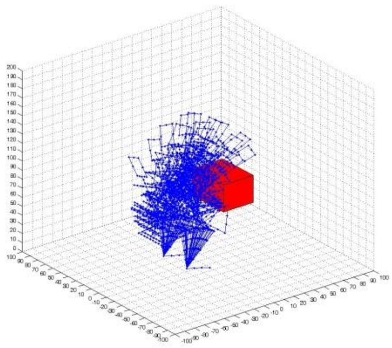

Figure 4-4 3D Link Model Representation of Brickmason

In particular, as shown in Figure 4-4, the M2B2P can analyze various postures that brickmason can carry out during work. Sequential overlay of linked human model can help identify awkward postures from safe postures. This can help provide more insightful guidelines to workers to help prvent developing work-related musculoskeletal disorders. Thus, it will significantly reduce the exposure of risk.

The result of test run simulation of the M2B2P model shows that it can robustly generate feasible set of postures in an abrupt manner of time. For instance, it took less than 2 seconds for all three cases with the result of up to 53 postures stored. This indicates that the model has promising results to implement on real construction sites in order to accurately study worker's posture.

Although, this model is in 3D compared to the previous 2D model of MBPP model, it still needs improvement such as incorporating building information modeling tools in order to improve the representation of real world construction site condition of the workers.

4.3 Summary

In this chapter, in order to test run the M2B2P model developed on earlier chapter, simple case study of real-life brickmason is introduced and the results are discussed. Although, there are still limitations in this model to accurately replicate real-life construction site situation, the test run result shows promising potential for further advanced research.

Chapter 5. Conclusions

5.1 Results and Discussion

Recently, there have been many research attempts in construction sector to integrate computer-aided visualization tools (i.e. Microsoft Kinect sensor) for enhancing safety management with an anticipation of monitoring and analysis of construction worker's behavior.

This study introduced a robust posture identification model of brickmason in order to classify awkward postures which are found to be one of the major causes of WRSMD. Unlike other deadly diseases such as cancer, recurring WRSMD can be stopped by primary prevention. Thus, primary focus of this study is to find a new method to control awkward posture of workers.

Moreover, in order to accurately identify posture of construction workers, the M2B2P model is developed. This model planned collision-free target reach postures for all six example posture planning problems (one human × six construction configurations).

The results of the model indicated a wide range of feasible postures for the 'no obstruction' and the less for 'the wall' configuration.

'

5.2 Contribution

Despite the prevalence of recurring WRMSD on various construction sites, many safety managers often neglected the importance of proper management of these illnesses. Unlike deadly diseases such as cancer, WRMSD can be reduced significantly by primary prevention. Although, this is an early stage research, this model has a high anticipation of contributing new method of primary prevention of WRMSD patients in construction field.

5.3 Further Study

There are various types of construction workers who are equally vulnerable on developing WRMSD. Furthermore, investigation on how to expand the subject of the model to other types of workers will be needed. Also, if possible further study on incorporating BIM to the current model to better reflect real-life environment will help improve the accuracy of this current model.

Appendices

Appendix A. Survey Form

Appendix B. The M2B2P model code

Appendix A. Survey Form

통계법 13조(비밀의 보호)에 의거 본 조사에서 개인의 비밀에 속하는 사항은 엄격히 보호됩니다.

ID				

안녕하십니까?

현재 서울대 건설기술연구실에서는 작업자들의 반복적인 작업으로 인하여 발생하는 근골격계 질환에 관한 연구를 하고 있습니다.

이에 본 설문조사는 건설근로자들을 대상으로 사용자의 요구사항 조사를 통하여 건설작업 환경 개선을 위한 방향 설정을 목적으로 작성된 것입니다.

본 설문조사의 내용은 **1) 직원 현황 조사 및 2) 건설 노무자 근골격계 질환 조사로 총 2개의 대항 목으로 구성**되어 있습니다.

향후 건설노무자들의 자세에 관한 연구 후 근로자 여러분들이 본 설문서가 요구하는 대로 정확하게 답변을 해 주신다면 건설산업에서 빈번히 발생하는 근골격계 질환을 관리할 수 있는 연구를 하는데 큰 도움이 될 것입니다. 본 설문의 개인신상 정보는 비공개로 처리될 예정입니다.

감사합니다. 2013. 11.

문의처 : 서울대학교 건설기술연구실 김태현 전화) 02-880-8311 e-mail) taehyunkim@snu.ac.kr

Part 1. 현장 건설근로자 일반 현황

☞ 다음은 현재 설문대상 근로자의 일반 현황에 대한 조사입니다. 질문을 잘 읽으시고 해당 번호에 체크(O 또는 V 표시) 해주시기 바랍니다.

1-1. 현장 건설근로자 현황 기초 조사

<table>
<tr><td rowspan="2">(1) 성 별</td><td>남</td><td>여</td><td rowspan="2">(2) 키, 몸무게</td><td>키</td><td>몸무게</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">(3) 연 령</td><td colspan="2">출생년도</td><td rowspan="2">(4) 현장명 (현장종류)</td><td colspan="2" rowspan="2"></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>(5) 직 종</td><td colspan="5">목공( ), 철근공( ), 미장공( ), 배관공( ), 조적공( ), 기타[기입]: ( )</td></tr>
<tr><td>(6) 현장경험</td><td colspan="5">6개월 이상 ~ 1년 미만( ), 1년 이상~5년 미만( ), 5년 이상~10년 미만( ), 10년 이상~20년미만( ), 20년 이상( )</td></tr>
<tr><td>(7) 하루평균 근로시간</td><td colspan="5">6시간 이하( ), 6시간 이상~8시간 미만 ( ), 8시간 이상~10시간 미만( ), 10시간 이상( )</td></tr>
</table>

1-2 한국 산업안전보건공단에서 발행한 근골격계 질환 예방 관리 프로그램 매뉴얼에 대하여 아십니까? (또는 교육받으신 적이 있습니까?)

구분	예	아니오

매뉴얼 인지 여부		
교육 이수 여부		

Part 2. 건설근로자의 근골격계질환 조사

☞ 다음은 현재 설문대상 건설근로자들의 현재 작업환경 대한 의견조사입니다. 질문을 잘 읽으시고 해당 번호에 체크(O 또는 V 표시) 해주시기 바랍니다.

2-1 작업 중 불편한 자세를 장시간(30분 이상) 필요로 합니까? (예: 쪼그리기)

①예	②아니오

"예"일 경우 구체적인 자세를 작성해주십시오.

2-2. 지난 일 년 동안 본인은 통증이 매일 지속적으로 일주일 이상 있었습니까?

①예	(통증부위:__________________________________)	②아니오	

구분	질문	아래 √ 하시오

		낮음 <----------보통--------->높음				
근무 피로도	귀하는 지난 한달 동안 작업이 끝나고 얼마나 종종 피곤을 느꼈습니까?	1	2	3	4	5
	귀하는 하루에 얼마나 반복적인 작업을 하십니까?	1	2	3	4	5
근무 내용	근육통증, 피로도 등으로 인하여 작업 중 실수를 하여 재작업을 해야 했던 경험이 있습니까?	1	2	3	4	5
	이러한 증상 때문에 결근 한 적이 있습니까?	1	2	3	4	5
	이러한 증상 때문에 작업을 바꾼적이 있습니까?	1	2	3	4	5
	작업 시 취급하는 대상물의 무게는 어떠한가? (예: 낮음 5kg 이하, 높음 20 kg 이상)	1	2	3	4	5
근무 환경	귀하의 현재 작업 현장 환경 만족도	1	2	3	4	5
	귀하께서는 현재 작업 현장 개선이 필요하다고 생각하십니까?	1	2	3	4	5

구분	질문	아래에 표기 (√) 하시오				
		낮음 <-----------보통----------->높음				
근무 자세	하루에 총 2시간 이상 머리 위로 손을 올리거나, 어깨 위로 팔꿈치를 올리는 반복적인 작업이 많습니까?	1	2	3	4	5
	작업 수행 위치? (예: 허리높이 아래 1, 어깨높이 이상 5)	1	2	3	4	5
	작업 시 유사한 손목이나 손의 동작이 반복적으로 수행 됩니까? (예: 분당 10회 이하 - 낮음, 분당 20회 이상 - 높음)	1	2	3	4	5
	운반 작업 시 허리의 반복성은? (예: 분당 3회 미만 – 낮음 / 분당 12회 이상 – 높음)	1	2	3	4	5

	작업 시 정적인 동작이 있는가?	1	2	3	4	5
	작업시 허리는? (예: 똑바로폄 –1 / 약간 굽히거나 비틈 (20~60도) - 3 / 과도하게 굽히거나 비틈 – 5)	1	2	3	4	5

구분	질문	아래에 표기 (√) 하시오				
체력 관리	여가 생활로 따로 체력관리를 하십니까?	축구	헬스	등산	조깅	기타(______)
	체력관리를 통해 부상방지에 도움이 얼마나 된다고 생각하십니까?	낮음 <-----------보통----------->높음				
		1	2	3	4	5

-설문에 참여해 주셔서 감사합니다-

Appendix B-1 The M2B2B Model MATLAB Code – the program.m code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
This program identifies feasible postures of
construction mason with a height of 180 cm
BECEILING will be constantly present in the model
representing the ceiling
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


function y = RANDOM_POSTURE(stature);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
조적공 전신 동작 랜덤 생성 코드
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
p1_L = -90 + (-35);
p1_U = -90 + (+35);
p1 = p1_L + rand (1)*(p1_U - p1_L);
p2_L = 0;
p2_U = 110;
p2 = p2_L + rand(1)*(p2_U - p2_L); % L, R Knee flexion (ROM: 70.54
=> 180-70.54) -> 약 110도로 설정

p3_L = -60; % 0도가 선 자세
p3_U = 45;
p3 = p3_L + rand(1)*(p3_U - p3_L); % L, R Hip flexion (ROM: -
60.85(앞쪽 굽힘) ~ 47(뒤쪽굽힘)) -> 약 -60, 45도로 설정

p4_L = -85; p4_U = 0;
p4 = p4_L + rand(1)*(p4_U - p4_L); % Spine flexion (ROM: -86.14(앞쪽
굽힘) ~ 0(뒤쪽 굽힘)) ->약 -85도로 설정

p5_L = -40; % 0도가 정 자세
p5_U = 40;
p5 = p5_L + rand(1)*(p5_U - p5_L); % Spine lateral flexion (ROM: -
41.6(왼옆쪽굽힘) ~ 45.05(오른옆쪽굽힘)) -> 좌우 다 약 40도로 설정

p6_L = (-180)-(60); % -180도가 정 자세
p6_U = (-180)-(-170);
p6 = p6_L + rand(1)*(p6_U - p6_L); % R Shoulder flexion (ROM:
61.67(뒤쪽굽힘) ~ -171.24(앞쪽굽힘)) -> 약 60, -170으로 설정
```

```
p7_L = -110; % 0도가 정자세
p7_U = 50;
p7 = p7_L + rand(1)*(p7_U - p7_L); % R Shoulder abduction (ROM: 53.99(안쪽꺽임) ~ -114.46(바깥쪽꺽임)) -> 약 50, -110으로 설정

p8_L = 0; % 0도가 정자세
p8_U = 130;
p8 = p8_L + rand(1)*(p8_U - p8_L); % R Elbow flexion (ROM: 133.24(안쪽꺽임) ~ 0(바깥쪽꺽임)) ->약 130으로 설정
p9_L = (-180)-(60); % -180도가 정 자세
p9_U = (-180)-(-170);
p9 = p9_L + rand(1)*(p9_U - p9_L); % L Shoulder flexion (ROM: 61.67(뒤쪽굽힘) ~ -171.24(앞쪽굽힘)) -> 약  60, -170으로 설정

p10_L = -50; % 오른쪽 왼쪽 반대 부호
p10_U = 110;
p10 = p10_L + rand(1)*(p10_U - p10_L); % R Shoulder abduction (ROM: 53.99(인쪽꺽임) ~ -114.46(바깥쪽꺽임)) -> 약 50, -110으로 설정

p11_L = 0; % 0도가 정자세
p11_U = 130;
p11 = p11_L + rand(1)*(p11_U - p11_L); % L Elbow flexion (ROM: 133.24(안쪽꺽임) ~ 0(바깥쪽꺽임)) -> 약 130으로 설정

% p1 = -90;
% p2 = 0;
% p3 = 0;
% p4 = 0;
% p5 = 0;
% p6 = -180;
% p7 = 0;
% p8 = 0;
% p9 = p6; % L Shoulder flexion
% p10 = p7; % L Shoulder abduction
% p11 = p8; % L Elbow flexion

y = [p0 p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11];
```

Appendix B-2 The M2B2B Model MATLAB Code – the BPLOT.m code

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
This function defines the obstacles including the
ceiling. It will model the workspace of the mason
as he/she lays the brick to build the wall. Different
feasible posture will be modeled based on this
changing obstacle.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

close all;
clear all;
tic
weight = 70*9.81; % 설문에 참여한 조적공 평균 몸무게(kg)
stature = 180; % 설문에 참여한 조적공 상위 5% 키 (cm)
load = 0*9.81; % 작업에 쓰이는 벽돌의 무게 (kg)

num_trials=500000;

num_registered_L_posture = 0;
num_registered_R_posture = 0;
rec =[];

thresh = 40;

method=0;

X_tar = 20; Y_tar = -40;
Z_tar = 80;

L_tar = 10;
W_tar = 10;
H_tar = 10;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

if (method==1),
  for i=0:10:200,
         for j=-100:10:100,
             for k=-100:10:100
```

```
                cname = ['CELL_X' num2str(k) 'Y' num2str(j) 'Z'
num2str(i)];
                cname = strrep(cname, '-', 'N');

                a = fopen(cname, 'w');
                fprintf(a, '');
                fclose(a);

            end;
        end;
    end;
end;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

L = LINK(stature);
L0 = L(1);
L1 = L(2);
L2 = L(3);
L3 = L(4);
L4 = L(5);
L5 = L(6);
L6 = L(7);
L7 = L(8);
L8 = L(9);
L9 = L(10);
L10 = L(11);
L11 = L(12);
L12 = L(13);
L13 = L(14);
Neck = L(15);
Head = L(16);
HeadWidth = L(17);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for i=0:10:200,
    for j=-100:10:100,
        for k=-100:10:100

        cell_name = ['CELL_X' num2str(k) 'Y' num2str(j) 'Z' num2str(i)];
        cell_name = strrep(cell_name, '-', 'N');
        eval(sprintf('%s = [];', cell_name));
```

```
        end;
    end;
end;


for i=1:num_trials,

    P = RANDOM_POSTURE(stature, heel_height);
    HAND_LOC = HAND_LOCATION(L,P);

    LHAND_LOC = [HAND_LOC(1) HAND_LOC(2) HAND_LOC(3)];
    RHAND_LOC = [HAND_LOC(4) HAND_LOC(5) HAND_LOC(6)];

    SHOULDER_LOC = SHOULDER_LOCATION(L,P);

    LSHOULDER_LOC = [SHOULDER_LOC(1) SHOULDER_LOC(2)
SHOULDER_LOC(3)];
    RSHOULDER_LOC = [SHOULDER_LOC(4) SHOULDER_LOC(5)
SHOULDER_LOC(6)];

    L_H_S_DIST = norm(LHAND_LOC - LSHOULDER_LOC, 3);
    R_H_S_DIST = norm(RHAND_LOC - RSHOULDER_LOC, 3);

    COM_LOC = COM_LOCATION_3D(L, P, weight, load);
    JOINT_LOC = JOINT_LOCATIONS(L, P);

    while ( (L_H_S_DIST<30) | (R_H_S_DIST<30) | (LHAND_LOC(3)<0)
| (RHAND_LOC(3)<0) | (LHAND_LOC(2)<0) | (RHAND_LOC(2)>0) |
(COM_LOC(1)>JOINT_LOC(1)) | (COM_LOC(1)<JOINT_LOC(7)) |
(COM_LOC(2)>JOINT_LOC(2)) | (COM_LOC(2)<JOINT_LOC(4))),

        P = RANDOM_POSTURE(stature, heel_height);
        HAND_LOC = HAND_LOCATION(L,P);

        LHAND_LOC = [HAND_LOC(1) HAND_LOC(2) HAND_LOC(3)];
        RHAND_LOC = [HAND_LOC(4) HAND_LOC(5) HAND_LOC(6)];

        SHOULDER_LOC = SHOULDER_LOCATION(L,P);

        LSHOULDER_LOC = [SHOULDER_LOC(1) SHOULDER_LOC(2)
SHOULDER_LOC(3)];
        RSHOULDER_LOC = [SHOULDER_LOC(4) SHOULDER_LOC(5)
SHOULDER_LOC(6)];

        L_H_S_DIST = norm(LHAND_LOC - LSHOULDER_LOC, 3);
```

```
        R_H_S_DIST = norm(RHAND_LOC - RSHOULDER_LOC, 3);

        COM_LOC = COM_LOCATION_3D(L, P, weight, load);
        JOINT_LOC = JOINT_LOCATIONS(L, P);

    end;

    RXX = num2str(floor(RHAND_LOC(1)/10)*10);
    RYY = num2str(floor(RHAND_LOC(2)/10)*10);
    RZZ = num2str(floor(RHAND_LOC(3)/10)*10);

    cell_name = ['CELL_X' RXX 'Y' RYY 'Z' RZZ];
    cell_name = strrep(cell_name, '-', 'N');

    eval(['a = ' cell_name ';']);

    temp = size(a);

    RP = [P(1) P(2) P(3) P(4) P(5) P(6) P(7) P(8) P(9) P(7) P(8) P(9)];

    if (temp(1) == 0),
        eval(sprintf('%s = [%s; %s %s];', cell_name, cell_name,
num2str(RP), num2str(RHAND_LOC)));

   end;

    flag = 0;

    if (temp(1)~=0),

        for j=1:temp(1),

            dist = sqrt((a(j,1)-P(1))^2 + (a(j,2)-P(2))^2 + (a(j,3)-P(3))^2
+ (a(j,4)-P(4))^2 + (a(j,5)-P(5))^2 + (a(j,6)-P(6))^2 + (a(j,7)-P(7))^2
+ (a(j,8)-P(8))^2 + (a(j,9)-P(9))^2 + (a(j,10)-P(10))^2 + (a(j,11)-
P(11))^2 + (a(j,12)-P(12))^2);

            if (dist<thresh),
                flag=1;
                break;
            end;

        end;

        if (flag==0),
```

```
            eval(sprintf('%s = [%s; %s %s];', cell_name, cell_name,
num2str(RP),                                    num2str(RHAND_LOC)));
num_registered_R_posture = num_registered_R_posture + 1;

        end;

    end;


    if (mod(i,1000)==0),
        rec      =      [rec;      i      num_registered_L_posture
num_registered_R_posture]
    end;


end;

if (method==1),
    for i=0:10:200,
        for j=-100:10:100,
            for k=-100:10:100

              cname = ['CELL_X' num2str(k) 'Y' num2str(j) 'Z'
num2str(i)];
              cname = strrep(cname, '-', 'N');

              a = fopen(cname, 'w');
              eval(sprintf('P = [%s];', cname));

              fprintf(a, '%f₩n', P');
              fclose(a);

            end;
        end;
    end;
end;

toc
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

figure (1);
axis([-100 100 -100 100 0 200]);

set(gca, 'Xtick', -100:10:100);
set(gca, 'Ytick', -100:10:100);
```

```
set(gca, 'Ztick', 0:10:200);

grid on;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

B = [0 0 0 0 0 0]; % No obstacles
%B = [-10 -40 50 40 80 10]; % wall
%B = [-10 -40 50 40 80 10; 0 10 80 10 10 10]; % wall+ ceiling

BPLOT(B);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

T = [X_tar Y_tar Z_tar L_tar W_tar H_tar];

TPLOT(T);

XX = num2str(floor(X_tar/10)*10);
YY = num2str(floor(Y_tar/10)*10);
ZZ = num2str(floor(Z_tar/10)*10);

cell_name = ['CELL_X' XX 'Y' YY 'Z' ZZ];
cell_name = strrep(cell_name, '-', 'N');

possibleP = 0;
impossibleP = 0;

if (method==0),
     eval(sprintf('P = [%s];', cell_name));

     temp = size(P);
     numP = temp(1);
     TorqueStorage = ones(numP,31);
     TorqueNorm = ones(numP,12);

     if (numP~=0),
          for i=1:numP,

          totalPotential = POTENTIAL(L,   P(i, :), B);

               if (totalPotential==0)

                    COM_LOC_OP = COM_LOCATION_3D(L, P(i,:), weight,
load);
                    MA=R(L, P(i,:), COM_LOC_OP);
```

```
                temp =   TORQUE(MA(1,:), WEIGHT(weight, load));
                for j=2:10
                    temp = [temp TORQUE(MA(j,:), WEIGHT(weight,
load))];                end

                tempNorm = TORQUENORM(temp);
                s = LOCATE (L, P(i, :));
                stability = BOS(s,COM_LOC_OP);

                temp=[temp stability];
                tempNorm=[tempNorm stability];
                TorqueStorage(i,:) = temp;
                TorqueNorm(i,:) = tempNorm;

                X = s(1:31,1);
                Y = s(1:31,2);
                Z = s(1:31,3);

                hold on;
                plot3(X, Y, Z, '.-')

                X = s(32:56,1);
                Y = s(32:56,2);
                Z = s(32:56,3);

                hold on;
                plot3(X, Y, Z, '.-')

                X = s(57:77,1);
                Y = s(57:77,2);
                Z = s(57:77,3);

                hold on;
                plot3(X, Y, Z, '.-')

                hold on;

                plot3(COM_LOC_OP(1),COM_LOC_OP(2),0,'o');
                possibleP = possibleP +  1;

            end;
        end;
    end;
end;
```

```
if (method==1),
     P = load(cell_name);

     temp = size(P);
     numP = temp(1)/14;
     TorqueStorage = ones(numP,31);
     TorqueNorm = ones(numP,12);

     if (numP~=0),
          for i=0:numP-1,

          tempP(1) = P(1+ 14*i, 1);
          tempP(2) = P(2+ 14*i, 1);
          tempP(3) = P(3+ 14*i, 1);
          tempP(4) = P(4+ 14*i, 1);
          tempP(5) = P(5+ 14*i, 1);
          tempP(6) = P(6+ 14*i, 1);
          tempP(7) = P(7+ 14*i, 1);
          tempP(8) = P(8+ 14*i, 1);
          tempP(9) = P(9+ 14*i, 1);
          tempP(10) = P(10+ 14*i, 1);
          tempP(11) = P(11+ 14*i, 1);
          tempP(12) = P(12+ 14*i, 1);
          tempP(13) = P(13+ 14*i, 1);
          tempP(14) = P(14+ 14*i, 1);

          totalPotential = POTENTIAL(L,  tempP, B);

               if (totalPotential==0),

                    COM_LOC_OP = COM_LOCATION_3D(L, tempP,
weight, load);
                    MA=R(L, tempP, COM_LOC_OP);
                    temp =  TORQUE(MA(1,:), WEIGHT(weight, load));
                    for j=2:10
                         temp = [temp TORQUE(MA(j,:), WEIGHT(weight,
load))];
                    end

                    tempNorm = TORQUENORM(temp);
                    s = LOCATE (L, tempP);
                    stability = BOS(s,COM_LOC_OP);

                    temp=[temp stability];
                    tempNorm=[tempNorm stability];
```

```
                TorqueStorage(i,:) = temp;
                TorqueNorm(i,:) = tempNorm;

                X = s(1:25,1);
                Y = s(1:25,2);
                Z = s(1:25,3);

                hold on;
                plot3(X, Y, Z, '.-')

                X = s(26:50,1);
                Y = s(26:50,2);
                Z = s(26:50,3);

                hold on;
                plot3(X, Y, Z, '.-')

                X = s(51:71,1);
                Y = s(51:71,2);
                Z = s(51:71,3);

                hold on;
                plot3(X, Y, Z, '.-')

                possibleP = possibleP +  1;

            end;
        end;
    end;
end;

registeredP = numP
possibleP = possibleP
```

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국 문 초 록

오늘날 한국을 포함한 선진국들의 건설산업 근로자들의 평균연령이 점점 고령화 되고 있다. 육체노동 집약적인 일들이 많은 건설 현장에서 고령화가 급속하게 진행되는 근로자들은 근골격계질환에 쉽게 노출되는 상황이다. 그러나 아직까지 현장에서 이에 대한 체계적인 관리가 미흡하고 안전관리자 및 현장근로자들의 관심 또한 미비한 실정이다. 이에, 최근 산업계에서도 Health, Safety, 및 Environment 의 중요성을 인지하게 되었고 기존의 연구들은 건설산업에서도 타 산업 (예: 제조업, 중공업 등) 처럼 인간공학적인 작업환경 설계를 적용할 수 있는 방안을 많이 진행하였다. 특히, 국외에서는 컴퓨터 시각화 기술을 이용하여 작업자들의 자세를 모델링 하려는 시도가 많다. 이에 본 연구는 건설현장에서 주로 발생하는 근골격계질환 위험 요소를 분석하여 그 질환을 저감시킬수 있는 요인들을 찾고, 이를 반영한 작업 중 자세 도출 모델인 M2B2P 모델을 제시하고자 한다.

제시된 모델은 1) Microsoft Kinect 센서의 동작인식을 위하여 실내 작업이 많은 근로자로 제한을 하고 2) 반복적인 작업이 빈번하고 작업환경 특성상 부적합한 자세가 많은 조적공을 선정한다. 기존의 이론에서 도출된 작업중 자세 모델로부터 3 차원 보정을 추가함으로써 작업 중 부적합한 자세를 쉽게 분류하도록

한다. 조적공의 사례분석을 통해 제시된 모델의 유효성을 확인함으로써 반영된 저감요인들의 타당성을 확인한다. 이를 통해 기존의 이론을 보완하고 건설산업에서의 인간공학 이론을 재정립하는 데 기여할 수 있으며 이를 바탕으로 건설 현장에서 부적합한 자세 및 인간공학적인 작업환경 계획을 수립하는데 도움을 줄 수 있다. 또한 건설 프로젝트에서 자주 발생하는 직업성 질환을 효율적으로 관리할 수 있는 방안에 대한 해답을 줄 수 있을 것으로 기대된다.

주요어: 안전관리, 근골격계질환, 인간공학, 조적공, 동작 분석, 인간성능

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