Development of a Real-Time Ergonomic Assessment Tool to Minimize Musculoskeletal Disorders Risk

Anisa Fauziah
Department of Industrial Engineering and Management
Institut Teknologi Bandung
Bandung, West Java, Indonesia
anisafauziah@students.itb.ac.id

Khoirul Muslim
Department of Industrial Engineering and Management
Institut Teknologi Bandung
Bandung, West Java, Indonesia
kmuslim@ti.itb.ac.id

Septian Dwi Chandra
Firmware Design Department
PT. Indonesia Epson Industry
Bekasi, West Java, Indonesia
septian.d.chandra@gmail.com

Abstract

This study proposes a design of an assessment tool that provide real-time feedback on ergonomic risks to workers based on their postures. Field study was performed by conducting direct visits to a manufacturing plant in Indonesia observing several production tasks to obtain primary data related to complaints of Work-Related Musculoskeletal Disorders (WMSDs) in the workplace. Tasks with a higher risk of injury were selected to perform task analysis to segment the task steps and to select appropriate risk assessment methods available such as Rapid Entire Body Assessment (REBA), Rapid Upper Limb Assessment (RULA), Ovako Working Posture Analysis System (OWAS), etc. An appropriate assessment tool was selected based on the critical characteristics of the tasks. In this study, the tasks being evaluated included cleaning up the residues of production, grinding processes, manual bending, and welding, and the appropriate assessment method used was OWAS. Measures to be considered as WMSDs risk factors were the posture of back, arms, legs, and weight being handled. These measures were considered in the design of the sensor system that integrated seven Inertia Measurement Units (IMU) placed on the specified body parts based on OWAS assessment method. An IMU sensor contains a tri-axial accelerometer, a tri-axial gyroscope, and a tri-axial magnetometer. In the proposed system, body segment angle values obtained from each of IMU sensor were saved in a log and uploaded into an online database using an android based application. In the android application, the score shows the value at risk, a warning signal is provided to the worker, and the signal is recorded into the database when the risk condition occurs in the form of a log.

Keywords

WMSDs, OWAS, real time, system sensors, IMU

1. Introduction

Highly increasing industrial competition requires company to increase their productivity. However, higher productivity can be hindered by work related musculoskeletal disorders (MSDs) prevalence among workers. WMSDs have been reported as the leading cause of industrial injury in developed and developing countries (Pollak and Castillo 2020). WMSDs can be defined as disorders that damage structure in the tendons, muscles, bones and joints, nerves, and vascular system (Simoneau et al. 1996). WMSDs can potentially cause for disruption and a decrease in the condition of muscles, bones, and joints and ultimately can impact work performance and worker productivity (Dewi 2016). For example, the United States has reported that WMSDs was the leading cause of occupational diseases and led to a total loses of around 850,000 workdays each year, with total medical expenses incurred reaching $ 20 billion to $ 43 billion (Humantech 2003).

Risk factors related to WMSDs include workload, work posture, repetition, and activity duration (Bridger 2003). Many aspects of industrial tasks require physical effort, especially manual material handling (Vignais et al. 2013), which increase physical workload. WMSDs caused by manual handling represent a large proportion of all WMSDs (Burgess-Limerick 2007, Euzenat 2010 in Vignais et al. 2013) and are a significant public health problem. In Indonesia, the use of human labor in the industrial world is still very dominant, especially for small and medium manufacturing industry players. Poor work posture causes static loading on specific soft tissues continuously. Repetition means doing activities with the same type of movement repeatedly in a short time (less than 30 seconds) and for more than 1 hour. It can damage parts of the body because the body continuously uses the same muscles and soft tissues and makes a person fatigued (Valinejadshoubi 2013). Activity duration is the amount of time required by workers to do work by considering the risk factors contained in work. The length of working time (duration) is related to the physical condition of the worker's body. If the work lasts for a long time without rest, the body's ability will decrease and cause pain in the limbs (Bridger 2003).

WMSDs can be improved by evaluating ergonomics risk factors in the workplace (Vignais et al. 2017). Current standard methods and procedures are mainly observational. Expert appraisers help a worker either during the activity or afterward by visual inspection of the recordings and manually filling out the appropriate checklists (Giannini et al. 2020). Some ergonomic assessment standards in the manufacturing industry include Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Ovako Working Posture Analysis System (OWAS), Occupational Repetitive Actions (OCRA) or Ergonomic Assessment Worksheet (EAWS) (Battini et al., 2014). The advantage of these methods include its simplicity that the rater does not need the experience to apply it during the observation phase (McAtamney and Corlett, E.N. 1993), and not too complicated to implement because it can be assisted by software (Takala et al. 2010). Apart from its advantages, this method has a weakness, namely subjective depending on a worksheet filled out by a field expert to perform a posture analysis to take quite a long time. (Malaise et al. 2019, Manghisi et al. 2017, Battini et al. 2014). These methods are more suitable for recording and analyzing simulated tasks, practical surveys in the workplace.

In contrast, the direct assessment method has the advantage of being more accurate compared to other methods since it provides direct information on various exposure variables (Gómez-Galán et al. 2017, Li and Buckle 1999). In term of reliability, direct measurement techniques have also been reported to be superior compared to others (David 2005). Another objective method can be done by designing an ergonomics evaluation method that provides real-time feedback on the evaluation of work postures and provides benefits in practice (Vignais et al. 2013, Mullineaux et al. 2012). One of the ergonomic assessment tools developed by several researchers today to solve this problem has come in the form of a sensor system. Sensor systems provide faster and more individual-focused ergonomic risk assessment, and hazard communication between practitioners and workers with the support of existing technology (Lee et al. 2017). Real-time systems can provide workers with information about their ergonomic behavior in current conditions so that that posture can be immediately modified (Vignais et al. 2013, Mullineaux et al. 2012). Furthermore, in the long term, the relationship between certain and dangerous postures can be studied by workers (Mullineaux et al. 2012). Currently, no direct assessment tool has been used in the industry to provide workers with real-time ergonomic information about their posture and movements (Malaisé et al. 2019), especially in Indonesia. This study aimed to design a real-time ergonomic risk factors assessment that can potentially help reduce the risk factors for WMSDs by available technology such as inertia measurement units (IMUs), which is small, inexpensive, and have low power requirement (Vignais et al. 2013).

1.1 Objectives

Designing a real-time ergonomic assessment tool for workers in the Indonesian manufacturing industry using a sensor system that can provide real-time feedback to workers to help reducing musculoskeletal disorders risk.

2. Literature Review

To prevent WMSDs in the workplace can be applied is to evaluate risk factors by planning a workplace redesign that considers ergonomic aspects (Manghisi et al. 2017). An ergonomic assessment was very important in preventing WMSDs (Tee et al. 2017) because it was closely related to productivity and movement efficiency, and operational safety (Battini et al. 2011). The method developed to achieve this is divided into three groups: self-report, direct measurement, and observational (Manghisi 2017). Ergonomic assessment methods that are popular and often referred to by researchers in ergonomic studies are RULA and REBA (Tee et al. 2017). The self-report method uses workers' diaries containing workplace exposures to physical and psychosocial factors, interviews, and questionnaires (David 2005, Battini et al. 2014). In general, data collection was done using written records. Still, now evaluations have begun to be carried out using video (Kadefors and Forsman 2000) or the use of web-based questionnaires (Dane et al. 2002). The advantage of this method is that it is easy to use, can be applied to various working situations and conditions, and is suitable for evaluating a large number of subjects at a relatively low cost. The weakness of this method is still subjective due to the possibility of different interpretation, understanding, and perception of fatigue from each operator, as well as its limited use and the results, need to be understood and validated further (Battini et al. 2014). The level of difficulty of the self-report method may vary depending on the worker's literacy, reading comprehension, or question interpretation (Spielholz et al. 2001). The reliability and validity of self-report methods are also too low to be used as a basis for ergonomic interventions in the workplace (Li and Buckle 1999).

Several simple methods, such as the observation method, have been developed to record exposure to ergonomic risks in the workplace and are based on direct observation of workers in the workplace. David (2005) divides this method into two types: simpler observation and advanced observation method. The first method was to record workplace exposures using check sheets, such as RULA, REBA, OWAS, etc. This check sheet evaluates the key biomechanical factors of WMSDs, including posture, external force or load manipulation, and task repetition (Manghisi et al. 2017). The secondary method was developed to evaluate posture variations for highly dynamic activities that record data either on videotape or analyzed by a computer using specialized software. This second type of observation method can also be field-based or video-based. These methods have the advantage of being cheap and practical to use in various workplaces. If other methods are used, it would be challenging to observe workers because of the disturbances caused (David 2005). This method has the main drawback: it requires field experts to perform posture analysis for a long time. Then, data were collected through subjective observations using pictures or videos (Manghisi et al. 2017).

David (2005), in his research, explains that the main challenge was choosing the proper method and the combination of these methods. Observation-based assessments are judged to best suit the needs of occupational safety and health practitioners (or those from related professions) who have limited time and resources and need a basis for setting priorities for intervention. Direct observation and video analysis of activities on construction workers have many limitations. Then, the sensor system can be used for ergonomic evaluation. This system was considered to be able to carry out ergonomic risk assessments faster and more focused on individuals (Lee et al. 2017) and provide benefits in practice (Mullineaux et al. 2012). In addition, this system makes hazard communication between practitioners and workers improved supported by existing technology (Lee et al. 2017).

The direct method consists of using specific electronic devices on the human body to measure work posture (Gómez-Galán et al. 2017). This method uses a monitoring instrument that relies on sensors attached directly to the subject for the measurement of exposure variables in the workplace (David 2005) and recording the angle, distance, and velocity of elements for analysis (Gómez-Galán et al. 2017). Direct measurement was usually used as a standard criterion for assessing ergonomic exposure (Spielholz 2001). This method also includes methods based on optical motion capture systems and fully wearable systems. Bortolini et al. (2018, 2020) developed an automatic software called Motion Analysis System (MAS) that quantitatively analyzes the ergonomic risks of operators performing manual and assembly tasks in the industry. This technology integrates a network of cameras and software to calculate a set of ergonomic indices, such as NIOSH, OWAS, RULA, REBA, and the first three sections of EAWS. MAS would be used to automatically evaluate industrial workplaces before and after optimization measuring the improvements achieved. According to Mullineaux et al. (2012), this system provides an advantage because it allows measuring posture in real-time and processes ergonomics evaluation online. Giannini et al. (2020) explained that if this system could provide workers with information about their current posture, they would be able to correct that posture immediately.

Vignais et al. (2013) researched an innovative system for real-time ergonomics feedback in the manufacturing industry using the real-time RULA method based on direct measurements using IMUs and goniometers for upper body posture.

Real-time feedback can help workers to determine correct posture and reduce the risk of WMSDs. Then Vignais et al. (2017) conducted research using the RULA and IMUs methods only for medical material workers. Research by Manghisi et al. (2017) and Schall et al. (2016) conducted a study on ergonomics assessment for workers in the medical department with RULA and IMUs. Giannini et al. (2020) conducted a study by integrating four ergonomic assessment tools, namely REBA, NIOSH, SI, and Snook & Ciriello, for ergonomics evaluation in the construction sector. The advantage of this method is that it is precise, and data can be collected automatically, and it was possible to monitor different variables over time. On the other hand, the main drawbacks are the high economic costs (Gómez-Galán et al. 2017; Manghisi et al. 2017), annoying and time-consuming (Spielholz 2001; Manghisi et al. 2017), and the difficulty of using this method in real-time in many work environments. The direct method can cause inconvenience to work when the sensor was operated, especially when the sensor requires a cable (Gómez-Galán et al. 2017). This method also has functional limitations related to musculoskeletal disorders that require further validation (Spielholz 2001).

3. Methods

Field study was performed by conducting direct visits to a manufacturing plant in Indonesia by observing several production tasks to obtain primary data related to complaints of WMSDs in the workplace. This data was used to obtain a biomechanical model based on worker activities. Tasks with higher risk of injury were selected to perform task analysis to segment the task steps and to select appropriate risk assessment methods available such as REBA, RULA, OWAS, etc. Sequentially, an appropriate assessment tool was selected based on the critical characteristics of the tasks. In this study, the tasks being evaluated included cleaning up the residues of production, grinding processes, manual bending, and welding.

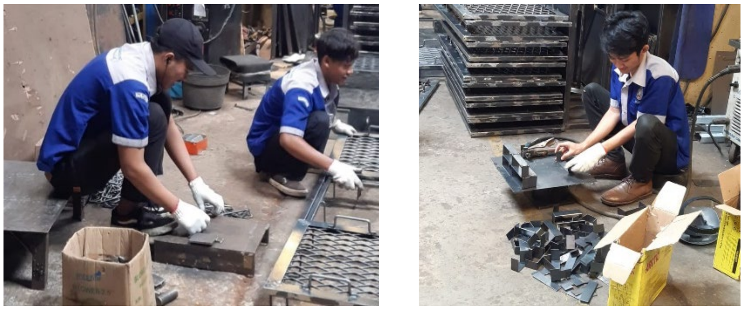
The sensor system was designed based on appropriate measures found in the task analysis related to ergonomic risk factor and selected assessment method. The assessment sensor system consisted of integration of seven IMUs placed on the specified body parts, namely the back, upper and lower arms of the right and left, as well as the right and left legs. IMUs sensor contains a tri-axial accelerometer, a tri-axial gyroscope and a tri-axial magnetometer. Data from the IMUs were processed using an android based application.

4. Data Collection

4.1 Field Study

Researchers observed work units, where workers have a higher risk of injury. Interviews with several workers were performed to obtain information on WMSD complaints that often occurred while doing their job. Tasks performed by the workers were analyzed by breaking them down into steps to identify its ergonomic risks. In this study, the tasks being evaluated included cleaning up the residues of production, grinding processes, manual bending, and welding (Figure 1).


(a) (b)



(c) (d)

Figure 1. The evaluated tasks in the research (a) cleaning up the residues of production, (b) grinding processes (c) manual bending, and (d) welding

Based on the characteristics of tasks performed by the workers, methods for ergonomic risk evaluation including REBA, RULA, OWAS, etc. were evaluated. Since most WMSDs risk factors were the posture of back, arms, legs, and weight being handled, OWAS was considered to be the most suitable method for assessment. Further, OWAS was chosen based on its simple scoring method make it easy to read and understood.

4.2 Variable Mapping

OWAS method was used to identify and evaluate poor work posture. This method consists of two parts; namely, an observation technique to evaluate work posture and a set of criteria for redesigning the method and workplace. It considers several factors related to health and safety, but the primary emphasis is on the discomfort caused by work posture (Karhu et al. 1977). The parameters that must be set manually and those calculated can be seen in Table 1.

Table 1. Parameters that must be set manually and calculated in the proposed system

Step	**Descripts**	**Variable**		**Task Analysis Input**	**Calculated**
1	Back	1	Straight	N	Y
		2	Bent	N	Y
		3	Twisted or bent to one side	N	Y
		4	Bent and twisted or bent and bent to one side	N	Y
2	Arms	1	Both arms below the shoulder level	N	Y
		2	An arm above shoulder level	N	Y
		3	Both arms above shoulder level	N	Y
3	Legs	1	Sitting, legs below seat level	N	Y
		2	Standing, legs straight	N	Y
		3	Standing on one leg, leg straight	N	Y
		4	Standing on both legs, legs bent	N	Y
		5	Standing on one leg, leg bent	N	Y
		6	Kneeling on one or both knees	N	Y
		7	Walking or moving	N	Y
4	Load	1	Less than 10 kg	Y	N
		2	Over 10 kg but less than 20 kg	Y	N
		3	More than 20 kg	Y	N
Output		Final Score		N	Y (from table)

Note: Y = Yes; N = No

4.3 System Design

Based on section 4.2, measures considered as risk factors for WMSDs were back posture, arms, legs, and body weight being handled. This posture change was incorporated into the sensor system design. The sensor used was the IMUs integration, consisting of seven sensors placed on the specified body parts, namely the back, right and left upper arms, and right and left upper and lower legs. The IMUs sensors contain a tri-axial accelerometer, a tri-axial gyroscope, and a tri-axial magnetometer.

Gyroscopes were used to measure or maintain orientation on the principle of establishing angular momentum. It can detect the movement of workers according to gravity, or in other words, detect the signs of workers during activities that occur on the x (roll), y (pitch), and z (yaw) axis of the worker's body. The accelerometer was used to detect the magnitude of the earth's gravity vector on the worker's posture. Gravity values can be converted into roll and pitch angle positions using simple trigonometric formulas. The pitch and roll values were used to correct the pitch and roll angle values of the gyroscope. The magnetometer was in charge of seeing the direction of the large vector of the earth's north magnetic field concerning body posture. The value of the magnetic field north can be converted to a yaw angle position using a simple trigonometric formula. The yaw value was used to correct the yaw angle value of the gyroscope. The design of the sensor system building can be seen in Figure 2.

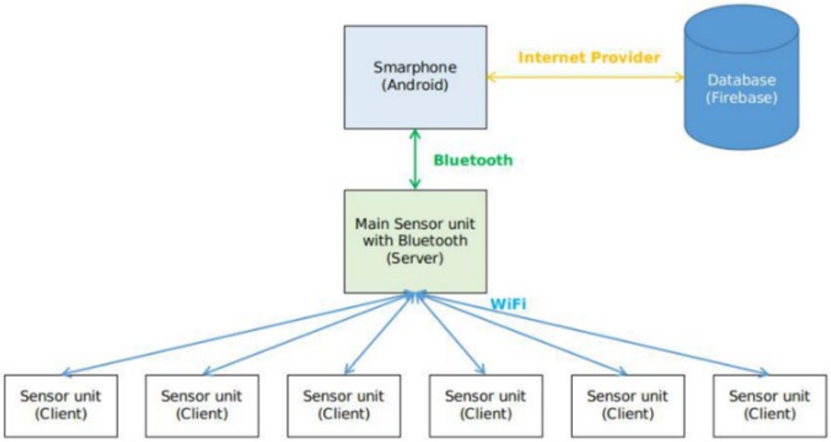


Figure 2. System concept

Figure 2. shows that the designed device consists of seven sensors placed on body parts, namely the back, right and left upper arms, and right and left upper and lower legs.

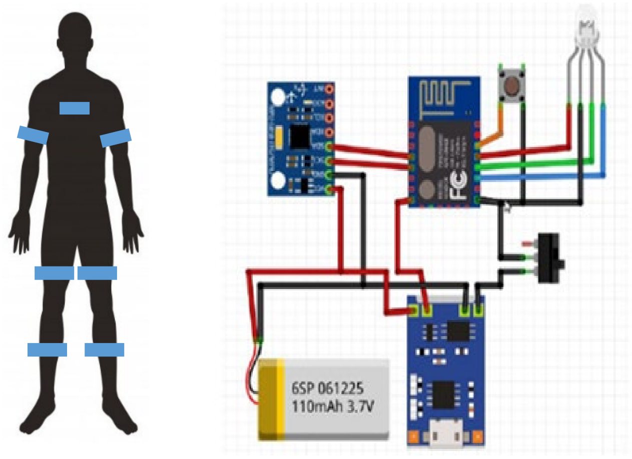


Figure 3. IMU sensor placement on the body and device design

The angle values obtained from each of IMU sensors would be saved in a log and uploaded to an online database using a smartphone application. The software created is a simple application for android smartphones (not available for iPhone). The application only functions to input worker/operator data (name, age, weight, etc.), receive sensor log data, and upload sensor log data to the database. IMU sensors placement and electronic tool design can be seen in Figure 3.

5. Results and Discussion

The ergonomic assessment tool designed is one of the direct measurement methods because it uses specific electronic devices on the human body to measure work posture (Gómez-Galán et al. 2017). This method relies on sensors mounted directly on the subject to measure exposure variables in the workplace (David 2005). This system integrates sensors and software to calculate a set of ergonomic indices, namely OWAS. The system enables real-time posture measurement and an online ergonomics evaluation process (Mullineaux et al. 2012). It provides workers with information about their current posture, and they will correct the posture immediately (Giannini et al. 2020). One of the disadvantages of this system is the high economic cost (Gómez-Galán et al. 2017; Manghisi et al. 2017) and the difficulty of using this method in real-time in many work environments. However, this method does not require wires, so it does not cause inconvenience to work when the sensor is operated.

This study produced several outputs such as IMUs server, IMUs node, and monitoring software. IMUs server with ESP32 + BLE specifications function as buzzers and vibrating motors (see Figure 4.). Buzzer and vibrating motor would alert the user if the posture is at risk. If the score indicates a risk value, a warning signal is given to the worker, and the signal is recorded into the database in the form of when a risk condition occurs in the form of a log. If the user does not change his posture within one minute, this sensor would give a warning again. The form of warning given is in the form of sound and vibration with a duration of 3 seconds. This sensor is also able to last for 6-8 hours of operation. IMUs node with specifications ESP8266 (see Figure 5.) is an integration of accelerometer, gyroscope, and magnetometer sensors, totaling 7 units. The IMUs node is a sensor that would be attached to 7 points on the body, namely the back, right and left upper arms, and right and left upper and lower legs. This sensor is also able to last 6-8 hours in operation.

Figure 4. IMUs Server

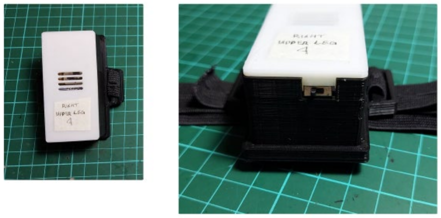
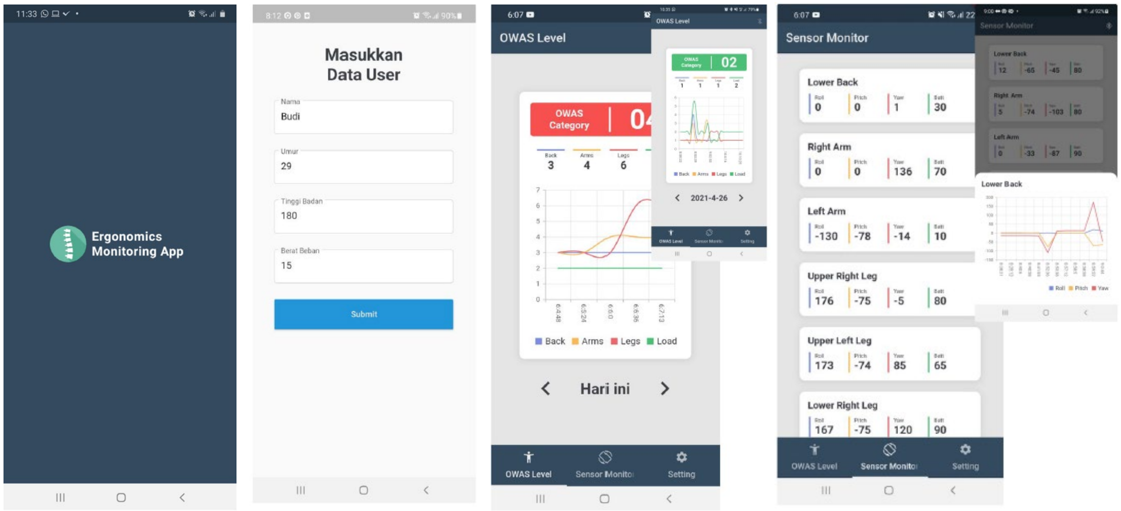


Figure 5. IMUs Node

The body segment angle values obtained from each IMU sensor are stored in a log and uploaded to an online database using an android-based application. This application is called an IMU monitoring device (see Figure 6.). This application requires an input of worker data (i.e., name, age, weight, etc.), receives sensor log data, processes postural angles to get score categories according to the OWAS scoring matrix. The output of the IMUs is uploaded to a google sheet (see Figure 7.). The sampling rate of IMUs is 100 data/second, but what is entered in the google sheet is only the average value of 100 data to anticipate that the battery can last for 8 hours. The sensor data history for 60 seconds (sampling every 5 seconds) would be displayed via the Web Server (see Figure 8.).



Nama
Budi

Umur
29

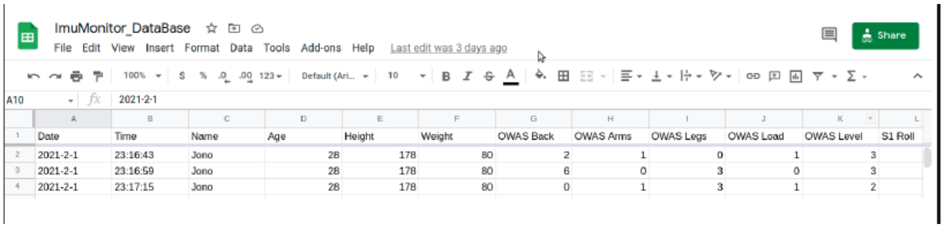
Tinggi Badan
180

Berat Beban
15

Back	Arms	Legs
3	4	6

	Roll	Pitch	Yaw	Batt
Lower Back	0	0	1	30
Right Arm	0	0	136	70
Left Arm	-130	-78	-14	10
Upper Right Leg	176	-75	-5	80
Upper Left Leg	173	-74	85	65
Lower Right Leg	167	-75	120	90

Figure 6. Ergonomic monitoring application display



	A	B	C	D	E	F	G	H	I	J	K	L
1	Date	Time	Name	Age	Height	Weight	OWAS Back	OWAS Arms	OWAS Legs	OWAS Load	OWAS Level	S1 Roll
2	2021-2-1	23:16:43	Jono	28	178	80	2	1	0	1	3	
3	2021-2-1	23:16:59	Jono	28	178	80	6	0	3	0	3	
4	2021-2-1	23:17:15	Jono	28	178	80	0	1	3	1	2	

Figure 7. IMUs Database

Sensor 1 Table

No.	Roll	Pitch	Yaw
5	-40	-73	-136

Figure 8. Web Server

6. Conclusion

In this study, we discussed the development of an ergonomic assessment tool. We proposed a tool that could provide real-time feedback to workers to minimize musculoskeletal disorders risk. This tool used the basic OWAS model, which is an ergonomic assessment worksheet commonly used in industry. The angle values obtained from each IMU sensor would be stored in a log and uploaded to an online database using a smartphone application. Further study is needed to validate the measurement accuracy, validity and reliability. Data collection and comparison to a more accurate system such as motion capture system by Vicon® are planned as the continuation of this study. Further, field study to obtain workers and employers acceptability of the system is needed. This study is expected to contribute to the improvement of work condition by reducing ergonomic risk factors in the workplace.

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Biographies

Anisa Fauziah is a postgraduate student in the Department of Industrial Engineering and Management at Institut Teknologi Bandung. She earned her bachelor degree title from Industrial Engineering of Jenderal Achmad Yani University. From 2019 until now, she works as a Laboratory Assistant at the Department of Industrial Engineering at Jenderal Achmad Yani University. She is a member of Indonesian Ergonomic Association. She enjoyed learning about human factors and ergonomics.

Khoirul Muslim is a lecturer in the Department Industrial Engineering at Institut Teknologi Bandung. He completed his bachelor's degree in the Department of Industrial Engineering at Institut Teknologi Bandung and received master and doctoral titles in Virginia Polytechnic Institute and State University. His research group is ergonomics, occupational, and safety engineering management and focuses on occupational biomechanics and industrial ergonomics.

Septian Dwi Chandra is an employee in the Firmware Design Department PT. Indonesia Epson Industry. He completed his bachelor's degree in the Department of Electrical Engineering at Sepuluh Nopember Institute of Technology.