Anthropometric and Biomechanics Analysis of Lower Limb Exoskeleton for The Indonesian Population

Rosyada ZF[1,a)], Sulardjaka[1,b)], Munadi[1,c)], Muslim E[2,d)]

[1] Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia
[2] Department of Industrial Engineering, University of Indonesia

[a)]rosyada@undip.ac.id, [b)]sulardjaka@undip.ac.id, [c)]munadi@undip.ac.id, [d)]erlinda@eng.ui.ac.id

Abstract. Robotic Lower limb exoskeleton is a powered mechanical device for medical rehabilitation of people with disabilities or paralyzed from the waist down (paraplegia). The number of people with paraplegia is quite large in Indonesia, whilst the devices available on the market are very expensive, not affordable to most Indonesian people. And they are designed for the size of European or American. So the Mechanical Department of Diponegoro University had been developed a prototype of an affordable lower limb exoskeleton robot. This research discusses the anthropometric and biomechanical aspects of the lower limb exoskeleton to fit the Indonesian posture and analyze the biomechanics for the user. Anthropometry analysis was performed using the Jack V8.4 software

1. Introduction

Paraplegia is a medical condition in the form of decreased motoric and sensory function, especially on the lower limb (lower extremity). As a result, the sufferer becomes paralyzed and cannot walk. The causes of this disease, in general, are trauma due to accidents or diseases such as motor neuron disease. According to the latest data from the Indonesian Ministry of Health, in 2012, persons with disabilities to walk were 0.25% of Indonesia's population. According to the Central Statistics Agency, Indonesia's population in 2012 was 245.4 million people, so the number of people with disabilities to walk is more than 600,000 people

Methods of healing treatment for paraplegia include the use of medication, physiotherapy, and surgery. Paraplegia causes decreased productivity and psychologically results in stress due to its inability to carry out normal activities. In the healing periods, people with paraplegia need help from other people for various types of activities that require lower limb movements, for example moving from bed to wheelchair.

One of the walking aids for patients with paraplegia is a device in the form of a skeleton that is driven by an electric motor, which is generally called robotic lower limb exoskeleton (RLLE). But the high prices make it difficult for sufferers, especially in Indonesia to get or own this device. In addition, the devices available on the market do not match the body size of an Indonesian. Therefore, the Department of Mechanical Engineering of Diponegoro University developed a prototype robotic lower limb exoskeleton. Zulkarnain in 2016 research on aspects of dynamic models and kinematics [1], Nasir in 2016 research on mechanical control aspects and Atmaja 2017 research on the strength of the frame structure [3].

The use of RLLE is fitted to the human body. In order for the alignment of size and in line motion of the robots and humans, anthropometric factors must be very concerned in the design [4]. The important factors include the degree of freedom of the robot, measures such as waist height, thigh length, calves and legs, and the position of joints and legs. The design must avoid the robot's position and movement that inhibit the user's movement and bad impact on the user's body.
This study researches on the Indonesian anthropometry size that should be used for the design of RLLE and analyzes the use of RLLE from biomechanical aspects. The results of the analysis of this study were used to refine the RLEE prototype that had been made in the Department of Mechanical Engineering, Diponegoro University

This exoskeleton also helps people to maintain the "S" curve of the spine. As stated in [5], it is important to maintain the natural S-curve to prevent chronic back injuries and to optimize the working posture. For the lower back, this involves maintaining some degree of lordosis. Bending forward or otherwise flattening the slight sway back (kyphosis) puts pressure on the sensitive discs of the lower back, which can ultimately lead to a severe back injury. Twisting of the back is similarly a key issue.

2. Literature Review

2.1. Robotic Lower Limb Exoskeleton

A survey of lower limb exoskeleton conducted by Bing et al in 2015 [6]. They classify by the function of the exoskeleton into three i.e. for rehabilitation, for assistance in human locomotion, and for strength augmentation as depicted in Figure 1. Exoskeleton for rehabilitation is used in the rehabilitation training for the orthopedic. Exoskeleton for human locomotion assistance used to help patients with lost strength of the lower limbs. Then the soldiers, workers, and personnel that must carry heavy loads, they can use the exoskeleton for strength augmentation.

A B C

Figure 1 The classification Exoskeletons. (A) rehabilitation, (B) locomotion assistance, (C) augmentation [6].

Another survey of the design and development of lower limbs exoskeletons was carried out by Aliman et al (2016) [7]. They define exoskeletons as mechanical devices that are used to fit the body and move in accordance with the body of the user. Then they are essentially anthropomorphic in nature. The development of the exoskeleton began in 1956 by Lent and was continued by Mizen in 1966. The exoskeleton that uses power was developed by Hardiman in 1971 which served to assist in material handling. Aliman et al classifying the lower limb exoskeleton into three functions. The first function is augmentation, which is to increase human strength at work. The second function is to restore gait or train muscular weakness. The third function is rehabilitation where the exoskeleton carries a heavy body and movement of the user.

The mechanical engineering department of Diponegoro University had been developed a prototype of an affordable lower limb exoskeleton robot for the rehabilitation of the paraplegia. The size of the exoskeleton is based on the Syaifudin 1996 [8]. The design is depicted in figure 4.

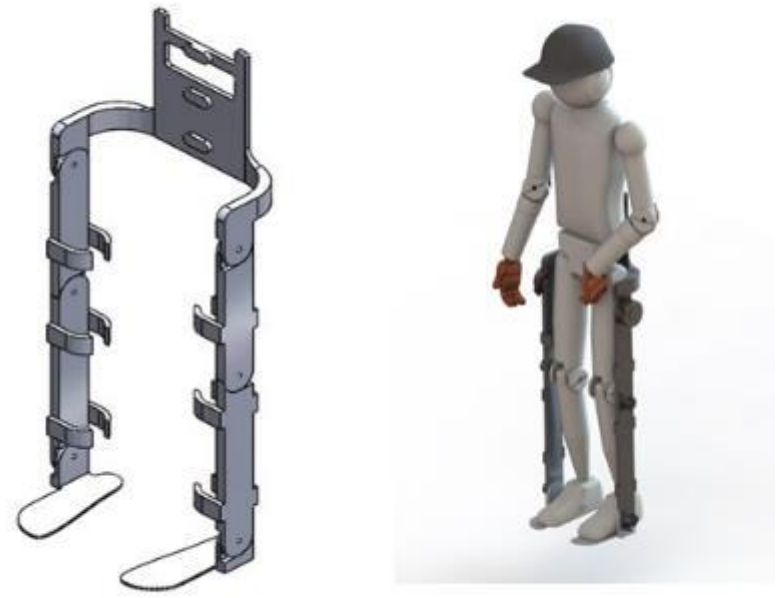

Figure 2. Prototype Design of UNDIP Lower Limb Exoskeleton.

2.2. Anthropometry
The need to pay attention to anthropometry aspects in the design process of facilities in the present decade is obvious. Its include the measurement of the human body, weight, and center of gravity of a body segment, body shape, distance for angular motion of the hands and feet, and so on.

Anthropometry is a collection of numerical data that relates to the physical characteristics of the human body such as the size, shape, and strength and application of the data for the design of product [9]. The application of anthropometric data can be done if there are available mean and SD (standard deviation) from a normal distribution. The normal distribution is indicated by the presence of mean values and standard deviations. While the percentile is a value which states that a certain percentage of a group of people whose dimensions are equal to or less than the value of 15. For example, 95% of the population is equal to or lower than 95 percentiles, 5% of the population is equal to or lower than 5 percentiles. The percentile value can be determined from the table of normal distribution probability. The anthropometric data will determine the exact shape, size, and dimensions associated with the product designed and the humans who will operate or use the product. Then the designer must be able to accommodate the body dimensions of the largest population that will use the product.

2.3. Lower Back Analysis
The lower back analysis (LBA) focus on the compression force in the lumbar disc of the lower back, especially the 4^{th}-5^{th} lumbar joint, called L4/L5. The force comes from the tension produced by muscles and transmitted through tendons. The force can be calculated from specific movement or exertion [5]. The maximum load in the lower back is 3400 N as stated as Action Limit by The National Institute for Occupational Safety and Health (NIOSH) [10]. This AL was defined as tissue tolerance where damage begins to occur in the spine.

2.4. OVAKO Working Posture Analysis (OWAS)
OWAS is applied to analyze the musculoskeletal risk when the whole body parts are working simultaneously [11]. OWAS verifies the safety level of the most common work postures for the back

(four postures), arms (three postures), and legs (seven postures), as well as the weight of the load handled (three categories). The quantification of each body parts is shown in Table 1 so that the whole body posture is described by those four body parts using a four-digit code. It was then classified into four action categories indicating the needs for ergonomic changes, as presented by Figure 5.

Table 1. OWAS action level

	Action	Digit
Back	Straight	1
	Bent	2
	Twisted	3
	Bent and twisted	4
Arms	Both arms below shoulder level	1
	One arm at or above shoulder level	2
	Both arms at or above shoulder level	3
Legs	Sitting	1
	Standing on two straight legs	2
	Standing on one straight leg	3
	Standing or squatting on two bent legs	4
	Standing or squatting on one bent leg	5
	Kneeling	6
	Walking	7
Load	Less or equal to 10 Kg	1
	Greater than 10 Kg and less or equal to 20 Kg	2
	Greater than 20 Kg	3

Back	Arms	Legs																				
		1			2			3			4			5			6			7		
		Load			Load			Load			Load			Load			Load			Load		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	2	3	4
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4

Interpretation of the result
1 - No action required
2 - Corrective actions required in the near future
3 - Corrective actions should be done as soon as possible
4 - Corrective actions for improvement required immediately

Figure 5. OWAS evaluation and result interpretation

2.5. Rapid Upper Limb Assessment (RULA)

RULA was developed by [12] to provide a rating of musculoskeletal loads in tasks where people have a risk of neck and upper-limb loading or activity. The tool provides a single score as a "snapshot" of the task, which is a rating of the posture, force, and movement required. The risk is calculated into a score of 1 (low) to 7 (high), as shown in Table 2. These scores are grouped into four action levels that provide an indication of the time frame in which it is reasonable to expect risk control to be initiated. RULA can be used to assess the posture and force that are associated with sedentary tasks [13], including sitting and standing modeled in this current study.

Table 2. RULA action level

Action Level	RULA Score	Indication
1	1 or 2	Posture is acceptable if it is not maintained or repeated for long periods
2	3 or 4	Further investigation is needed, and changes may be required
3	5 or 6	Investigation and changes are required soon
4	7	Investigation and changes are required immediately

2.6. Static Strength Prediction

Static Strength Prediction analysis run in Jack Human Simulation (known as SSP), provides biomechanical strength assessment in a static posture. Differ from free body diagram calculation, this analysis is conducted in the 3D model, build in Jack. This analysis was developed by [14] to answer the need to assess manual exertion analysis in computer-aided job design software.

3. Methods

In this study, we applied the newest anthropometric data of Indonesian people and four biomechanics approach in evaluating the exoskeleton application in daily practice. All analyses were carried out in static posture using Jack Human Simulation software, version 8.4 for 64 bit Windows. The postures chose in the analysis simulated human daily activity which will be assisted by using the lower limb exoskeleton.

4. Results and Discussion

4.1. Anthropometric data

From the design of the UNDIP lower limb exoskeleton, it can be determined the body that will fit the exoskeleton as described in figure 5. Data obtained from Anthropometry Indonesia [15]. The average weight is 65 kg and the average height is 165 cm.

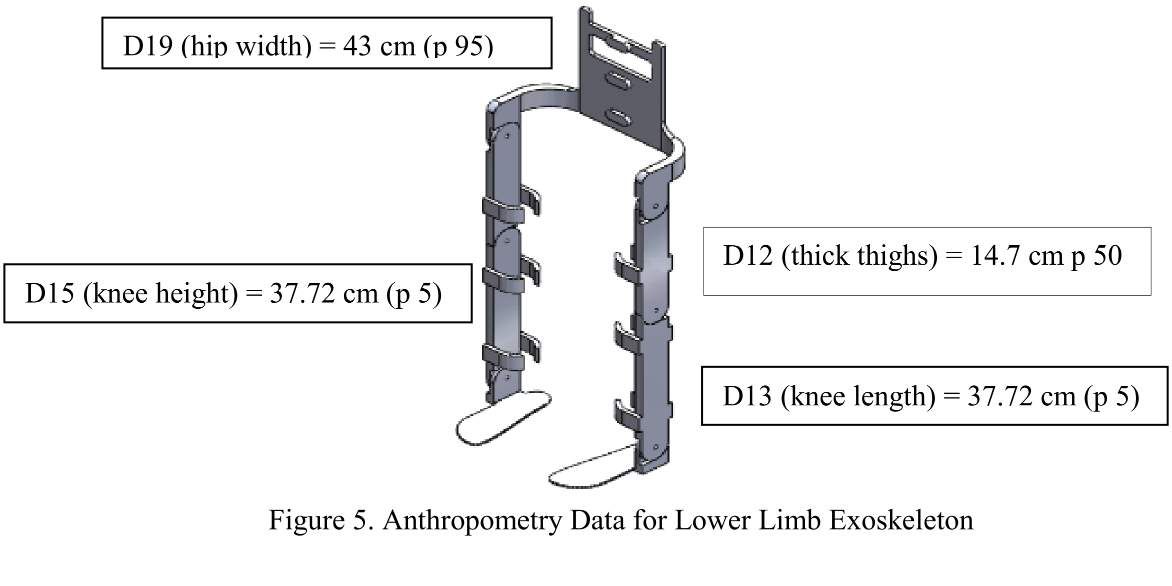

Figure 5. Anthropometry Data for Lower Limb Exoskeleton

4.2. Biomechanical Analysis

Biomechanical analysis conducted in Software Jack V8.4 for three postures of the RLLE and four measurements such as. The results are collected in table 3.

Table 3. Measurements of the LBA, RULA, OWAS, and SSP

Measurement		Posture		
		Standing	Walking	Sitting
L4/L5 Forces (N) (LBA)	Compression	425	641	471
	AP Shear	10	10	10
	Lateral Shear	0	0	0
Percent Capable Summary (SSP)	Wrist	100%	100%	100%
	Elbow	100%	100%	100%
	Shoulder	100%	100%	100%
	Torso	100%	100%	100%
	Hip	99%	99%	100%
	Knee	100%	100%	80%
	ankle	99%	100%	40%
OWAS Code		1121	1121	1111
RULA	Grand Score	3	3	2
Body Group A Posture Rating	Upper Arm	1	1	1
	Lower Arm	2	3	1
	Wrist	1	1	1
	Wrist Twist	1	1	1
	Total	3	3	2
	Muscle use	normal, no extreme	normal, no extreme	normal, no extreme
	Force/Load	2-10 kg intermittent	2-10 kg intermittent	2-10 kg intermittent
	Arms	not supported	not supported	not supported
Body Group B Posture Rating	Neck	1	2	1
	Trunk	1	1	1
	Total	1	2	1
	Muscle use	normal, no extreme	normal, no extreme	normal, no extreme
	Force/Load	< 2kg intermittent	< 2kg intermittent	< 2kg intermittent
Legs and Feet Rating	Seated, legs and feet	well supported	well supported	well supported
	Weight	even	even	even

All the measures in Table 3 are normal, except for SSP in the sitting posture, RULA in the standing posture, and RULA in the walking posture. In the SSP for sitting posture, the capability for the knee is 80% while for the ankle only 40%. It is the weakness of Jack's software. The sitting position on Jack software is without chairs. Sitting position on a chair that can support human body weight cannot be modelled in Jack. So the results of measurements in the sitting position produce a low number for the knee and especially for the ankle.

The measurement results for RULA produce a score of 3 for standing posture and a score of 3 for walking posture. It means further investigation is needed, and changes may be required. Detailed measurements indicate the need for attention to the lower arm. The existence of this RLLE causes the lower arm is no longer free to move near the hips and thighs. For this reason, the RLLE design is recommended to use thin materials and machines.

5. Conclusions

In designing the lower limb exoskeleton, anthropometric data must be considered so that it can be used safely. The design of the UNDIP's robotic lower limb exoskeleton is recommended to use thin materials and machines.

We have to take note that results based on the use of biomechanics are always estimates, not actual measurements. The magnitude of compression and exertion in the various segments of the body is based on geometry and mechanical relationships, as confirmed in [5].

References

[1] Munadi, Zulkarnain MI, Ariyanto M, Iskandar N, and Setiawan JD 2017 *Kinematics and Dynamic Analysis of Lower Limb Exoskeleton Robot*, SNTTM Conf Proc, p 147-153

[2] Munadi, Nasir MS, Ariyanto M, Iskandar N and Setiawan JD 2016 *Design and Simulation of PID Controller for Lower Limb Exoskeleton Robot*, AIP Conf Proc. 1983, p 060008-1-060008-12

[3] Atmaja R, Munadi and Tauviqirrahman M 2017 *Stress Analysis of Lower Limb Exoskeleton for Walking Assistance using Finite Element Method*, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 13 pp. 3864-3866

[4] Zoss AB, Kazerooni H, Chu A. *Biomechanical Design of the Berkeley Lower Limb Exoskeleton (BLEEX)*. IEEE/ASME Trans Mechatronics. 2006;11(2):128–38.

[5] Macleod D. *THE RULES OF WORK A Practical Engineering Guide to Ergonomics*. 2nd ed. Boca Raton: CRC Press; 2013. 197 p.

[6] Chen B, Ma H, Qin LY, Gao F, Chan KM, and Law SW. *Recent developments and challenges of lower extremity exoskeletons*. Vol. 5, Journal of Orthopaedic Translation. Elsevier Ltd; 2016. p. 26–37. Available from: http://dx.doi.org/10.1016/j.jot.2015.09.007

[7] Aliman N, Ramli R and Haris SMM. *Design and development of lower limb exoskeletons: A survey*. Vol. 95, Robotics and Autonomous Systems. Elsevier B.V.; 2017. p. 102–16. Available from: http://dx.doi.org/10.1016/j.robot.2017.05.013

[8] Syaifudin M and Alatas Z. 1996 *Anthropometric Studies of Javanese People in the Context of Indonesian Human Reference Compilation*, Proceeding of Radiation and Environmental Safety

[9] Nurmianto E. *Ergonomy: Basic Concept and Applications*. 1st ed. Surabaya: Guna Widya; 2004.

[10] Herkowitz HN, Dvorak J, Bell GR, Nordin M and Grob D. 2004 T*he Lumbar Spine 3rd ed*. Online. Philadelphia: Lippincott Williams & Wilkins

[11] Karhu O, Kansi P and Kuorinka I. 1977 *Correcting working postures in industry: A practical method for analysis*. Appl Ergon 8(4) p199–201.

[12] McAtamney L and Corleet EN 1993 *RULA: A survey method for the investigation of work-related upper limb disorders*. Appl Ergon. 24(2) p 91–9.

[13] Stanton N, Hedge A, Brookhuis K, Salas E and Hendrick H. 2005 *Handbook of Human Factors and Ergonomics Methods*. CRC Press;

[14] Chaffin DB. *Development of computerized human static strength simulation model for job design* 2002 Hum Factors Ergon Manuf. 7(4) p 305–22.

[15] PEI PEI. Antropometri Indonesia [Internet] [cited 2019 Apr 20]. Available from: http://www.antropometriindonesia.org/index.php

Joint Conference 6th Annual Conference on Industrial and System Engineering (ACISE) and 1st International Conference on Risk Management as an Interdisciplinary Approach (ICRMIA)

present this

Certificate of Recognition

Number 215/UN7.P/HK/2019

to

Zainal Fanani Rosyada

for the valuable contribution as **Paper Presenter** entitled

Anthropometric and biomechanic analysis of lower limb exoskeleton for Indonesian population

Semarang, April 24, 2019

Dr. Ratna Purwaningsih, S.T.,M.T.
Head of Industrial Engineering Department,
Faculty of Engineering,
Diponegoro University

Dr. Aries Susanty, S.T.,M.T.
Chairperson, Organizing Committee
ACISE-ICRMIA 2019