iMEDiTEC 2017

ORIGINAL PAPER

Determination of Center of Gravity on Electric Standing Wheelchair

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ABSTRACT

Decubitus is one of the most serious diseases in the medicine. Decubitus occurs due to sitting for long periods in the wheelchair so that the tail bone is suppressed and caused injury. In this case, the disease is common in patients with spinal cord injury. In stages 3 and 4, this disease can cause death. Based on these problems, electric wheelchairs that have the feature to transform into a stand will be developed. However, one factor that needs to be considered in making an electric standing wheelchair is the center of gravity. In this paper, the center of gravity is analyzed using Inventor software to determine the stability point of the electric standing wheelchair. In the simulation, the electric standing wheelchair will be loaded with a human starting from 50 - 90 kg and the transformation angle will be adjusted from 0 - 60 ° to compare the displacement of the center of gravity point when sitting to the standing position. The simulation results show that the varying human load and transformation angle changes affect the center of gravity location. The heavier the human load and the greater the angle of transformation change causes the center of gravity to be closer to the front wheel axle, this is because the mass distribution is more concentrated on the front wheel. However, in the entire electric standing wheelchair test still remain balanced because the center of gravity location is within the projection of the four wheels.

INTRODUCTION

Persons with disabilities in a productive age in Indonesia continue to increase, the main causes are low safety standards and natural disasters. The Indonesian Ministry of Health in collaboration with the WHO, which started in 1975, has interviewed 3317 and found no less than 9.2% had physical limitations and disabilities (Irwanto et al., 2010). A considerable amount of disability, of course, will be a problem. Particularly in terms of participation in the development sector which is the human rights of every individual. According to a survey conducted by the Department of Social Affairs with the Indonesian Central Bureau of Statistics (BPS) in the publication of 2008, the number of disabilities in Indonesia reaches 1 million and the largest type of disability is mobility / lame disability with 382,787 inhabitants. For that, we need a mobility aid, such as electric wheelchairs for people with disabilities to be able to indulge, increase their independence, and their participation in development.

Several types of electric wheelchairs have been produced, but medical experience has shown that sitting for long periods in a wheelchair causes some health problems for people with disabilities. These health problems can include joint stiffness, muscle shrinkage, reduced bone mineral density, and the most serious problems are decubitus ulcers (Cuddigan et al., 2001; Miyahara et al., 2008; Niezgoda et al., 2006; Thomas et al. , 2005). Decubitus is tissue damage and skin area caused by sitting or lying down for a long time on one particular body part. It also causes ischemia, cell death, and tissue necrosis, such as compressed capillaries, and restricted blood flow (Lyder et al., 2008).

A research has been done on 422 patients at Felegehiwot Hospital, Ethiopia showed that 71 patients (16.8%) had decubitus ulcers (Gedamu et al., 2008). This prevalence rate is still lower than that of Sweden (22.9%), Italy (27%), and Thailand (47.6%). Research has also been conducted in Ankara, Turkey found as many as 59.2% of patients experiencing decubitus ulcers and treated in the intensive care unit. Patients suffering from decubitus ulcers have a high risk of death. Kuwahara in 2005 reported the death rate of decubitus ulcer patients at stages 3 and 4 was 68.8% (Agrawal et al., 2012). This percentage is certainly very large and should have an important concern. In addition, decubitus ulcers become the third most expensive disease after cancer and cardiovascular disease. Therefore, preventive measures are needed for people with disability to avoid decubitus ulcers. Based on these problems, an electric wheelchair that has the transformation feature to stand will be developed. The electric standing wheelchair is often required in the medical field because it can provide health benefits, as a means of rehabilitation, prevent decubitus, and reduce the negative effects caused by sitting in a wheelchair for long periods of time. In addition, people with standing postures have a higher level of confidence than people sitting in wheelchairs (Arva et al., 2009).

One of the factors that must be considered when making this electric standing wheelchair is the center of gravity because modifying the shape of a wheelchair to a standing position will change the center of gravity and loss of stability. Poor stability levels lead to wheelchair difficulties for motion and maneuver (Moody et al., 2012). The location of the center of gravity has an effect on the dynamic nature of the system because it determines the value of the moment of inertia responsible for its dynamic stability (Wieczorek et al., 2017). In addition, the loss of wheelchair stability may potentially harm the user. The wheelchair stability assessment system becomes essential for measurement-based wheel reconfiguration and achieves an optimal balance between stability and maneuverability (Stefanov et al., 2014). So, in this paper focused on finding the location of the center of gravity of the standing wheelchair without human load and with varying human load so that can be analyzed the stability of the standing wheelchair. Center of gravity analysis is done by simulation on Inventor software.

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MATERIALS AND METHOD

Center of Gravity of a two-dimensional body

The center of gravity of an object located at an average weight. In physics, the center of gravity of an object is the point where the mass of an object can be assumed for many purposes and to be concentrated. The center of mass gravity of the mass is the point at which all the weight of matter is considered to be concentrated (Khaleel et al., 2013). The center of gravity in the 2-field object can be calculated using Eq. (1) and Eq. (2) (Johnston *et al*., 2009) :

$$\Sigma My : xW = \Sigma x \, \Delta W \tag{1}$$

$$\Sigma Mx : \bar{y}W = \Sigma y \, \Delta W \tag{2}$$

The first element coordinates are denoted by x1 and y1, the second element with x2 and y2, and etc. The force applied to each plate element is denoted by ΔW1, ΔW2, ..., ΔWn. This force or weight is directed to the center of the earth so it can be assumed to be parallel. The result is a single force in the same direction. The magnitude of this force is obtained by adding the weight element magnitude.

$$\Sigma F2 : \quad W = \Delta W_1 + \Delta W_2 + \ldots + \Delta W_n \tag{3}$$

To obtain the coordinates x and y, the moment W generated on the y and x axes must be equal to the number of moments of element weights

$$\Sigma My : \quad xW = x_1 \Delta W_1 + x_2 \Delta W_2 + \ldots + x_n \Delta W_n \tag{4}$$

$$\Sigma Mx : \quad \bar{y}W = y_1 \Delta W_1 + y_2 \Delta W_2 + \ldots + y_n \Delta W_n \tag{5}$$

This equation is to determine the weight of W and the coordinates of x and y center of gravity on the plane.

Methods

The standing wheelchair design is designed using Autodesk Inventor Professional 2015 CAD software to make it easier to assemble. The mildest material is used in this design because the material is not too heavy and strong enough to withstand the human load. In designing, anthropometric data of Indonesians are used to provide comfort for wheelchair users. The wheels, footrest, battery, and dc motor are configured according to their fabric. It aims to reach the approximate weight of the standing wheelchair close to the fact that the weight distribution on the wheels is evenly distributed. The standing wheelchair design is shown in Fig. 1 and Fig. 2.

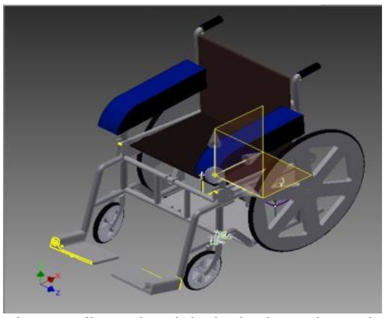

Fig. 1 The electric standing wheelchair design when sitting position

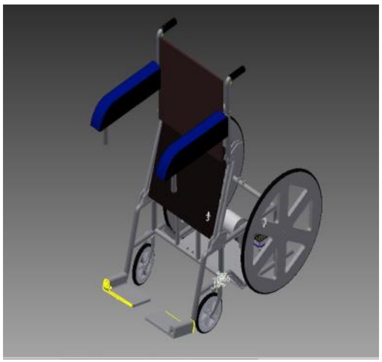

Fig. 2 The electric standing wheelchair design when standing position

Center of gravity is the balance point of the object or point where the object will be balanced without any tendency to spin. Therefore, determining the location of the center of gravity is required for the stability of the wheelchair stand. Factors that may affect the stability of an object are the size of the pedestal, the location of the gravity to the pedestal, the height of the center of gravity, the mass of the body, and the frictional force. When a system is on a flat surface, the two front and rear wheels touch the ground and the imaginary horizontal line connects the three wheels in a triangle, the result being the tread. As long as the center of gravity remains in the tread, the system will be statically stable (Johnson et al., 2010).

Previous research in determining the location of the center of gravity has been done by several researchers. Determining the center of gravity on a tricycle is done by Eukase et al (Austin et al., 2015). SolidWorks software is used to determine object mass, the center of gravity location, the height of the center of gravity (HG), track length, distance between the front wheel axle and center of gravity (LG). The results show that the model is unstable at high speeds above its critical speed, but can be improved by reducing the value of LG and HG. Preparation of a balance platform to determine the center of gravity in the wheelchair and sagittal fields of the patient is done by Lemaire et al (Lemaire et al., 1991). This method is used to evaluate the level of wheelchair stability and estimate the possible rolling resistance. Using the Eq. (6) static for the system moment, the location of the center of gravity can be calculated (Winter et al., 2010):

$$\Sigma Mp = 0$$

$$Fc \,.\, Lc + Fw \,.\, Lw - Fp \,.\, Lc = 0 \tag{6}$$

Where,

Mp	= Moment about wheelchair
Lc	= Distance from front wheel axle to center of gravity
Lw	= Distance from rear wheel axle to center of gravity
Fp	= Weight of the patient
Fw	= Force on front wheel
Fc	= Force on rear wheel

After the design of the standing wheelchair is made, the simulation is done to obtain the location of Center of Gravity. In the simulation, the transformation angle changes are made from 0 - 60 °. The 60 ° angle is the maximum point of the wheelchair standing to be able to transform into standing. As for the weight of patients will be made to vary from 0 - 90 kg. The standing wheelchair properties parameters have been summarized in table 1.

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Table 1 Modeled the electric standing wheelchair properties

Parameter	Value
Mass	45.70 kg
Area	4083809.6 mm²
Volume	19482017.1 mm³
Wheelbase distance (WB)	46 cm
Track Length (TR)	56 cm

Mass, area, and volume can be known from the material properties table in the Inventor software. Wheelbase is the distance between the front wheel axle with the rear wheel axle, while the track length is the distance between the two rear wheel axles. For more details, the length of wheelbase and track length can be seen in Fig. 3.

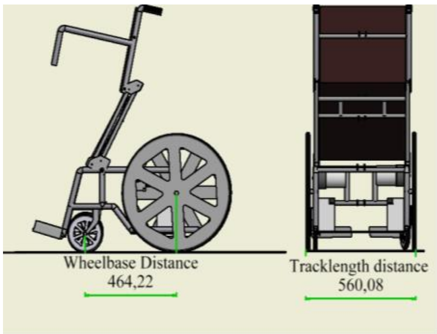

Fig. 3 Distance wheelbase dan tracklength on electric standing wheelchair

RESULTS AND DISCUSSION

The result of this simulation is obtained from the center of gravity of electric standing wheelchair when given the human load ranging from 0 - 90 kg and displacement point of the center of gravity from sitting to standing position. The value of these parameters will be used to analyze how balanced an electric standing wheelchair when used. Fig. 4 shows the initial location of the center of gravity on a wheelchair without human load.

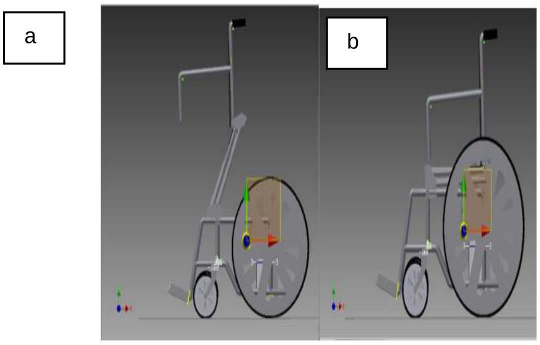

Fig. 4 The initial location of the center of gravity (a) when standing position and (b) when sitting position

In Fig. 4 we can see that the center of gravity is closer to the rear wheel axle than the front wheel axle, which means that the mass on the rear wheel is heavier than the mass on the front wheel. However, the location of the center of gravity is still within the projection of the four wheels indicating that the electric standing wheelchair remains balanced in the static state.

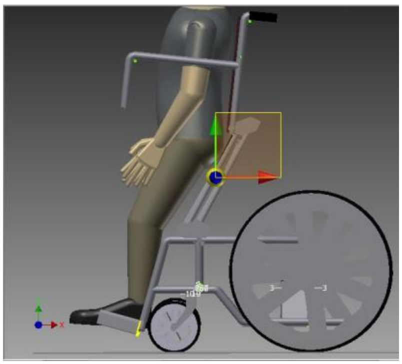

Fig. 5 The location of center of gravity at 70 kg human load when standing position

Fig. 5 shows the center of gravity location at 70 kg human load and transformation angle change of 60°. The center of gravity location shows the displacement, which is increasingly higher from the ground and closer to the front wheel axle than the center of gravity location without the human load closer to the rear wheel axle shown in Fig. 4.

Table 2 The simulation results center of gravity without human load

Parameter	Degree				
	0°	15°	30°	45°	60°
Height of CG from the ground (HG)	26.60 cm	27.86 cm	28.96 cm	29.80 cm	30.35 cm
Distance from front axle to CG (FG)	33.53 cm	33.12 cm	32.26 cm	31.27 cm	30 cm
Distance from rear axle to CG (RG)	12.47 cm	12.88 cm	13.74 cm	14.73 cm	16 cm
FG to WB Ratio (FG/WB)	0.73	0.72	0.7	0.68	0.65
RG to WB Ratio (RG/WB)	0.27	0.28	0.3	0.32	0.35

Table 2 is the simulation results without human load. From the data in table 2, the transformation angle change from sitting to standing position influences the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 26.60 cm, transformation angle of 15° height of HG is 27.86 cm, transformation angle of 30° height of HG is 28.96 cm, transformation angle of 45° height of HG is 29.80 cm, and transformation angle of 60° (maximum standing position) height of HG is 30.35 cm. The increase in angle changes causes the HG value to increase. This will cause the stability of the wheelchair is reduced. In addition, at the transformation angle of 0°, 15°, 30°, 45°, and 60° the center of gravity position is closer to the rear wheel axle than the front wheel axle because the load distribution on the electric standing wheelchair is larger on the rear wheels than the front wheels.

Table 3 The simulation results center of gravity at 50 kg human load

Parameter	Degree				
	0°	15°	30°	45°	60°
Height of CG from the ground	47.74 cm	50.43 cm	53.21 cm	54.84 cm	55.37 cm

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(HG)					
Distance from front axle to CG (FG)	29.20 cm	28.70 cm	25.64 cm	20.05 cm	16.46 cm
Distance from rear axle to CG (RG)	16.80 cm	17.30 cm	20.36 cm	25.95 cm	29.54 cm
FG to WB Ratio (FG/WB)	0.63	0.62	0.56	0.44	0.36
RG to WB Ratio (RG/WB)	0.37	0.38	0.44	0.56	0.64

Table 3 is the simulation results on a human load of 50 kg. From the data in table 3, human load affects the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 47.74 cm, transformation angle of 15° height of HG is 50.43 cm, transformation angle of 30° height of HG is 53.21 cm, transformation angle of 45° height of HG is 54.84 cm, and transformation angle of 60° (maximum standing position) height of HG is 55.37 cm.

Table 4 The simulation results center of gravity at 60 kg human load

Parameter	Degree				
	0°	15°	30°	45°	60°
Height of CG from the ground (HG)	49.69 cm	52.50 cm	55.43 cm	57.11 cm	57.64 cm
Distance from front axle to CG (FG)	28.75 cm	28.35 cm	25.11 cm	19.26 cm	15.20 cm
Distance from rear axle to CG (RG)	17.25 cm	17.65 cm	20.89 cm	26.74 cm	30.80 cm
FG to WB Ratio (FG/WB)	0.63	0.62	0.55	0.42	0.33
RG to WB Ratio (RG/WB)	0.37	0.38	0.45	0.58	0.67

Table 4 is the simulation results for a 60 kg human load. From the data in table 4, human load affects the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 49.69 cm, transformation angle of 15° height of HG is 52.50 cm, transformation angle 30° height of HG is 55.43 cm, transformation angle of 45° height of HG is 57.11 cm, and transformation angle of 60° (maximum standing position) height of HG is 57.64 cm. In addition, at the transformation angle of 0°, 15°, and 30° the center of gravity position is closer to the rear wheel axle than the front wheel axle because the load distribution on the electric standing wheelchair is larger on the rear wheels than the front wheels.

Table 5 The simulation results center of gravity at 70 kg human load

Parameter	Degree				
	0°	15°	30°	45°	60°
Height of CG from the ground (HG)	51.79 cm	54.22 cm	57.28 cm	59 cm	59.54 cm
Distance from front axle to CG (FG)	30.60 cm	27.90 cm	24.56 cm	18.35 cm	14.18 cm
Distance from rear axle to CG (RG)	15.40 cm	18.10 cm	21.44 cm	27.65 cm	31.82 cm
FG to WB Ratio (FG/WB)	0.67	0.6	0.53	0.4	0.31
RG to WB Ratio (RG/WB)	0.33	0.4	0.47	0.6	0.69

Table 5 is the simulation results for a 70 kg human load. From the data table 5, human load affects the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 51.79 cm, transformation angle of 15° height of HG is 54.22 cm, transformation angle of 30° height of HG is 57.28 cm, transformation angle of 45° height of HG is 59 cm, and transformation angle of 60° (maximum standing position) height of HG is 59.54 cm.

Table 6 The simulation results center of gravity at 80 kg human load

Parameter	Degree				
	0°	15°	30°	45°	60°
Height of CG from the ground (HG)	52.63 cm	55.67 cm	58.84 cm	60.53 cm	61.15 cm
Distance from front axle to CG (FG)	28.05 cm	27.68 cm	24.16 cm	17.92 cm	13.23 cm
Distance from rear axle to CG (RG)	17.95 cm	18.32 cm	21.84 cm	28.08 cm	32.77 cm
FG to WB Ratio (FG/WB)	0.62	0.6	0.53	0.39	0.29
RG to WB Ratio (RG/WB)	0.38	0.4	0.47	0.61	0.71

Table 6 is the simulation results on a human load of 80 kg. From the data in table 6, human load affects the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 52.63 cm, transformation angle of 15° height of HG is 55.67 cm, transformation angle of 30° height of HG is 58.84 cm, transformation angle of 45° height of HG is 60.53 cm, and transformation angle of 60° (maximum standing position) height of HG is 61.15 cm. In addition, at the transformation angle of 0°, 15°, and 30° the center of gravity position is closer to the rear wheel axle than the front wheel axle because the load distribution on the electric standing wheelchair is larger on the rear wheels than the front wheels.

Table 7 The simulation results center of gravity at 90 kg human load

Parameter	Degree

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	0°	15°	30°	45°	60°
Height of CG from the ground (HG)	53.80 cm	56.94 cm	60.18 cm	61.89 cm	62.53 cm
Distance from front axle to CG (FG)	27.92 cm	27.52 cm	23.87 cm	16.83 cm	12.59 cm
Distance from rear axle to CG (RG)	18.08 cm	18.48 cm	22.13 cm	29.17 cm	33.41 cm
FG to WB Ratio (FG/WB)	0.61	0.6	0.52	0.37	0.27
RG to WB Ratio (RG/WB)	0.39	0.4	0.48	0.63	0.73

Table 7 is the simulation results on a human load of 90 kg. From the data in table 7, human load affects the location of the center of gravity. At the transformation angle of 0° (sitting position) height of HG is 53.80 cm, transformation angle of 15° height of HG is 56.94 cm, transformation angle of 30° height of HG is 60.18 cm, transformation angle of 45° height of HG is 61.89 cm, and transformation angle of 60° (maximum standing position) height of HG is 62.53 cm. In addition, at the transformation angle of 0°, 15°, and 30° the center of gravity position is closer to the rear wheel axle than the front wheel axle because the load distribution on the electric standing wheelchair is larger on the rear wheels than the front wheels, however the transformation angle of 45 ° and 60 ° the center of gravity position is closer to the front wheel axle than the rear wheel axle because the load distribution in the electric standing wheelchair is larger on the front wheels than the rear wheels.

From the graph in Fig. 6, it can be analyzed that the different human body weight and change of transformation angle from sitting into standing position affect the location of the height of center of gravity (HG). The higher the value of HG, then the balance of the electric standing wheelchair will be reduced. The highest equilibrium of the wheelchair occurs at no human load with HG values between 26.60 – 30.35 cm (transformation angle change 0 - 60°). When the electric standing wheelchair loaded with human load, the highest equilibrium occurs in a wheelchair with a 50 kg human load having an HG value between 47.74 – 55.37 cm (transformation angle change from 0 to 60°). However, as long as the center of gravity location is within the projection of the four wheels, the electric standing wheelchair will remain balanced. Fig. 7 shows the center of gravity displacement from sitting to a standing position on a 70 kg human load. When transformed into standing, the location of the center of gravity move higher and closer to the front wheel axle.

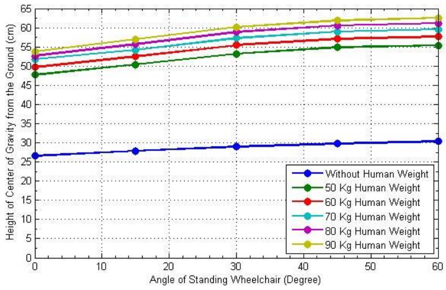

Fig. 6 The relationship between height of center of gravity and angle of standing wheelchair

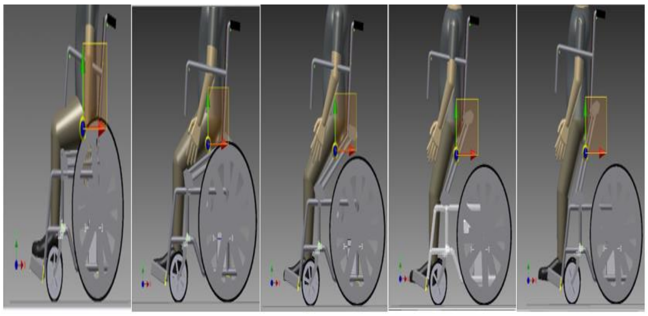

Fig. 7 The location of center of gravity from sitting to standing positon at 70 kg human load

CONCLUSION

A standing wheelchair design has been simulated and analyzed using Inventor software. The result of the simulation is the location of the center of gravity, wheelchair mass, the center of gravity of ground (HG), the distance between the front wheel and rear wheel (WB), distance between COG with front wheel axle (FG) Between COG with rear wheel (RG). The parameter values are used to determine the stability system of this wheelchair. The results of all simulations indicate that the electric standing wheelchair remains stable and balanced when given the human load 50 - 90 kg, and the transformation angle changes from 0 to 60° because the center of gravity location is still within the projection of the four wheels. However, the greater the load received and the greater the change in the angle of transformation, then the stability of the wheelchair will also be reduced. From the design of the wheelchair stand, it is expected to prevent patients experiencing decubitus ulcers and as a tool of rehabilitation for patients with spinal cord injuries.

ACKNOWLEDGEMENT

This work was financially supported by Ministry of Research, Technology and Higher Education of the Republic of Indonesia.

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