Implementation of Fall Detection for WAR-Exoskeleton Robot

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***Abstract*—In this paper, we presented a method of detecting the state of the lower limb exoskeleton for a fall detection function based on the WAR exoskeleton robot platform. While in motion, the exoskeleton is to follow the gait pattern data. The exoskeleton functions on distributive control where the hip joints and knee joints are controlled by the PID controller. Several equations are derived which outlines the conditions needed to keep the exoskeleton balanced and unlikely to fall. Deviations from the expected patterns and angle changes in the exoskeleton robot may cause instability and imbalance. Experimental results on the moment during leg motion and positional changes of the centroid while robot is in motion are obtained and used as conditions for fall detection. The method proposed is effective for fall detection in war-exoskeleton robot.**

***Index Terms*—fall detection; assistive device; exoskeleton robot; gait pattern; lower limb motion**

I. INTRODUCTION

From survey data of around 1.88M disabled people, (Department of Empowerment of Persons with Disabilities, in year 2017), 48.97%, have been found to have lost their hearing, 18.39% have been found to have lost their ability to speak, 10.26% have been found to have lost their sight and the rest have been found to have lost the ability to use other limbs or body functions. Though a lot of the disabilities are those related to the sense however, the numbers of body related disabilities are increasing as time goes by. Therefore, we aim focus on how to serve those whose disability is of the lower limb, and aim to create an exoskeleton which allows them to walk in step motion similar to normal people.

Lower limb exoskeleton robots are wearable devices designed mainly to enhance the physical performance of its users and aid in the locomotion of paraplegics [1]. The method of control for these exoskeleton robots are thus designed to accommodate its paraplegic users. Such methods include hand held controls and proportional myoelectric control which directly links the nervous system to the exoskeleton robot through electromyographic (EMG) signals [2]. It must be noted that the former requires the user to undergo training to be effective. Such training is to ensure the user is able to press the button with accurate timing.

Additional methods of establishing exoskeleton- human interaction utilize sensors in contact with the user's limbs to detect movement. These sensors then instruct the exoskeleton to move along with the user's lower limbs [1]. Alternatively, exoskeletons could gather the information without sensors applied directly on the user but instead sensory sensors to gather information relating to quantities such as force, torque, angular velocity and angular acceleration in order to synchronize the movements of the exoskeleton to the user's legs [3]. However, such methods are unable to be applied efficiently to paraplegic users as these methods require the user to be able to move their lower limbs in the first place.

Regardless of the method of control, information is sent to the exoskeleton commanding it to move. In order to achieve this, the exoskeleton is powered by a power source such as battery packs of lithium and nickel metal hydride origin. With a power source, the exoskeleton can function [4]. To move the limbs of the user, the exoskeleton is typically connected to the limbs by connection cuffs and orthoses shells [3]. Due to its close interactions with its users, such robots are built to be compatible with the human body. As such, exoskeletons contain several degrees of freedom (DOF) or joints which allows for freedom of movement [5]. It is possible to use elastic joints to reduce the stiffness in movement of the exoskeleton, allowing for better human device interaction. [6] Human device interaction is also improved by accounting for the differences in height and weight and adjusting the exoskeleton accordingly [7].

Since most exoskeletons are built such that the device and limbs act in parallel, these DOFs are located where there are joints on the human body. In the lower limb exoskeleton, these locations are namely the hips, knees and ankles. For joint rotations in which the device cannot rotate in an axis of rotation parallel to the limb however, the device does not have to be placed in parallel. For instance, to enable the abduction rotation of the hip, the

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BLEEX exoskeleton model positioned the center of rotation in the rear part of the hip joint mechanism instead [5]. While these components are important in the construction of the lower limb exoskeleton, in this paper, we aim to detect the state of the lower limb exoskeleton platform while stand and motion. We propose a method of detecting the state of the exoskeleton robot by determining the total moment of lower limb along with the vertical positional change of the centroid while robot is in operation. In acquiring such information, the movement of the exoskeleton can be calibrated to ensure that the user does not lose balance and is able to walk safely. To continue a WAR-Project [8] work, we present the method of fall detection to control the joint motion of robotic platform while its operation with the motion functions.

In this paper, we purposed the technique of fall detection function to protect user's wearable while robot operation, the center of mass is to be determine using the simple trigonometry solution with robot kinematic. In section 2, we briefly describe the walking assist robot platform. In section 3, we propose the method of fall detection. The experimental results are presented in section 4 and finally, the conclusions and future works are described in section 5.

II. Walking Assist Robot

The walking assist robot, WAR [8] was developed at Intelligent Robotic Laboratory, Sripatum University. A WAR robot is the wearable robot for lower limb muscle assistance with four degree of freedom (DOF), to assist lower limb motion with the walking pattern function without the EMG signal. The robot motion function consisted the step of standing up/down function when the user posture on sit a chair and the step walking by following the gait pattern data. The specification of WAR-Exoskeleton robot (Fig. 1), the robot hardware is designed to have a maximum speed at 0.25 m/s when it is operated. The robot dimension height, width, and depth are 110 cm, 90 cm, and 50 cm respectively. The total weight is approximately 25 kg with the aluminum structure. The robot structure can be adjusted to allow a range of user height from 170 cm to 180 cm and it is carried a maximum weight up to 80 kg. The source of power is 12 vdc 7.5 amp with series two batteries as lead-acid batteries which are attached at the rear part of robot, this system can be performed an approximate 60 minute on continuous robot operation. The mechanical movement part is driven by four DC motors with spur gearhead which help to power the hip and knee position of each leg. The dc motors are controlled to work in-sync to rotate each hip joint and knee joint, so the robot can imitate the walking pattern of a person.

The robot functional is performed by manual operation which is press on the switch button that installed at the cane. To control this system, the distributed control system is utilized with a master controller and four slave controllers. These slave controllers command the operation of the revolute joints motion with close loop control via the data submitted to/from a master controller. A master controller is to compute the position of gait trajectory of the foot path and to perform the digital gyro and accelerometer sensors module that attached on a lower back and both ankles. To operate this system, two button switches (green and red color) are installed on the cane the button switch of green color performs step walking and seat up/down by press a button switch of red color. The emergency function is to press both button switches and hold on five seconds, the alert command sends to the smart phone device via the cellular phone network. This system overview is illustrated in Fig. 2.

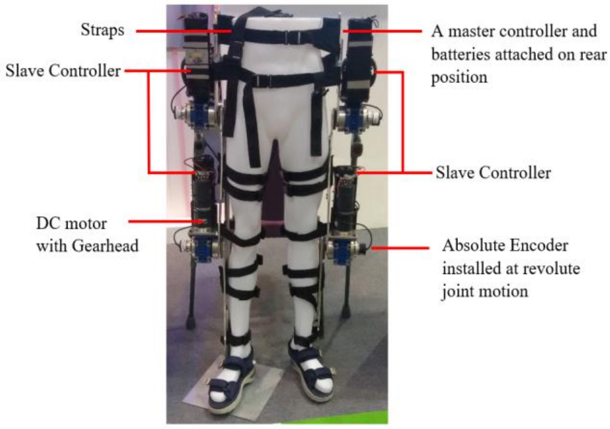

Figure 1. A prototype of the WAR-Exoskeleton robot.

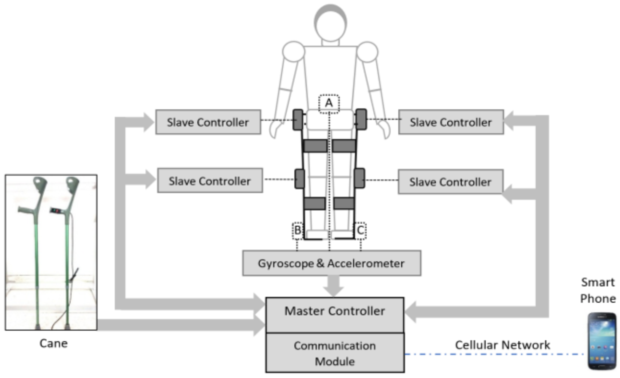

Figure 2. The system overview of walking assist robot.

III. Falling and Balancing

There are many methods of ensuring the exoskeleton remains in balance such as through the use of EMG signals which allows the user a lot of control and depends on them to remain in balance [9]. However, the use of EMG signals is difficult to implement as there are many muscles at work and each person uses their muscles slightly differently resulting in varied signals [9], [10]. There is another method of control where the exoskeleton will stop when the user does not exert force on the robot platform. In research [11], the robot platform imitates the user's movement, aiding the user produce the force required. As such, when the user stops, so does the exoskeleton, preventing it from falling. This method requires the user to actively participate in walking.

In this paper, we aim add a fall detection function with PID controller of the control system based on the existing WAR-Exoskeleton [8] as shown in Fig. 3.

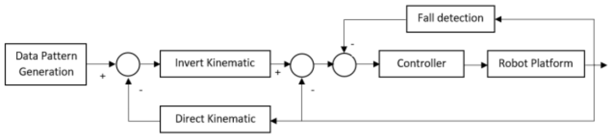

Figure 3. Diagram of Control algorithm robot platform.

In this work, the method proposes to detect the robot posture which would indicate whether the robot is unbalanced. The xy-plane projection is used to determine a centroid position of robot platform when its position changes along y axis and the yz-plane projection is used to determine the distance of path trajectory of the footplate along with the total moment of leg as shown in Fig. 4. The method of balance proposed mainly utilizes the four absolute encoders already attached on the both side of the hip joints and knee joints in order to determine the angle of joints motion of the robot platform while it is in operation.

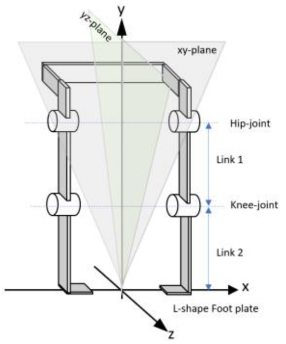

Figure 4. 2D Plans of robot posture projection.

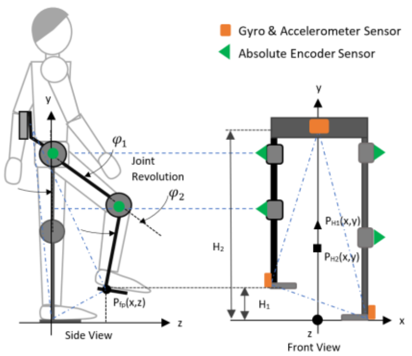

Figure 5. Robot locomotion of position changing.

To find the moment of leg, let the length of the upper leg segment be denoted as L_1 and lower leg segment be denoted as L_2 the angle of the hip joint and knee joint in degrees be denoted as φ_1 and φ_2 respectively. In order to determine state of the robot platform, the total moment of force must be calculated. Let the mass of the upper segment of the exoskeleton be M_1 and the mass of the lower segment M_2.

The positioning of the legs may be separated into three states consisting of state 1 where $\varphi_1 > 0$ *and* $\varphi_2 > \varphi_1$, state 2 where $\varphi_1 > 0$ *and* $\varphi_1 > \varphi_2$, and state 3 where $\varphi_1 < 0$. The moment of the leg (Q_t) is denoted in equation (1). (For all calculations, the positive magnitudes of the angle are used).

$$Q_t = \frac{M_1}{2} L_1 \sin(\varphi_1) + M_2(L_1 \sin(\varphi_1) + L_2 \sin(X) \quad (1)$$

where: variable X differs for each state with its value in state 1 being $\varphi_2 - \varphi_1$, in state 2 being $\varphi_1 - \varphi_2$ and in state 3 being $\varphi_1 + \varphi_2$.

Having calculated Q_t, we establish the parameter $Q_{threshold}$ to set the range for the acceptable moment outputs which ensures the exoskeleton robot will not fall forwards or backwards. If the value of Q_t exceeds the bounds of what is expected, the exoskeleton can be assumed to be unbalanced. The exoskeleton robot platform will cease to move when the exoskeleton's balance forward or backwards is unstable or in other words, when $Q_t > Q_{threshold}$. Now that the value of Q_t has been calculated and information on the state of balance forwards and backwards has been obtained, we can calculate the value of another variable through the side view. The height of the footplate from the ground (along the y axis) is denoted as H_1. Equation (2) gives the value of H_1, the height along the y axis. The value of variable X is the same as in equation (1).

$$H_1 = H_2 - (L_1 \cos(\varphi_1) + L_2 \cos(X)) \quad (2)$$

To determine whether the exoskeleton will fall sideways, a trigonometric approach is taken where the exoskeleton is viewed as a triangle. The vertices are marked by footplate on the floor, the foot being lifted up and the center of the user's lower back. We base our calculations of the centroid on the centroid formula. The position of the user's waist is assumed to be constant and, therefore x_3 and y_3 (otherwise denoted in the Fig. 5 as H_2) can be measured in standard position and will not change. We assume that the foot placed on the ground does not change and is positioned at the origin. In that case, x_1 and y_1 are zero. While the other foot is being lifted, it does not change in the x direction and therefore x_2 is constant and measurable at standard position. y_2 is equivalent to H_1 found before. As such, the centroid of the triangle follows the equation (3) for all states.

As all *x* values are constant, the *x* coordinate for the centroid does not change. The *y* coordinate of the centroid must change and this change can be used to determine if the exoskeleton platform will fall. If the difference in the y coordinate of the new centroid from the standard position centroid exceeds the threshold, the system recognizes that the user has lost their balance.

$$P_H(x,y) = \left(\frac{x_1+x_2+x_3}{3}, \frac{y_2+H_1+H_2}{3}\right) \quad (3)$$

P_H can be used to determine whether the exoskeleton will fall sideways and similar to Q_t, it can be written as a variable condition for a balancing program in the form of $P_H(x,y) > P_{threshold}$ where $P_{threshold}$ defines the acceptable range of the centroid output. Therefore, the equations from above are used in conjunction to create a program function that detects the extent of the exoskeletons lean and determines whether it will fall.

IV. Experiment Results

In the experimental phase, a person weighing 75 kg with height 173 cm performs the functional testing in our experiment. The angle of joint motion obtained from the 12 bits absolute encoder that attached both on hip joints and knee joints. In this system, a master controller (Atmega2560 controller board) is used to process the fall detection function and the motion planning with trajectory control, the slave controllers (atmega32b controller board) are used to perform the close loop control of each DC motor with an absolute encoder.

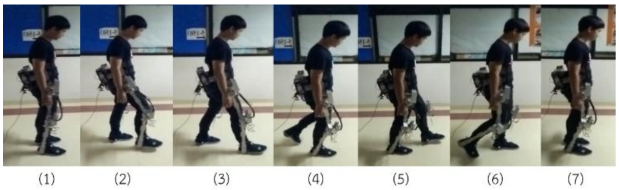

Figure 6. Experiment of gait pattern cycle.

In experiment, the following percentages of total body weight were used to calculate the natural leg: the thigh amounts to 9.6% of total body weight, while the shit and foot are 4.5% and 1.4% respectively. From the calculation, M_1, the combined mass of the user and exoskeleton for the upper leg and M_2, the combined mass of the user and exoskeleton for the lower leg is to 12.20 kg and 9.43 kg respectively. The length L_1 and L_2 of the upper and lower legs are 30 cm and 33 cm respectively. H_2 is found to be 90 cm. The experiment is shown in Fig. 6.

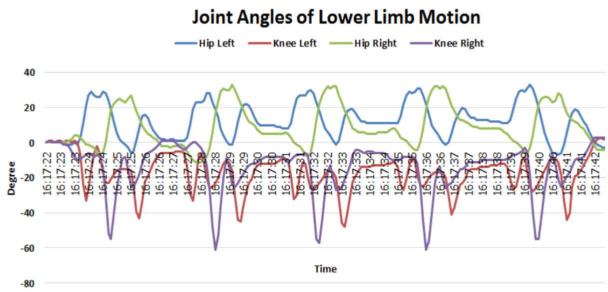

Figure 7. Joint motion of gait pattern

Fig. 7 describes the raw data collected in a single trial. The different lines indicate the change in angle of different joints. In the trial, five steps are taken and therefore there are five different instances of the same pattern shown in the experiment. In each iteration of the pattern, the motions of the right and left legs were similar indicating both sides should yield the same calculations when put through the equations derived.

For the experiment, five trials, each consisting of five iterations of walking motions, were conducted. The result of the moment of leg data is illustrated in Fig. 8 and the change centroid data is illustrated in Fig. 9. The data indicates that as long as the values for total moment and coordinate of the centroid of the exoskeleton robot platform are within such peaks, the exoskeleton is in a state of balance. From the data received, $Q_{threshold}$ is set to be 145 for forward swings and 77 for backward swings. $P_{threshold}$ is set to be 33.

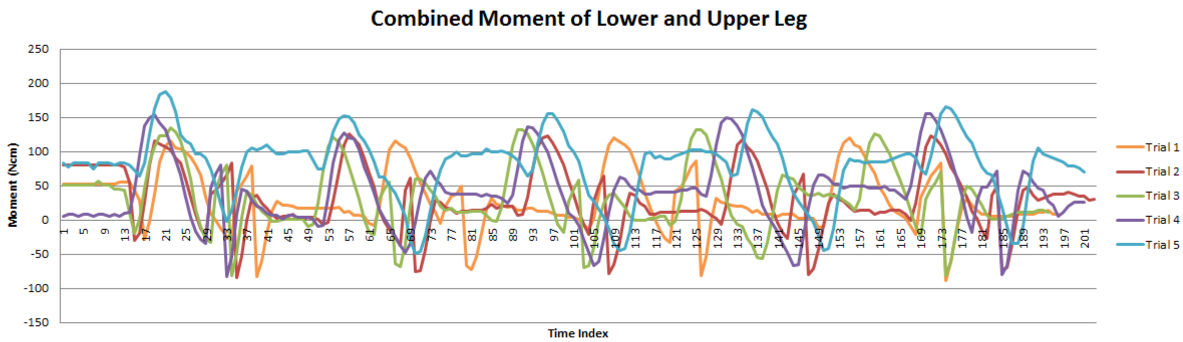

Figure 8. The experimental results of moment output of gait patterns.

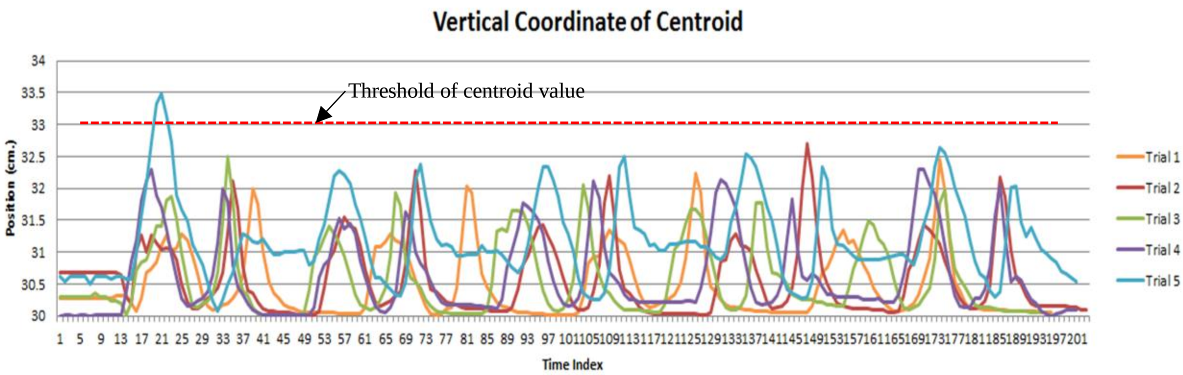

Figure 9. Centroid coordinate change for fault detection.

V. CONCLUSION AND FUTURE WORKS

In this work, an experiment was conducted and data was obtained. The two variables were calculated using the derived formula and the desired result achieved. The value of $Q_{threshold}$ and $P_{threshold}$ was set based upon the platform experimented upon as in Table I. Having successfully set the threshold, a program would be made which would prevent the robot platform from falling. When the threshold is exceeded, the program would command the robot to reverse its motions successfully keeping the exoskeleton from falling. As such, this particular platform would be kept in balance. It would be beneficial to further refine the method of balance and derive new equations to make the method of fall detection usable for situations other than walking. These situations may include running, jumping, or walking up the stairs – situation upon which the current model fails to detect imbalance. Future research on the lower limb exoskeleton may also include the possibility of additional degrees of freedom and joints in places such as the ankle which would serve to give additional comfort to the user and create more nature movements.

TABLE I. EXPERIMENTAL RANGE OF MOMENT AND CENTROID COORDINATES

Experiments	**Total Moment value (N.cm)**		**Y Coordinate of Centroid (cm)**	
No. trials	Swing Forward (Max.)	Swing Forward (Min.)	Max.	Min.
1	119.92	88.34	32.47	30.01
2	126.18	85.07	32.70	30.01
3	134.52	81.97	32.49	30.01
4	155.05	82.86	32.30	30.00
5	187.93	49.07	33.49	30.08
Avg.	144.72	77.46	32.69	30.02

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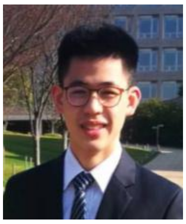

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