

Kinematic Analysis of Sit-To-Stand Assistive Device for the Elderly and Disabled

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Abstract—This paper introduces a robotic walking and sit-to-stand support system, Smart Mobile Walker(SMW), and presents kinematic analysis of the system. For supporting person's sit-to-stand movement, the motion of SMW is modeled by the analysis of kinematics. The results of analysis are used for simulations and its feasibility is investigated by simulations. The feasibility shows our analysis of kinematics can be applied as a base of making optimal motion trajectory for helping sit-to-stand.

Keywords – Rehabilitation robotics; Assistive technology; Sit to Stand; Analysis of Kinematics; Motion Trajectory

I. INTRODUCTION

Recently, the number of elder people is increasing and thus interest of welfare for the elderly and disabled are rapidly rising as well. This rapid increase of attention implies that elders require more technical aid to support their daily living. Especially, numerous problems can be seen in the essential activities such as sitting down and standing up. Therefore, many recent studies focus on solving those problems.

Researches about sit-to-stand can be categorized into two parts; perspective of analyzing sit-to-stand motion and designing device.

In the analyzing sit-to-stand motion, a trajectory of physical points such as head, arms, trunk, hip, knee and ankles has been studied. One approaches to design and validate of a three-segment human body model [4]. And some researches tried to find optimal trajectories using cost function [5].

In the designing device, some trials of assistive devices for sit-to-stand movement have been reported. The powered knee-orthosis have been proposed to help user's sit-to-stand movement [2]. And passive gravity balanced assistive device introduced [1]. This device use gravity for reducing joint torque when sit-to-stand and a hybrid method is used to manipulate center-of-mass of the system. There is a device supporting user's hip using moving bed and handrail [3]. And walker type which is similar with normal walker is introduced [8]. Lately, a robot which can help multimodal walking and sit-to-stand motion has been proposed. An assistive robotic device,

KineAssist, [6] has been applied for therapy of rehabilitation as like gait and balance training.

In [1], the device is proposed to support user's hip for helping his sit-to-stand movement. It decreases required torque at the knee and efficiently supports the upper body. In [6], the device was designed to support user's trunk, because this paper insists that supporting trunk is the important factor in sit-to-stand movement. Similarity of above two papers is the support of upper body, which is a major factor in sit-to-stand. Therefore, SMW is designed to support arms in order to control upper body.

Section 2 briefly introduces our device, SMW. Section 3 proposes analysis of forward and inverse kinematics. Section 4 describes results from verification. Section 5 presents conclusion including remarks and future works.

II. SMART MOBILE WALKER(SMW)

SMW has been developed as a device for helping the elderly and disabled. Especially, SMW's development focuses on giving a hand to their daily living like walking and sit-to-stand movement. Thus, we had designed the SMW in order to support user's walking and sit-to-stand movement.

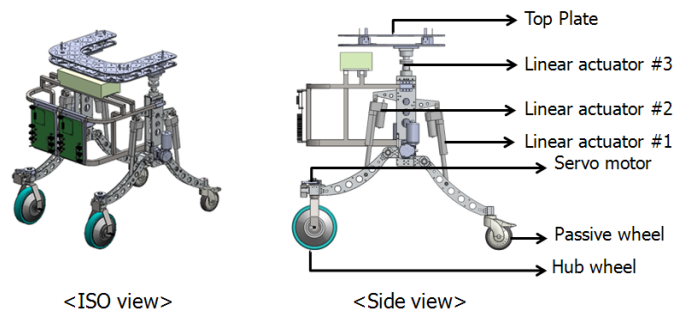


Figure 1. CAD of Prototype of SMW

The SMW is composed of six linear actuators, two hub motors, two passive wheels, two servo motors and a top plate. Each servo motor controls steering angle of the hub motors for

walking support. Four linear actuators, linking legs and the body, control orientation and position of the top plate. Remaining two linear actuators, linking the top plate and the body, create up and down motion to the top plate.

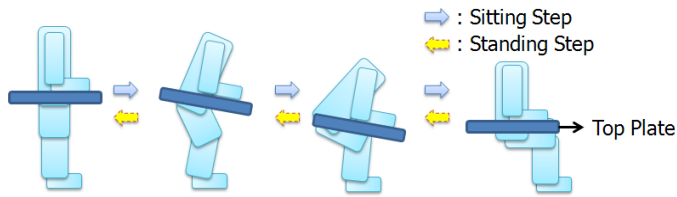


Figure 2. The Sit-to-Stand Motion with Top Plate

Sit-to-stand assistance using SMW can be performed by controlling the linear actuators. The angle and height of the top plate change following the linear actuators. Therefore kinematic analysis is essential to get the relationship between top plate condition and linear actuators' length.

III. KINEMATIC ANALYSIS

Sit-to-stand assistance rarely needs different motion on left and right side of SMW. Thus kinematics model can be simplified to half body model. There are three linear actuators and a servo motor and a hub motor on one side. However degree of freedom required to the top plate is 3. Therefore we need to fix two actuators to have unique inverse kinematics solution. Steering servo and linear actuator #3 are to be fixed for the reason.

A. Forward Kinematics

Forward kinematics of SMW is defined as figuring out position and angle on the top plate from given linear actuator lengths. The hub wheel motion is directly related to the x coordinate of the top plate. Thus it is not under consideration on kinematic analysis. Then the output parameter is simplified as the height and angle of the top plate.

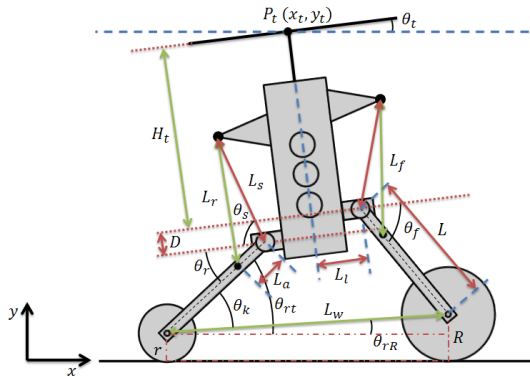


Figure 3. Simplified SMW for forward kinematics

Fig.3 shows the simplified model for forward kinematics. There are two variables, length of the front actuator and rear actuator. Angles between the body and legs are decided by linear actuators lengths as equation (1).

$$\left. \begin{aligned} \theta_r &= \text{acos} \left(\frac{L_s^2 + L_a^2 - L_r^2}{2L_s L_a} \right) - \theta_s \\ \theta_f &= \text{acos} \left(\frac{L_s^2 + L_a^2 - L_f^2}{2L_s L_a} \right) - \theta_s \end{aligned} \right\} \quad (1)$$

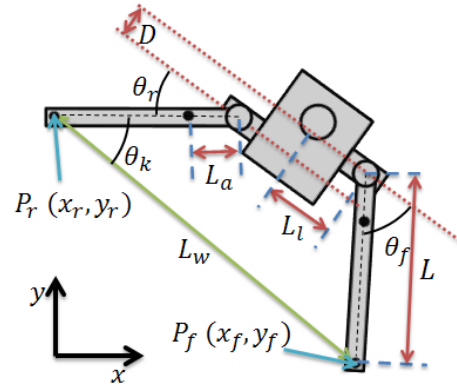


Figure 4. Part of SMW for Analyzing Forward Kinematics

As the length of the legs and body size is known, we can specify a quadrilateral formed by drawing a line connecting the wheel axis of hub wheel and passive wheel as Fig.4. The length of the line can be calculated as equation (2), by assuming the rear leg is overlapped on X axis of local coordinate system and the origin is on passive wheel axis.

$$\left. \begin{aligned} x_f &= x_r + L + 2L_l \cos(\theta_r) + D \sin(\theta_r) + L \cos(\theta_r + \theta_f) \\ y_f &= y_r - 2L_l \sin(\theta_r) + D \cos(\theta_r) - L \sin(\theta_r + \theta_f) \end{aligned} \right\} \quad (2)$$

$$\theta_k = \text{atan} \left(\frac{y_r - y_f}{x_f - x_r} \right)$$

$$\theta_{rR} = \text{asin} \left(\frac{R - r}{L_w} \right) \quad \left(L_w = \sqrt{(x_f - x_r)^2 + (y_f - y_r)^2} \right)$$

From the length of the line and radius of wheels, angle θ_{rR} can be decided as above. Then the angle of the top plate is decided as equation (3).

$$\theta_{rR} = \text{asin} \left(\frac{R - r}{L_w} \right) \quad \left(L_w = \sqrt{(x_f - x_r)^2 + (y_f - y_r)^2} \right)$$

$$\theta_t = \theta_k + \theta_{rR} - \theta_r \quad (\theta_{rt} = \theta_k + \theta_{rR}) \quad (3)$$

$$\left. \begin{aligned} x_t &= x_r + L \cos(\theta_{rl}) + L_l \cos(\theta_l) - (H_t + D) \sin(\theta_l) \\ y_t &= y_r + L \sin(\theta_{rl}) + L_l \sin(\theta_l) + (H_t + D) \cos(\theta_l) \end{aligned} \right\} (4)$$

The height of the top plate can be represented as equation (4) using trigonometric functions. It assumes that the y axis coordinate at ground is zero. X axis coordinate has zero at the center of passive wheel.

B. Inverse Kinematics

Inverse kinematics is opposite to forward kinematics. The information of top plate becomes input data and output are length of actuators. We define new points and model constant lengths for analyzing inverse kinematics. The simplified model is shown in Fig. 5.

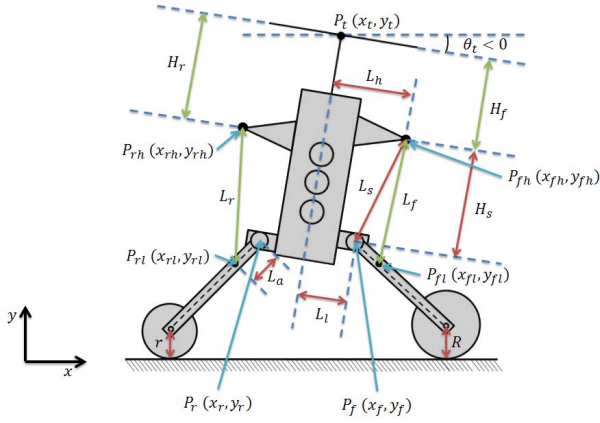


Figure 5. Simplified Model for Inverse Kinematics

There are three variables; x-coordinate, y-coordinate of top plate and the angle of top plate. These factors are used as input data. If the information of top plate were determined, lengths of actuators would be calculated. In this time, we use sets of six points for getting length of actuators. First, we define coordinates of four points.

$$\left. \begin{aligned} x_{fh} &= x_t + H_f \sin \theta_t + L_h \cos \theta_t \\ y_{fh} &= y_t - H_f \cos \theta_t + L_h \sin \theta_t \end{aligned} \right\} P_{fh}$$

$$\left. \begin{aligned} x_{rh} &= x_t + H_r \sin \theta_t - L_h \cos \theta_t \\ y_{rh} &= y_t - H_r \cos \theta_t - L_h \sin \theta_t \end{aligned} \right\} P_{rh}$$

$$\left. \begin{aligned} x_f &= x_t + (H_f + H_s) \sin \theta_t + L_l \cos \theta_t \\ y_f &= y_t - (H_f + H_s) \cos \theta_t + L_l \sin \theta_t \end{aligned} \right\} P_f$$

$$\left. \begin{aligned} x_r &= x_t + (H_r + H_s) \sin \theta_t - L_l \cos \theta_t \\ y_r &= y_t - (H_r + H_s) \cos \theta_t - L_l \sin \theta_t \end{aligned} \right\} P_r$$

From above result, we can derive two points where equip the actuator on the each leg. For this, we define another variable as indicated in Fig. 6.

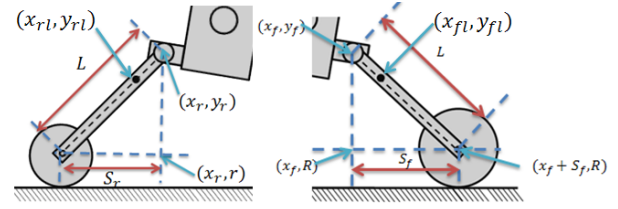


Figure 6. Simplified Model for Inverse Kinematics

From the point information, lengths of each actuator can be found as equation (5).

$$S_f = L \sin \left(a \cos \left(\frac{|y_f - R|}{L} \right) \right) \quad S_r = L \sin \left(a \cos \left(\frac{|y_r - r|}{L} \right) \right)$$

$$x_{fl} = x_f + \frac{S_f L_a}{L} \quad y_{fl} = y_f + \frac{(y_f - R) L_a}{L}$$

$$x_{rl} = x_r - \frac{S_r L_a}{L} \quad y_{rl} = y_r - \frac{(y_r - r) L_a}{L}$$

$$\left. \begin{aligned} L_f &= \sqrt{(x_{fh} - x_{fl})^2 + (y_{fh} - y_{fl})^2} \\ L_r &= \sqrt{(x_{rh} - x_{rl})^2 + (y_{rh} - y_{rl})^2} \end{aligned} \right\} (5)$$

Ultimately, length of actuators can be calculated from the information of top plate. There is no doubt that if front wheel runs forward or backward, it would change x-position of the top plate. However since we focused on sit-to-stand motion this time, we can neglect the movement of front wheel.

IV. VERIFICATION

In this section we will discuss the feasibility of SMW. The feasibility is investigated by simulation, which is performed by taking 2 steps. First step is finding length of actuators from arbitrary information of top plate by using inverse kinematics. Second step is getting information of top plate using length of past actuators by forward kinematics. Fig.7 represents the schematic diagram of simulation procedure.

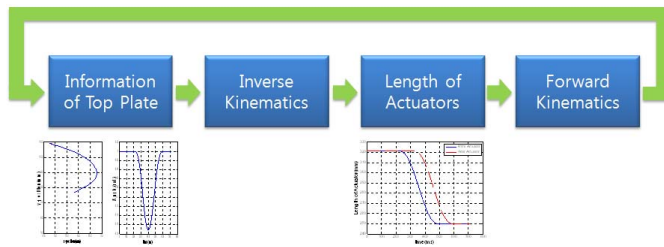


Figure 7. Schematic Diagram of Simulation Procedure

In first step, certain reference trajectory of the top plate was taken as Fig. 8.

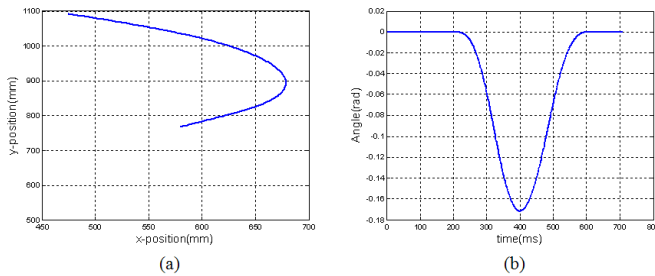


Figure 8. Reference Trajectory of Top Plate

Fig. 8(a) is position of top plate and Fig. 8(b) is orientation of top plate. We apply inverse kinematics to this reference trajectory for getting length of actuators. After getting the length of actuators, we used it as input data for forward kinematics. Through forward kinematics, we can obtain information of the top plate. Fig.9 shows error between reference trajectory and information of top plate from forward kinematics.

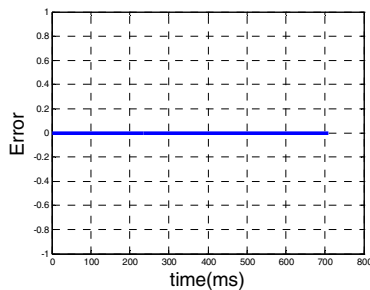


Figure 9. Error between Reference and Result of Forward Kinematics

There are no errors between reference and result of forward kinematics. This means that if there were a specific motion trajectory which needs to be obtained, it is possible to realize it by using analysis of kinematics.

V. CONCLUSION & FUTURE WORK

This paper analyzed kinematics of the robotic walking and sit-to-stand support system, SMW. Its feasibility is investigated by simulation. Moreover, a possibility that kinematics can be applied in order to develop optimal motion trajectory was verified. Therefore, next research can be made focusing more on generating optimal motion trajectory, expected to experiment to gather information of trajectories and evaluate them. This research also expects to apply physical theories and develop the algorithm for making optimal motion trajectory.

ACKNOWLEDGMENT

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TABLE I. PARAMETERS IN ANALYSIS OF KINEMATICS

Symbol	Forward & Inverse Kinematics Definition
x_t	The x-coordinate of top plate
y_t	The y-coordinate of top plate
θ_t	The angle between top plate and horizontal axis
L_r	The length of rear linear actuator

L_f	The length of front linear actuator
r	The radius of rear wheel
R	The radius of front wheel
L_s	The distance between linking point of body and actuator and leg's joint
L_a	The distance between leg's joint and linking point of actuator and leg
L_l	The distance between leg's joint and the middle of body
L	The distance of leg

Symbol	Forward Kinematics Definition	Symbol	Inverse Kinematics Definition
x_r	The x-coordinate of rear wheel	x_r	The x-coordinate of rear joint
y_r	The y-coordinate of rear wheel	y_r	The y-coordinate of rear joint
x_f	The x-coordinate of front wheel	x_f	The x-coordinate of front joint
y_f	The y-coordinate of front wheel	y_f	The y-coordinate of front joint
H_t	The distance between top and front leg's joint	H_r	The distance between top and linking point of actuator and body on rear side
D	The difference between rear wheel and front wheel	H_f	The distance between top and linking point of actuator and body on front side
L_w	The distance between center of rear wheel and front wheel	H_s	The distance between leg joint and linking point of actuator and body
θ_s	The angle between	L_h	The distance between middle of body and

	L_s and inclined axis		linking point of actuator and body
θ_r	The angle between rear leg and inclined axis	x_{rh}	The x-coordinate of linking point of actuator and body on rear side
θ_f	The angle between front leg and inclined axis	y_{rh}	The y-coordinate of linking point of actuator and body on rear side
θ_k	The angle between rear leg and line from center of rear wheel to center of front wheel	x_{fh}	The x-coordinate of linking point of actuator and body on front side
θ_{rt}	The angle between rear leg and horizontal axis	y_{fh}	The y-coordinate of linking point of actuator and body on front side
θ_{rR}	The angle between line horizontal axis and line from center of rear wheel to center of front wheel	x_{rl}	The x-coordinate of linking point of actuator and rear leg
Symbol	Inverse Kinematics Definition	y_{rl}	The y-coordinate of linking point of actuator and rear leg
S_r	The distance between rear leg joint and center of rear wheel on horizontal axis	x_{fl}	The x-coordinate of linking point of actuator and front leg
S_f	The distance between front leg joint and center of front wheel on horizontal axis	y_{fl}	The y-coordinate of linking point of actuator and front leg