WAIST ASSISTIVE WEARABLE POWERED EXOSKELETON FOR ARMED PERSONNEL

BTP MID-TERM REPORT PHASE II

submitted by

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BACKGROUND & PREVIOUS WORK

An exoskeleton is a wearable device that can be used for protection, support, and strength enhancement. The fundamental components of the exoskeleton are frame, joints, and fixtures. Joints are controlled using either hydraulic, pneumatic actuators, or electric motors. Fixtures are attached to the exoskeleton to rigidly connect the exoskeleton to the operator. Apart from the mechanical joints and fixtures, pre-planned trajectories must be given as input to the exoskeleton. In the previous work, biped walking has been simulated. It has been done using inverse kinematics by calculating the joint parameters at every instant. However, the method has resulted in unstable walking for larger step lengths. Hence, a new method has been implemented in this phase to obtain stable walking.

1.1 BACKGROUND

1.1.1 *DH Parameters*

Denavit–Hartenberg parameters (also called DH parameters) are the four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator [4]. DH parameters are the combination of link twist angle, link length, joint angle, and joint distance. The transformation matrix, which can be found using DH parameters, transforms the position of a point from a non-inertial frame to an inertial frame.

1.1.2 *Kinematic Analysis*

Forward kinematics determine the position & orientation of the end-effector w.r.t the inertial frame for the given configuration of the exoskeleton. After determining DH parameters, transformation matrices are calculated. When the position vector of the end-effector in the non-inertial frame is multiplied with the transformation matrix, the result gives the position of the end-effector w.r.t the base. Whereas, inverse kinematics must be analyzed to control the exoskeleton in task space. Joint parameters can be calculated using numerical methods or analytical methods.

1.2 OBJECTIVES

The primary objectives of the project in phase II are mentioned below:

1. To stabilize the walking pattern of biped in real-time environments
2. To implement the stabilized walking pattern of biped in the exoskeleton
3. To design a CAD model of the exoskeleton

1.3 WORK PLAN

Currently, we are working on the biped simulation to stabilize walking in real-time environments. We are working on new methods that can control the walking pattern precisely. Once we reach the above goal, we will implement the above walking pattern in the exoskeleton and design a control system. If time permits we will develop a CAD model of the exoskeleton.

2 TRAJECTORY PLANNING AND ZMP METHOD

In the previous work, biped walking has been simulated in MATLAB using inverse kinematics. However, the method has resulted in unstable walking for larger step lengths. Hence, in phase II, a new method has been implemented by planning the trajectories of hip and ankle joints, which resulted in a stable walking pattern.

2.1 ZERO MOMENT POINT

Human gait can be divided into two cycles in a single walking cycle: single support phase and double support phase. In a single support phase, one leg is in contact with the ground whereas the other leg swings across the stance leg. In a double support phase, swing and stance leg interchange the positions while both being in contact with the ground. Center of gravity plays an important role in maintaining the static stability of a biped. CoG must always fall in the support polygon within the legs to maintain static stability. In order to maintain dynamic stability, the center of pressure(CoP) should strictly be inside the support polygon. Zero-moment point(ZMP) or CoP is defined as the point on the ground at which the resultant of ground reaction forces act[1]. The coordinates of ZMP are obtained by using the below equations

$$x_{ZMP} = \frac{\sum_{i=1}^{n} m_i(\ddot{z_i} + g)x_i - \sum_{i=1}^{n} m_i \ddot{x_i} z_i - \sum_{i=1}^{n} I_{iy} \ddot{\Omega_{iy}}}{\sum_{i=1}^{n} m_i(\ddot{z_i} + g)} \tag{2.1}$$

$$y_{ZMP} = \frac{\sum_{i=1}^{n} m_i(\ddot{z_i} + g)y_i - \sum_{i=1}^{n} m_i \ddot{y_i} z_i - \sum_{i=1}^{n} I_{ix} \ddot{\Omega_{ix}}}{\sum_{i=1}^{n} m_i(\ddot{z_i} + g)} \tag{2.2}$$

$$\begin{aligned} \text{where, } m_i &= \text{mass of link and respective inertial component } I_{ix} \& I_{iy} \\ \Omega_{ix}, \Omega_{iy} &= \text{absolute angular accelerations of the link} \\ (x_i, y_i, z_i) &= \text{coordinates of CoM of link i} \end{aligned}$$

In the single support phase, ZMP should be located inside the stance foot region, whereas, in the double support phase, ZMP should fall within the supported region.

2.2 TRAJECTORY PLANNING

For ZMP to fall within the support polygon, trajectories of the joints must be defined. Hence, we can consider biped as two 2R manipulators: stance and swing leg. For hip trajectory, stance ankle joint is considered as the base and hip is considered as the end effector. For ankle trajectory of the swing leg, hip joint is considered as the base and ankle is considered as the end effector. For a biped walking on a sagittal(x-z) plane, motion of the stable leg is assumed to be an inverted pendulum[2]. In addition, we assume biped does not fold the stable leg while walking and the foot to be always parallel to the ground. Hence, the walking sequence can be determined by computing trajectories of hip, ankle, and knee joints.

2.2.1 *Swing Leg's Trajectory*

Ankle Trajectory : We define the ankle joint trajectory of swing leg as follows[3]

$$x_A(t) = x_i + \left(\frac{3x_f}{t_f^2}\right)t^2 - \left(\frac{2x_f}{t_f^3}\right)t^3 - x_i + \frac{x_f}{2} \tag{2.3}$$

$$\begin{aligned} z_A(t) =& -kx_i(x_f + x_i)^2 + k(x_f + x_i)(x_f + 3x_i)(x_A(t) + (x_i + \frac{x_f}{2})) \\ & - k(2x_f + 3x_i)(x_A(t) + (x_i + \frac{x_f}{2}))^2 + k(x_A(t) + (x_i + \frac{x_f}{2}))^3 \end{aligned} \tag{2.4}$$

$$\begin{aligned} \text{where, } k &= \frac{h}{(x_m - x_i)(x_m - x_i - x_f)^2} \\ (x_i, z_i) &= \text{Coordinates of ankle joint of stance leg at time } t_0 \\ (x_i + x_f, z_f) &= \text{Coordinates of ankle joint of stance leg at time } t_f \\ x_m &= \text{x coordinate of ankle joint at maximum vertical height} \\ h &= \text{Step height} \end{aligned}$$

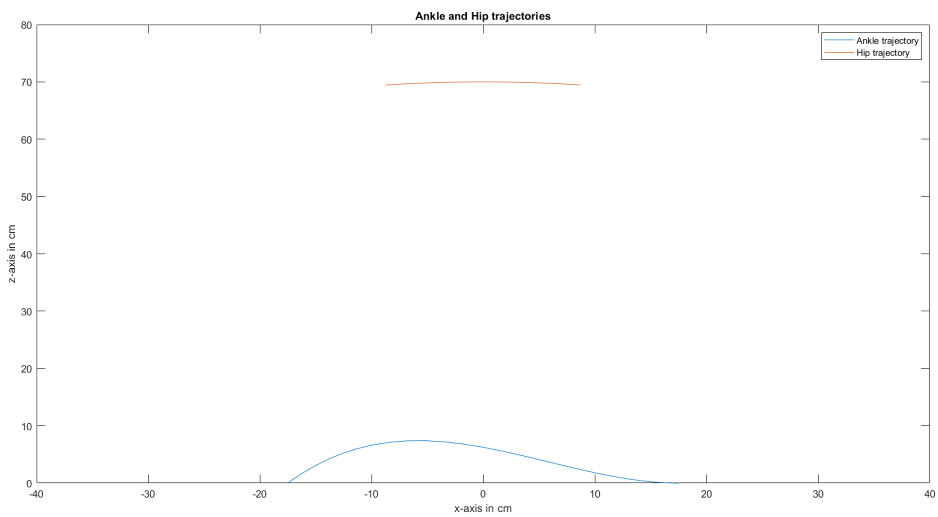


Figure 2.1: Ankle and Hip trajectories

2.2.2 *Stance Leg's Trajectory*

Hip Trajectory : We define the hip joint trajectory of stance leg as follows

$$x_H(t) = \frac{x_f}{4} + v_s t + (\frac{v_e - v_s}{2t_f} - 1.5rt_f)t^2 + rt^3 \tag{2.5}$$

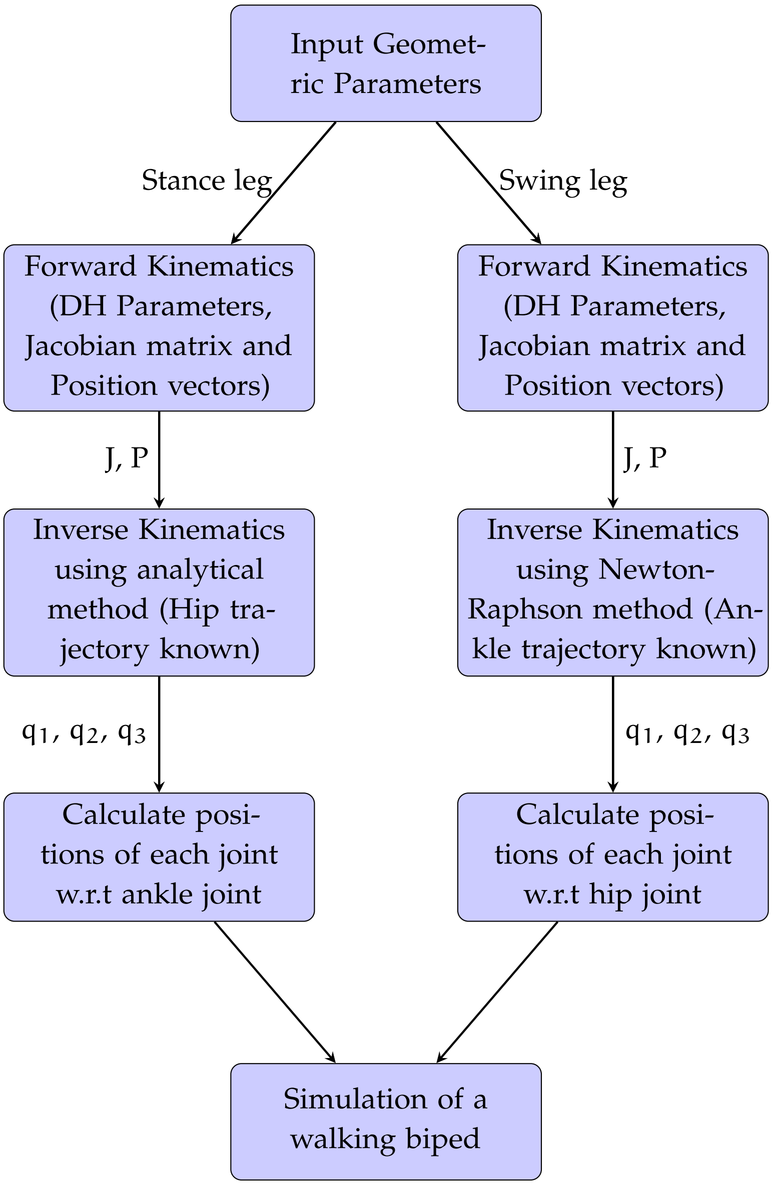
$$z_H(t) = \sqrt{(l_1 + l_2)^2 - (x_H(t))^2} \tag{2.6}$$

$$\begin{aligned} \text{where, } r &= -2\left(\frac{xf}{2t_f^3} - \frac{v_s + v_e}{2t_f^2}\right) \\ v_s &= \text{Velocity of hip at } t_0 \\ v_e &= \text{Velocity of hip at } t_f \\ l_1 \;\&\; l_2 &= \text{Length of shank and thigh} \end{aligned}$$

2.3 BIPED WALKING ALGORITHM USING TRAJECTORY PLANNING

As shown in 2.2, we input the geometric parameters such as shank, thigh, and step lengths to simulate the walking motion of biped. Forward and inverse kinematic analysis are performed to calculate the positions of joints w.r.t the reference frame.

Figure 2.2: Algorithm for stable biped walking



3 RESULTS

Walking of biped has been simulated using trajectory planning and ZMP method as discussed in chapter 2. Following geometric parameters have been given as inputs to demonstrate walking :
Step length = 35 cm
Step height = 6.25 cm
Hip velocity = 2.5 cm/s
Simulation time = 3 s
Length of foot = 15 cm
Width of foot = 10 cm
Length of shank and thigh = 35 cm

3.1 KINEMATIC ANALYSIS OF STANCE LEG

DH Parameters : DH parameters for the stance leg are given in the table 3.1

Inverse Kinematics of stance leg : Hip joint of the stance leg follows a circular trajectory with ankle joint as its center. Coordinates of the knee and hip joints w.r.t ankle joint can be calculated using inverse kinematics(analytical method). Joint positions and angles can be calculated w.r.t base at every instant as shown in figure 3.1

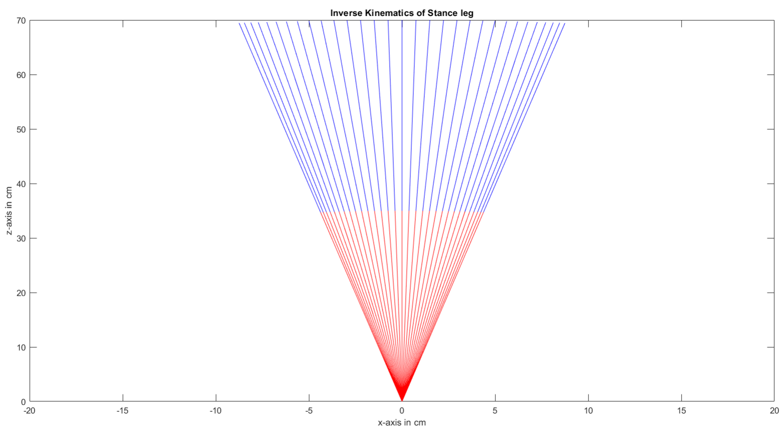


Figure 3.1: Joint positions of stance leg w.r.t base

Table 3.1: DH Parameters for stance leg

Link	θ_k	d_k	a_{k-1}	α_{k-1}
1	$\theta_1 + \pi/2$	0	$-f$	$\pi/2$
2	θ_2	0	l_1	0
3	$\theta_3 - \pi/2$	0	l_2	0
4	0	0	0	$-\pi/2$

Table 3.2: DH Parameters for swing leg

Link	θ_k	d_k	a_{k-1}	α_{k-1}
1	$\theta_1 - \pi/2$	0	0	$\pi/2$
2	θ_2	0	l_2	0
3	$\theta_3 + \pi/2$	0	l_1	0
4	0	0	f	$-\pi/2$

3.2 KINEMATIC ANALYSIS OF SWING LEG

DH Parameters : DH parameters for the swing leg are given in the table 3.2

Inverse Kinematics of swing leg : Ankle joint of swing leg follows a polynomial trajectory of the third degree. Coordinates of knee and ankle joints w.r.t hip joint can be calculated using inverse kinematics(Newton-Raphson method). Joint positions and angles can be calculated w.r.t base at every instant as shown in figure 3.2

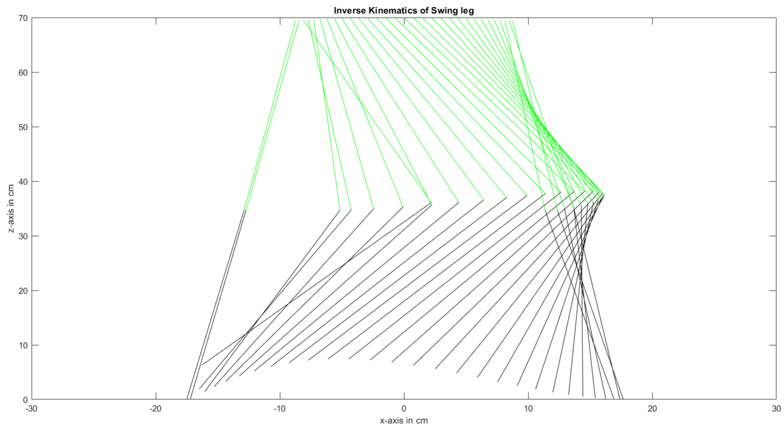


Figure 3.2: Joint positions of swing leg w.r.t base

3.3 INVERSE KINEMATICS OF BIPED

Combined joint positions of biped w.r.t reference frame are shown in figure 3.3

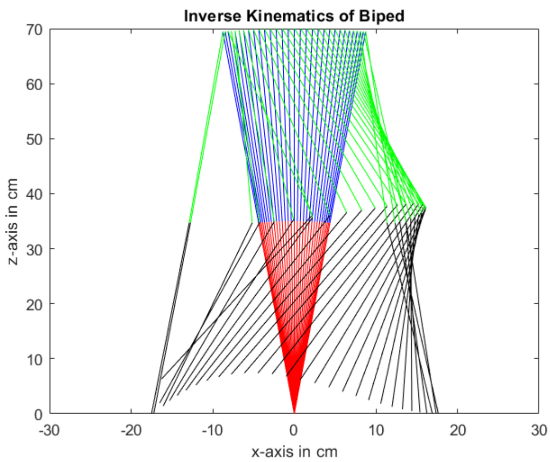


Figure 3.3: Joint positions of biped w.r.t reference frame

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