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# Modeling and Design of an Active Leg Orthosis for Tumble Protection

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***Abstract*—**The design of an active leg orthosis for tumble protection is proposed in this paper. The orthosis would be applied to assist elders or invalids in rebalancing while they fall unexpectedly. We observe the regain balance motion of healthy and youthful people, and find the difference to elders or invalids. First, the physical model of leg would be established, and we consider the leg motions are achieve through four joints (phalanx stem, ankle, knee, and hip joint) and five links (phalanges, talus, tibia, femur, and hip bone). To formulate the dynamic equations, the coordinates which can clearly describe the position in 3D space are first defined accordance with the human movement of leg, and the kinematics and dynamics of the leg movement can be formulated based on the robotics. For the purpose, assisting elders and invalids in avoiding tumble, the posture variation of unbalance and regaining balance motion are recorded by the motion-capture image system, and the trajectory is taken as the desire one. Then we calculate the force and moment of each joint based on the leg motion model through programming MATLAB code. The results would be primary information of the active leg orthosis design for tumble protection.

***Keywords*—**Active leg orthosis, Tumble protection

## I. Introduction

FALL happen in all groups commonly due to unexpected postural disturbances. When unbalance occurs during standing or walking, youthful and healthy people can regain balance before falling. However, elders or invalids cannot response instantly and unable to adjust the center of weight for body-balance immediately. Since they are without sensitive sensor to notice the postural disturbances, or their muscle strength has been aging. In addition, falls would cause serious injuries, especially for the elder or invalids. About fall investigations, Ashton-Miller et al. [1]-[15] devoted forward fall included regaining balance motion, joint torque effect, kinematics and kinetics, and the authors considered difference age, gender, and health. In initial research, they observed the joint torques applied the recover from a forward fall[1], and discussed the differences of ages and genders in sudden stops and balance recovery from a forward fall[5], [6]. Then, they find that the peak normalized anterior cruciate ligament strain was 30% larger for the impulsive compression loading in valgus and flexion compared with an impulsive compression loading in isolated flexion [9]. In addition, the segmental dynamics of forward fall arrests were studied accordance with a 2-DOF discrete impact model which was constructed through system identification and validated using experimental data.

For the design of tumble protection, orthoses is one of the most import part. Leg orthoses are most belong to a passive mechanism, and they are mainly used to support the weight of human during motion. In recent years, investigator study the semi-active orthosis. Agrawal et al. [16]-[20] proposed a graving-balancing mechanism which using parallelogram mechanism and spring to balance the weight of the leg. The device can be used as an effective orthosis for rehabilitation in conjunction with a walking frame and an overhead safety harness. In addition, the active leg exoskeleton has been presented [21]-[26]. Agrawal et al. [21] devised an active leg exoskeleton which is a motorized leg orthosis having 7DOFs with hip and knee actuated in the sagittal plane. Kofman et al. [22] designed an electro-mechanical stance-control knee-ankle- foot orthosis where the knee joint employs a novel friction- based belt-clamping mechanism to enable a more natural gait. Thelen et al. [23] considered difficulties of people with neurological disorders, and measured 3D movement to assess the biomechanical factor that affect dynamic function. The leg exoskeleton combined electrical stimulation are established to assist invalids walking normally. Kawamoto[24], [25] proposed a hybrid assistive limb which is used as a assistive device providing walking motion support to persons with hemiplegia. They used the bioelectrical signal sensor, power unit, and controller to realize the walking motion.

Related past research works has been focused on the causes of the forward falling and the mechanism design of walking assistant. The unbalance is caused of the unexpectedly postural disturbances; however, elders and invalids cannot regain balance instantly, and fall often make them with serious injure. For the purpose, assisting elders and invalids in avoiding tumble, the tumble protection is gradually important research. We investigate human responses for regaining balance during forward falling to plane the desired trajectory. First, the posture variation of unbalance and regaining balance are recorded by the motion-capture image system, and the trajectory is taken as the desire one. The physical model are established to analysis the kinematics and dynamics of regaining balance motion to find the force and moment applied each links and joints during this motion. This would be one of the most important foundations to design the active orthosis which can help elders and invalids avoiding falling.

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## II. MOTION CAPTURE

To design an active leg orthosis for tumble protecting, we need to observe the regaining balance motion of the young and healthy people and record the trajectory to be a desire on in this orthosis. Here, we adopt a motion-capture image system to record the motion, and this system composes of a high-speed camera, LED marks, and a computer with position analysis software which is shown in Fig. 1. Since the falling motion is faster than the other motion, we set the capture frequency as 179 frames per second. To increase the preciseness of positions, the LED marks are used to mark the key point of links and joint. Six marks are arranged on the slide obliques (SOB), anterior superior ilias spine (ASI), knee (KNE), ankle (ANK), 5th meatatarsal (MT5), and heel (HEE), and illustrated in Fig. 2. In general, people would sway arm to assist regaining balance while falling unexpectedly. However, in this paper, we would exclude the arm effects and focus on the leg responses in regaining balance motion. The hand would keep on the chest during recording the motion. Fig. 3 shows four motion capture images of the motion. Finally, the image would be transmitted to the computer and analyzed via the position analysis software, and we would obtain the angular position variation of each joint.

Observing the regaining balance motion, it would be divided into three stages: (I) beginning forward unbalance; (II) swing leg forwardly; (III) striding to regaining balance. Fig. 4 shows the illustrations of the three stages, and Fig. 5 shows the angular position of each joint. In stage I, people are balance condition, and angle positions are 3.73, 0.18, 126.12, 56.56 degrees of hip, knee, ankle, and meatatarsal joint, respectively. Then, people begin to falling forwardly, and all angular position change small quantity except ankle joint. In stage II, people sense the forward unbalance will cause the impending fall, and swing the leg to move the mass center of the body. In addition, the period is only about 0.3 seconds, and the largest variation of angular position occurred in this stage. People need to response immediately and supply large force and torque to achieve the swing motion. The force/torque of swing forwardly would affect the step of the striding length which is one of the

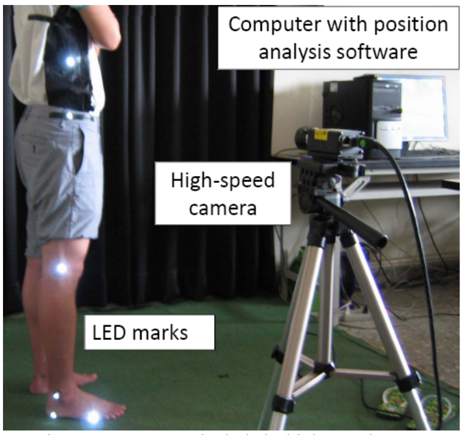



Fig. 1 The motion-capture system included a high-speed camera, LED marks, and a computer with position analysis software.

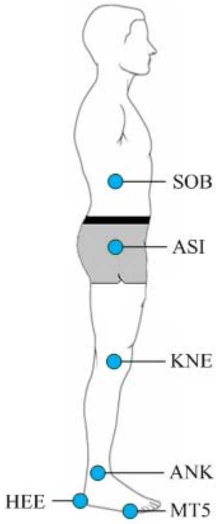
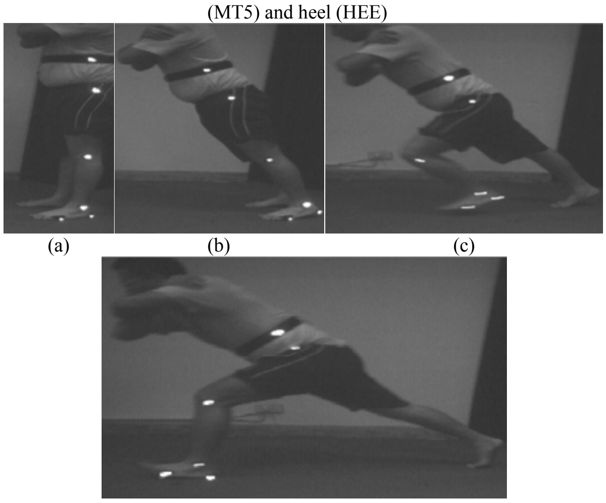



Fig. 2 The arrangement position of five LED marks: side obliques(SOB), anterior superior ilias spine (ASI), knee (KNE), ankle (ANK), 5th meatatarsal (MT5) and heel (HEE)



(a) (b) (c)

(d)

Fig. 3 The picture of regain balance motion recording by motion-capture system. (a) balance condition; (b) forward posture disturbances; (c) lifting and forwardly swing the leg; (d) striding to regaining balance.

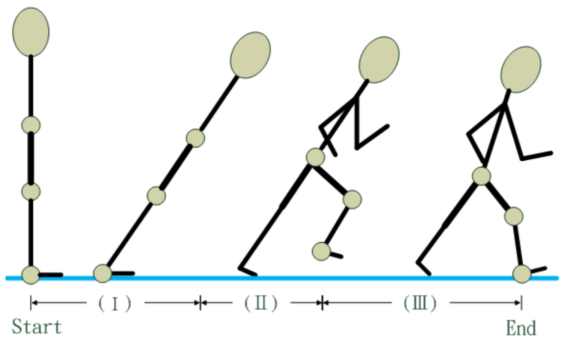



Fig. 4 Illustrations of the three stages of regaining balance motion: (I) beginning forward unbalance; (II) swing leg forwardly; (III) striding to regaining balance.

important factors which affect the regaining balance motion of success. If the striding step is too short, the weight cannot be remove between two legs, and it would causes the regaining balance motion fail. Here, the suitable step length is 1.104m if people are balance until tilting 12 degrees. However, people can regain balance via shorter the striding step length if they sense unbalance earlier while the tilting angle had not been large. In stage III, people stride and regain balance, and the weight center would be around the middle of two foot. From the results, we can find that the time of sensing the unbalance, swing force/torque, and striding step length would caused the regaining balance motion success or fail. The trajectory recorded by motion-capture image system would be adopted a desired on to calculate the suitable force and torque need to supply during regaining balance motion.

## III. Dynamics of Leg Motion

In this paper, we apply robotics to analysis the dynamics of the leg motion. First, the coordinates of legs is defined to describe the position variation of motion during unbalance and regaining balance, and the kinematic and dynamic equations are established accordance with forward and backward equations of the Newton-Euler formulation.

### *A. Coordinates*

We consider three assumptions in this investigation: (1) the leg motion belong to 2DOF motion in sagittal plane, i.e., the angular variations in frontal and transverse plane are ignored; (2) two legs are symmetrical, i.e., the physical characteristics of two leg are the same; (3) the mass center of each part is located at the middle point.

Since the legs are assumed as symmetrical, we would only formulate the motion equations of right leg, and the dynamic equations of left leg is similar to right one. We simply the leg as five-link manipulator composed by foot, instep, tibia, femur, and hip. To formulation the motion we defined six coordinates to describe the angular and translation positions, and the illustrations are shown in Fig. 6. They are reference coordinates $\mathbf{X}^0\mathbf{Y}^0\mathbf{Z}^0$, phalange coordinates $\mathbf{X}^p\mathbf{Y}^p\mathbf{Z}^p$, talus coordinates $\mathbf{X}^{ta}\mathbf{Y}^{ta}\mathbf{Z}^{ta}$, tibia coordinates $\mathbf{X}^{ti}\mathbf{Y}^{ti}\mathbf{Z}^{ti}$, femur coordinates $\mathbf{X}^f\mathbf{Y}^f\mathbf{Z}^f$, and hip bone coordinates $\mathbf{X}^h\mathbf{Y}^h\mathbf{Z}^h$. The reference coordinates $\mathbf{X}^0\mathbf{Y}^0\mathbf{Z}^0$ is fixed coordinates; the other coordinates are body coordinates and rotate/translate with each link. In addition, $l_{fo}$, $l_i$, $l_{ti}$, and $l_f$ are symbolic of the length of instep, tibia, and femur, respectively. The angular position under balance condition are symbol into $\psi$ as the included angle between the horizontal plane of foot and instep, $\alpha$ angle between tibia and instep, $\beta$ angle between femur and tibia, and $\gamma$ angle between hip and femur. Fig. 6 also shows these initial angular definitions.

Accordance with the preceding assumption and definition, the transformation matrix can be derived in Eq. (1)-(5). $x_i$, $y_i$, and $z_i$ are the position vector in $i$-coordinates; $\mathbf{T}_i^j$ is the transformation matrix form $i$ to $j$ .

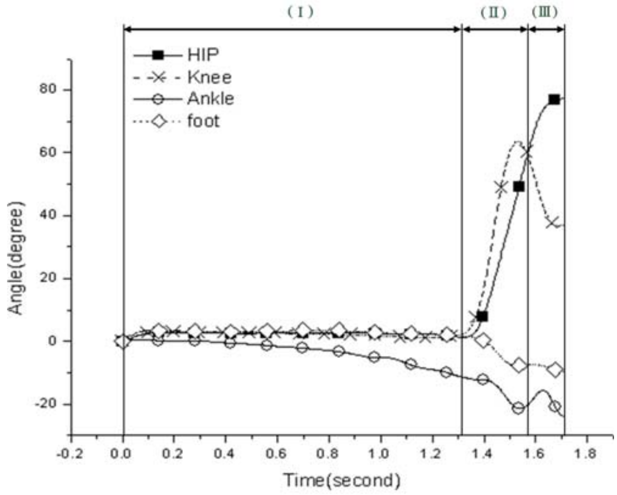



Fig. 5 the angular positions of each joint

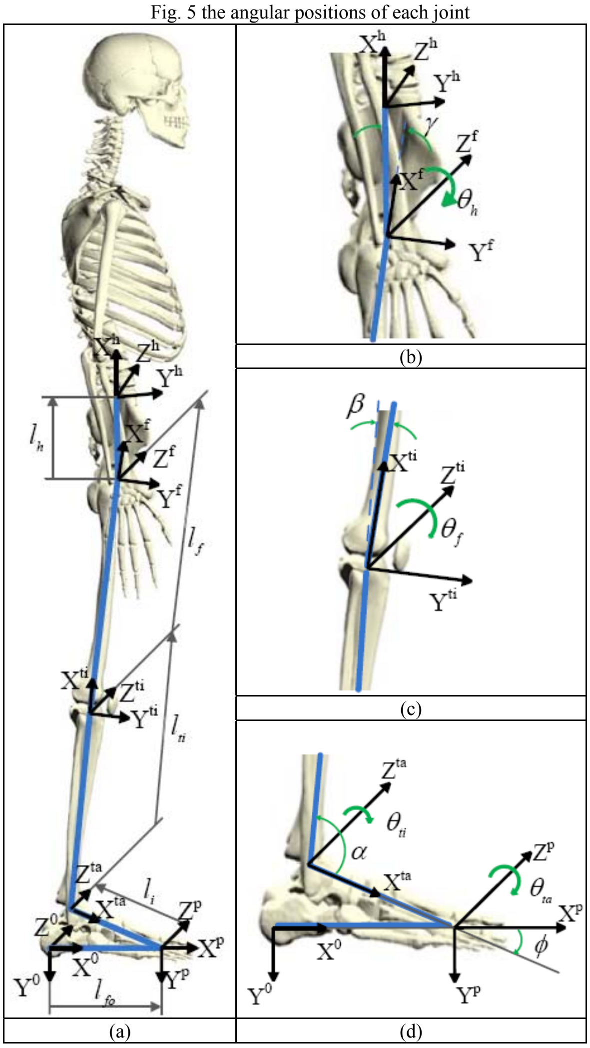


Fig. 6 The definition of coordinates, parameters and variables.(a) the coordinates and lengths of each link; (b) included angle $\gamma$ and rotational angle $\theta_h$ of the hip joint (c) included angle $\beta$ and rotational angle $\theta_f$ of the knee joint; (d) included angles $\alpha$ and$\psi$ ; rotational angle $\theta_{ti}$ and $\theta_{ta}$ of the talus and metatarsal joints.

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & d_{p,x} \\ 0 & 1 & 0 & d_{p,y} \\ 0 & 0 & 1 & d_{p,z} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \mathbf{T}_0^p \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \mathbf{T}_p^{ta} = \begin{bmatrix} C(\phi+\theta_{ta}) & -S(\phi+\theta_{ta}) & 0 & l_i C(\phi+\theta_{ta}) \\ S(\phi+\theta_{ta}) & C(\phi+\theta_{ta}) & 0 & l_i S(\phi+\theta_{ta}) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = \mathbf{T}_p^{ta} \begin{bmatrix} x_{ta} \\ y_{ta} \\ z_{ta} \\ 1 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} x_{ta} \\ y_{ta} \\ z_{ta} \\ 1 \end{bmatrix} = \begin{bmatrix} C(-\alpha+\theta_{ti}) & -S(-\alpha+\theta_{ti}) & 0 & l_{ti} C(-\alpha+\theta_{ti}) \\ S(-\alpha+\theta_{ti}) & C(-\alpha+\theta_{ti}) & 0 & l_{ti} S(-\alpha+\theta_{ti}) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{ti} \\ y_{ti} \\ z_{ti} \\ 1 \end{bmatrix} = \mathbf{T}_{ta}^{ti} \begin{bmatrix} x_{ti} \\ y_{ti} \\ z_{ti} \\ 1 \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} x_{ti} \\ y_{ti} \\ z_{ti} \\ 1 \end{bmatrix} = \begin{bmatrix} C(\beta+\theta_f) & -S(\beta+\theta_f) & 0 & l_{fe} C(\beta+\theta_f) \\ S(\beta+\theta_f) & C(\beta+\theta_f) & 0 & l_{fe} S(\beta+\theta_f) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_f \\ y_f \\ z_f \\ 1 \end{bmatrix} = \mathbf{T}_{ti}^{f} \begin{bmatrix} x_f \\ y_f \\ z_f \\ 1 \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} x_f \\ y_f \\ z_f \\ 1 \end{bmatrix} = \begin{bmatrix} C(-\gamma+\theta_h) & -S(-\gamma+\theta_h) & 0 & 0 \\ S(-\gamma+\theta_h) & C(-\gamma+\theta_h) & 0 & 0 \\ 0 & 0 & 1 & l_h \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_h \\ y_h \\ z_h \\ 1 \end{bmatrix} = \mathbf{T}_{f}^{h} \begin{bmatrix} x_h \\ y_h \\ z_h \\ 1 \end{bmatrix} \tag{5}$$

where $d=[d_{p,x}\ d_{p,y}\ d_{p,z}]^T$ is the translation vector of the phalange; $\theta_{ta}$, $\theta_{ti}$, $\theta_f$, and $\theta_h$ are the angular positions of meatatarsal, ankle, knee, hip joints; $S$ is mean sin, and $C$ is mean cos.

## B. Kinematic and Dynamics

After defining the transformation matrices, the kinematic can be derived accordance the forward equations of Newton-Euler formulations. The angular velocity $\omega_i$, angular acceleration $\dot{\omega}_i$, translational speed $V_i$, and translational acceleration $\dot{V}_i$ of $i$ link are formulated in Eq. (6)-(10).

For phalange link

$$\begin{aligned} &\boldsymbol{\omega}_p = \mathbf{0}, \qquad \dot{\boldsymbol{\omega}}_p = \mathbf{0}, \\ &\mathbf{V}_p = \begin{bmatrix} \dot{d}_{p,x} & \dot{d}_{p,y} & \dot{d}_{p,z} \end{bmatrix}^T, \\ &\dot{\mathbf{V}}_p = \begin{bmatrix} \ddot{d}_{p,x} & g_0 + \ddot{d}_{p,y} & \ddot{d}_{p,z} \end{bmatrix}^T. \end{aligned} \tag{6}$$

For talus link

$$\begin{aligned} &\boldsymbol{\omega}_{ta} = \begin{bmatrix} 0 & 0 & \dot{\theta}_{ta} \end{bmatrix}^T, \qquad \dot{\boldsymbol{\omega}}_{ta} = \begin{bmatrix} 0 & 0 & \ddot{\theta}_{ta} \end{bmatrix}^T, \\ &\mathbf{V}_{ta} = \mathbf{V}_p + \begin{bmatrix} -l_i C(\phi+\theta_{ta})\dot{\theta}_{ta} \\ l_i S(\phi+\theta_{ta})\dot{\theta}_{ta} \\ 0 \end{bmatrix}, \\ &\dot{\mathbf{V}}_{ta} = \dot{\mathbf{V}}_p + \begin{bmatrix} -l_i C(\phi+\theta_{ta})\dot{\theta}_{ta}^{\,2} - l_i S(\phi+\theta_{ta})\ddot{\theta}_{ta} \\ -l_i S(\phi+\theta_{ta})\dot{\theta}_{ta}^{\,2} + l_i C(\phi+\theta_{ta})\ddot{\theta}_{ta} \\ 0 \end{bmatrix}. \end{aligned} \tag{7}$$

For tibia link

$$\begin{aligned} &\boldsymbol{\omega}_{ti} = \boldsymbol{\omega}_{ta} + \begin{bmatrix} 0 & 0 & \dot{\theta}_{ti} \end{bmatrix}^T, \qquad \dot{\boldsymbol{\omega}}_{ti} = \dot{\boldsymbol{\omega}}_{ta} + \begin{bmatrix} 0 & 0 & \ddot{\theta}_{ti} \end{bmatrix}^T, \\ &\mathbf{V}_{ti} = \mathbf{V}_{ta} + \begin{bmatrix} -l_{ti} S(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}\right) \\ l_{ti} C(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}\right) \\ 0 \end{bmatrix}, \\ &\dot{\mathbf{V}}_{ti} = \dot{\mathbf{V}}_{ta} + \begin{bmatrix} \left( \begin{aligned} &-l_{ti} C(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}\right)^2 \\ &\quad -l_{ti} S(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}\right) \end{aligned} \right) \\ \left( \begin{aligned} &-l_{ti} S(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}\right)^2 \\ &\quad +l_{ti} C(\phi+\theta_{ta}+\theta_{ti}-\alpha)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}\right) \end{aligned} \right) \\ 0 \end{bmatrix}. \end{aligned} \tag{8}$$

For femur link

$$\boldsymbol{\omega}_f = \boldsymbol{\omega}_{ti} + \begin{bmatrix} 0 & 0 & \dot{\theta}_f \end{bmatrix}^T, \qquad \dot{\boldsymbol{\omega}}_f = \dot{\boldsymbol{\omega}}_{ti} + \begin{bmatrix} 0 & 0 & \ddot{\theta}_f \end{bmatrix}^T, \tag{9-a}$$

$$\begin{aligned} &\mathbf{V}_f = \mathbf{V}_{ti} + \begin{bmatrix} -l_f S(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f\right) \\ l_f C(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f\right) \\ 0 \end{bmatrix}, \\ &\dot{\mathbf{V}}_f = \dot{\mathbf{V}}_{ti} + \begin{bmatrix} \left( \begin{aligned} &-l_f C(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f\right)^2 \\ &\quad -l_f S(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}+\ddot{\theta}_f\right) \end{aligned} \right) \\ \left( \begin{aligned} &-l_f S(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f\right)^2 \\ &\quad +l_f C(\phi+\theta_{ti}+\theta_{ta}-\alpha-\theta_f-\beta)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}+\ddot{\theta}_f\right) \end{aligned} \right) \\ 0 \end{bmatrix}. \end{aligned} \tag{9-b}$$

For hip bone

$$\begin{aligned} &\boldsymbol{\omega}_h = \boldsymbol{\omega}_f + \begin{bmatrix} 0 & 0 & \dot{\theta}_h \end{bmatrix}^T, \qquad \dot{\boldsymbol{\omega}}_h = \dot{\boldsymbol{\omega}}_f + \begin{bmatrix} 0 & 0 & \ddot{\theta}_h \end{bmatrix}^T, \\ &\mathbf{V}_h = \mathbf{V}_f + \begin{bmatrix} -l_h S(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f+\dot{\theta}_h\right) \\ l_h C(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f+\dot{\theta}_h\right) \\ 0 \end{bmatrix}, \\ &\dot{\mathbf{V}}_h = \dot{\mathbf{V}}_f + \begin{bmatrix} \left( \begin{aligned} &-l_h C(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f+\dot{\theta}_h\right)^2 \\ &\quad -l_h S(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}+\ddot{\theta}_f+\ddot{\theta}_h\right) \end{aligned} \right) \\ \left( \begin{aligned} &-l_h S(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\dot{\theta}_{ta}+\dot{\theta}_{ti}+\dot{\theta}_f+\dot{\theta}_h\right)^2 \\ &\quad +l_h C(\phi+\theta_{ta}+\theta_{ti}-\alpha-\theta_f-\beta-\theta_h+\gamma)\left(\ddot{\theta}_{ta}+\ddot{\theta}_{ti}+\ddot{\theta}_f+\ddot{\theta}_h\right) \end{aligned} \right) \\ 0 \end{bmatrix}. \end{aligned} \tag{10}$$

The dynamics can be next established based on the backward equations of Newton-Euler formulation. In this paper, we focus the effects of leg motion for regaining balance, so the force caused by the upper body is identified as $\mathbf{f}_{body}$ applied on the top of hip bone. Then, the force $\mathbf{f}_i$ and moment $\mathbf{n}_i$ applied each link are derived via Eq.(11).

$$\begin{aligned} &\mathbf{f}_i = \mathbf{f}_{i+1} + m_i\left[\dot{\mathbf{v}}_i + \dot{\boldsymbol{\omega}}_i \times \Delta\mathbf{r}_i + \boldsymbol{\omega}_i \times \left(\boldsymbol{\omega}_i \times \Delta\mathbf{r}_i\right)\right] \\ &\mathbf{n}_i = \mathbf{n}_{i+1} + \left(\Delta\mathbf{s}_i + \Delta\mathbf{r}_i\right) \times \mathbf{f}_i - \Delta\mathbf{r}_i \times \mathbf{f}_{i+1} + \mathbf{D}_i\dot{\boldsymbol{\omega}}_i + \boldsymbol{\omega}_i \times \left(\mathbf{D}_i\boldsymbol{\omega}_i\right) \\ &\qquad \text{for } i = h, f, ti, ta, p \end{aligned} \tag{11}$$

where $m_i$ is the mass of $i$ link; $\Delta\mathbf{r}_i$ is the vector from $i$-coordinates to the mass center of $i$-link; $\Delta\mathbf{s}_i$ is the vector from the origin of $(i\text{-}1)$- coordinates to the one of $i$-coordinates; $\mathbf{D}_i$ is the inertial of the $i$-link. To achieve the purpose, assist elders and invalid in avoiding fall, the force and moment applied on the each link and joint would be analysis. These data would be ones of the most important foundations to design the active orthosis, such as choosing actuators with enough power, designing strength frame.

## IV. Simulation

The kinematics and dynamics have been established based on the robotics. We program the equations in to MATLAB, and adopted the desire trajectory recorded by the motion-capture image system. The set of the parameters are shows in Table I, and the simulation results are shown in Fig. 7.

Observing the simulation results, we discuss some characteristics of the force and moment. In stage I, the force and torque are smaller than the other stage, since we consider this stage is beginning unbalance but have not any response during this period. The largest force and torque are occurred in stage II to swing the leg for remove the position of the weight center. Since the large variation of angular positions needs to achieve in short periods, 0.3 seconds. The response of stage II would influence the success or fail of the regaining balance motion. Finally, the second high peaks are happen in stage III to stride and regain balance. In addition, the maximum forces applied on hip, femur, tibia, and foot are 963.58, 1519.11, 1546.58, and 1536.68 N, respectively; the maximum torque applied on hip, knee, ankle meatatarsal are separately 104.27, 579.76, 1037.38, and 822.50 N-m. The force applied on hip is less than the other joint, and the muscle around hip bone is in fact frail than the other muscle on leg. The forces applied on femur and tibia are larger, and it can be supplied by the strong muscle of thigh and shank. The maximum moment is occurred on the meatatarsal, so that the wrench of ankle is often happen during unexpected postural disturbances. However, there is some noise in results. The one of the causes is that the LED markers would be rocked during the regaining balance motion. Since falls belong to intense motion, it has some difficult to fix the LED marks on the leg. In further investigation, the filter can be adopted to remove the noise.

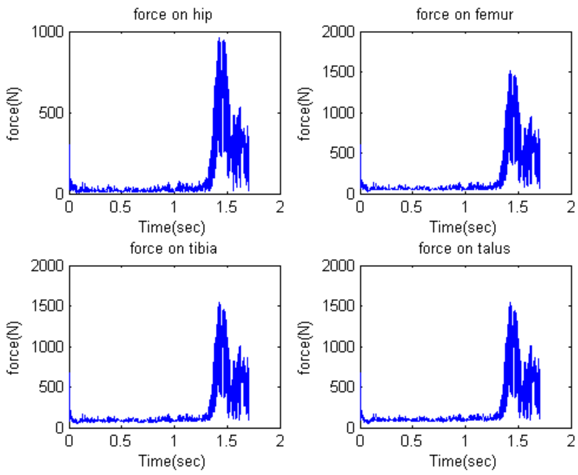
## V. Conclusion

The primary investigation of the active leg orthosis for tumble protection is studied in this paper. The desired regaining balance motion is recording, and the motion would be divided in three stages to describe. In addition, the physical model of leg movement is established, and kinematic and dynamic equations are formulated based on the robotics. Finally, the force and moment of each link and joint are calculated via MATLAB program, and their characteristics are discussed accordance with the human conformation and common condition of falls.

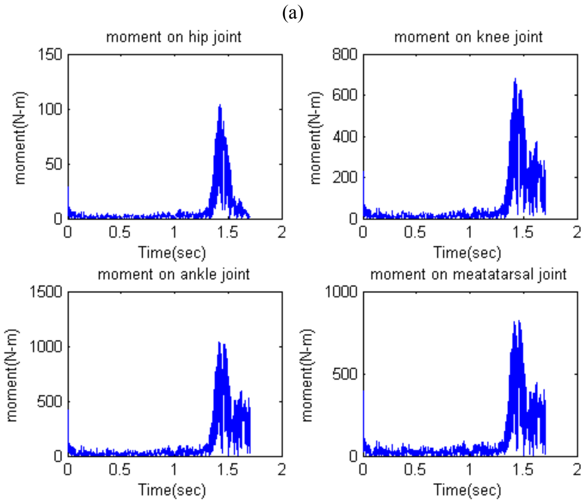
However, the fall and regaining balance are more difficult to study than walk motion, since the response is very fast. In further, there are four key point need to continue investigating: (1) the installation of LEC marks need to be improved to reduce the noise; (2) the measurement system for force and moment will be established to verify the correct of simulations; (3) the mechanism of the active orthosis will be made up to practice the design concept; (4) the sensors for angular positions/velocities and translational positions/velocities will be install to feedback the condition for controller. The active orthosis for tumble protection will be a meaningful investigation for assisting elders and invalids in avoiding falls.

TABLE I
THE DEFINITIONS OF PARAMETERS

| Symbol | Definition | Quantity | |
|---|---|---|---|
| $m_h$ | mass of the hip | 3 | kg |
| $m_{fe}$ | mass of the femur | 4 | kg |
| $m_{ti}$ | mass of the tibia | 3 | kg |
| $m_{fo}$ | mass of the foot | 1 | kg |
| $l_i$ | length of instep | 0.15 | m |
| $l_{ti}$ | length of tibia | 0.3 | m |
| $l_{fe}$ | length of femur | 0.45 | m |
| $l_h$ | length of hip | 0.2 | m |




(a)




(b)

Fig.7 The force and moment applied on each link of regaining balance motion

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