Transferring Human Biped Walking Function to a Machine -Towards the Realization of a Biped Bike-

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SYNOPSIS

It is anticipated that legged locomotive robotic vehicles will provide the abilities for traveling across vast terrains, for varieties of tasks, such as mining, foresting, and agriculture. One noticeable concern of such systems is the generation of motion pattern.

In our study, we accomplished human walking motion in 2D, using a biped model with simple bar-like legs, and reciprocal leg stretch-contraction motion. Although extremely simple, this model possesses common characteristics to that of human biped walking, such as normal step length, duty factor, and reaction force patterns. We found that, by using additional stretch-contraction mechanisms to the knees, the same kicking and sinking motion can generate slope-climbing motions similar to that of walking on level ground.

1 INTRODUCTION

Having equivalent functionality of that of legged animals in a manned vehicle will allow us to travel to places far beyond than ever before, benefiting from its capabilities for exploration while on the whole preserving the environment. Such a vehicle, a Biped Bike, can be utilized for pre-mining explorations, in forestry for the prevention of forest fire, in agriculture for the harvesting of crops, as emergency vehicles, or even for recreations – just to name a few. Legged robots working in a natural environment should be compact with a small projected area of ground coverage, especially in the narrow passages such as dense forest. Biped locomotive robots have the merit of compactness, compare to that of multi-legged robots.

To date, researches of legged locomotive vehicles have been done mainly toward the developments of multi-legged (tripod or hexapod) vehicles that relied on a static configuration for its stability (for a historical summary, see (1)). However, these multi-legged vehicles tend to be large, requiring larger ground coverage, while on the contrary, a biped walker with a small projection area provides the advantage of being compact. Recent studies of biped locomotion conducted by humanoid researchers have accomplished a great deal in teams of achieving high performance for biped walkers (2), (3). Despite of these advancements, further researches are still needed, especially in the area of locomotion that deal with travelling across varieties of terrains. We believe by exploring studies of human biped walking and the use of dynamic simulations will provide a clear path towards an efficient and robust bipedal locomotive system.

A controller, which can produce walking motion pattern, that resemble that of human are important consideration in developing a biped vehicle. One of the purposes of this research is to explore and allude to the effect of human walking motion. As it is clear that the complete muscular structure of the human body is currently too complex to synthesize, due to the complexity and the large number of the individual body part. However, taking the assumption that the sophisticated human walking motion as a whole is well within our reach. We refer to the sophisticated motion that had been resulted from an optimization to fit, the environment and its adapting body dynamics. In other word, the redundant freedoms are erased (organized) to fit the physical constraints of the environment and its body. By going through this process of fitting or utilizing physical constraints, we will ensure to reach the goal in achieving sophisticated bipedal walking motion.

The notion that the physical structure of the human body inherently possesses dynamics, which can generate walking motion originated from studies of passive and ballistic walking (4, 5). They showed that their walking machines were able to walk down on shallow slopes without the use of a controller (6). Further researches extended the passive walking model to active model, however their efforts have focused on the stability of walker (7, 8 and 9), rather than the generation of motion patterns.

In our current study, we were able to accomplished human-like biped walking motion in 2D, via a biped model with prismatic ankle joints, point feet, a free hip joint, and reciprocal leg stretch-contraction motion. Although extremely simple, this model possesses common characteristics to that of human biped walking, such as normal step length, the duty factor of supporting phase, and pattern of floor reaction force. This model gains forward driving force by the legs kicking and sinking motion similar to that of a human. We found that by equipping an additional stretch-contraction mechanism to the knees, the same kicking and sinking motion can generate slope-climbing motions similar to that of walking on level ground.

2 MODELING

The modelling of a bipedal walker can be broken into two steps. The first step is defining the physical structure (the overall body), the second is the deriving of the motion pattern for the modelled body.

2.1 Mechanism

The mechanism of our model is constructed from two bar legs, the upper body is a point mass, point shaped feet, no friction hip joint, an prismatic joints with variable length constraints (equivalent to infinite gain position control) at the ankles (or the knees). The ground is flat and the contact forces are generated via elastic and viscous-elastic elements in the vertical direction, and via friction elements in the horizontal direction. A sketch of this model is shown in Figure 1. θ is the hip joint angle measured from vertical axis. This resembled a compass-like model, similar to that of (10). Currently the model is in two dimensions, restricted in the sagittal plane.

Fig. 1 Compass-like biped walker

The mass distribution of the model resembles a human (11). The specifications of this model are shown in Table 1.

Table 1 Physical parameters of the biped model

Torso mass	28.3[kg]
Leg mass	7.85[kg]
Foot mass	1.2[kg]
Leg moment of inertia (with a foot)	0.8549[kg m2]
Leg length (neutral position)	1.0[m]
Restitution coefficient	0.0
Floor young's modulus	1/10000 of iron's

The dynamical simulator DADS is being use to construct this physical model of our system. DADS provide various body and connection elements for constructing simulation models and can analyse general mechanical configuration.

The right of Fig. 1 shows our biped model within DADS. The prismatic joints between the legs and the point shaped feet are not visible, and the contact forces are only detected, then act upon at the point feet, in other words, the leg body or foot body themselves do not interact with the ground. The feet are fixed at the lower leg with an offset 5 [cm] inward from the end of the leg.

2.2 Motion pattern

Walking motion can be generated by changing the length of the legs synchronously with the legs swing as a complex of pendulums. The hip joint is not actuated; no controller is included in the system.

We show the conditions in which the point foot should moves in Fig. 2. The simplest motion produced by the foot (that means the length of the legs) is to stretch and contract the leg at three times higher the frequency than that of the leg's swing.

The initial condition of walking, we pause at the exact mid stance phase (Fig. 2 2nd left) and provide a suitable horizontal velocity to the upper-body and the foot of the swinging leg. The state trajectory of this bipedal walking is considered, of being on the line of the instable equilibrium, therefore its stability is highly sensitive to the initial condition.

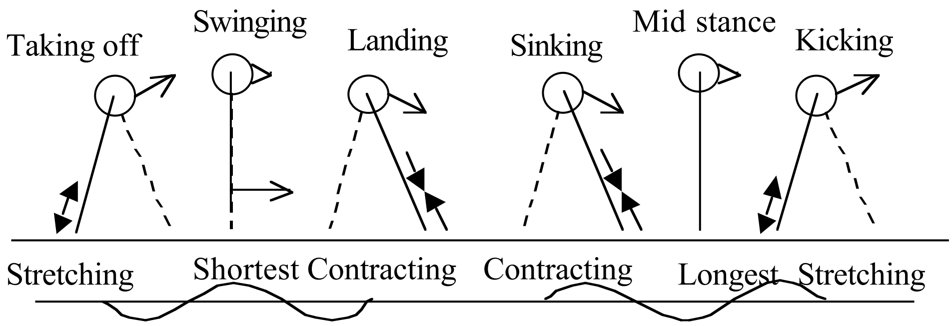

Fig. 2 Conditions of leg length in swing phase, and extrapolated stance phase

Our research considers only steady motion; the transient motion (e.g. start and stop walking) has been left for future work.

2.3 Basic motion

To derive the basic swing motion for making the leg's prismatic motion pattern, we use a fixed length leg version of the biped model. At the initial moment, the biped stands still with two legs opened as hip angle θ. If the upper body launched with a suitable initial velocity along the longitudinal axis, the backward leg will swing forward with a walking-like motion, and will touch down at a symmetrical point of the ground. The time from taking off to landing was determined to be three times higher frequency of the sinusoidal kicking and sinking motion of the telescopic legs. Both the initial velocity for the upper body and the frequency of the telescopic leg determines the sinusoidal amplitude of the leg's motion. This is the nominal value, for the sinusoidal prismatic motion of the legs, but further fine-tuning of these parameters is needed to achieve stable biped walking.

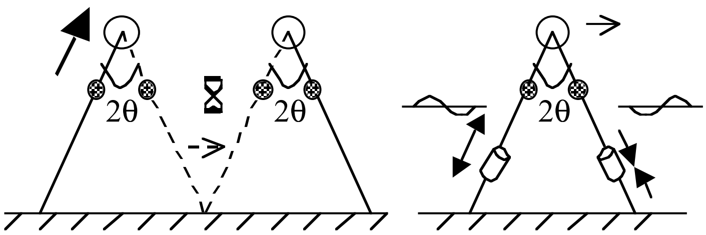

Fig. 3. Calculation of leg motion from fixed leg

3 SIMULATION RESULT

3.1 Overview of walking motion

In Fig. 4, we show the result of stable walking by making use of the dynamical simulator DADS. Parameter fine-tuning has been made. We changed the appearance of the model from Fig. 4 to a stick figure. The Biped walks from left to right. This is the most stable and sophisticated motion pattern; the foot touches down at the same time as the swing end. This occurs when the hip angle θ is 0.32 rad. Here, the number of continuous steps is eleven. The period of one step is 1.035 s, and the amplitude of the sinusoidal prismatic motion is 3.64 cm.

Fig. 4. Simulated one-step motion, and motion pattern change vs. step length

In this method, the changing of the hip angle θ affects the walking motion pattern. The narrower θ brings scuffing (undesirable touch down before the correct moment), on the contrary the wider θ causes a flipping back motion (overshooting swing before landing).

3.2 Resemblance to human walking

As mentioned earlier that 0.32 rad for θ is the suitable angle for walking motion. This angle actually corresponds to the common step length of humans. Unstable walking motion needs a lot of control and actuation to continue. In human walking, stability relates to efficiency, and is related comfortableness and commutity. Stability criterion for optimisation (parameter fine tuning), as the result corresponds to characteristics of human walking.

We show the reaction force of the floor for θ = 0.32 rad, in Fig. 5, comparing to that of humans reaction force. The solid line represents the right foot, and the dotted line represents the left foot. Both have been normalized to the total body mass. As shown, correspondence exists with the two patterns of magnitudes (12).

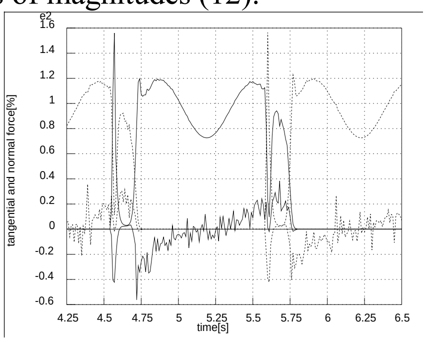

Fig. 5. Reaction force from the floor

The duty factor of double and single support phase can be calculated to be around 20% for a single stride, shown in Fig. 5. This percentage also correlates to that of humans (12).

4 EXTENTION FOR SLOPES

We extended our biped model for travelling on level ground to slopes. The extension is by adding prismatic joints to each knee. In the case of the level ground the slope angle is set to zero.

4.1 Derivation of the extended model

The biped model standing on a slope with a leg open angle, θ, a slope angle, α, which will, decides the needed displacement of each leg length geometrically, as shown in Fig. 6. The displacement, x, is derived from the equation:

$$\frac{\sin(\frac{\pi}{2}+\theta-\alpha)}{2L\sin(\theta)}=\frac{\sin(\alpha)}{x},$$

Therefore, displacement equals to:

$$x=\frac{2L\sin(\theta)\sin(\alpha)}{\cos(\theta-\alpha)}.$$

Each prismatic joint at the knees is moved in a sinusoidal manner. The amplitude of the sinusoid is the half of the former displacement (x). The period is the same as the period of one stride (two steps). Each phase is set as counter phase. Then, the leg is longest at the maximum backward position, and shortest at the maximum forward position, in the case of going up a slope, and vice versa, in the case of going down slope.

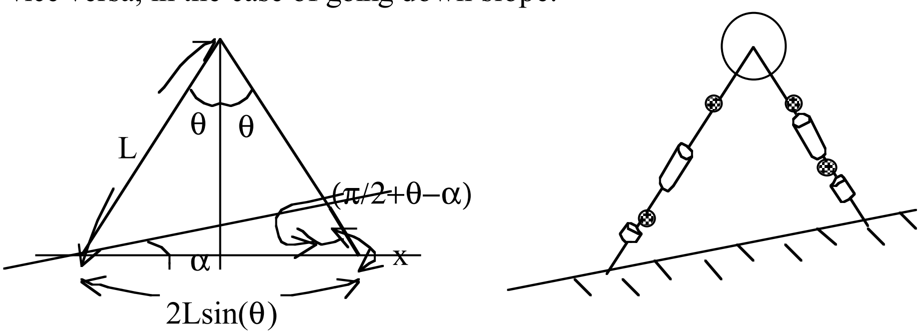

Fig. 6. Extension of the biped model for slopes

Our extended bipedal walker is shown on the right of Fig. 6. It is equipped with two prismatic joints at the knee, for adapting to slopes. It has also prismatic ankle joints for kicking and sinking to obtain propulsion.

As same as in the case of level ground, the Basic Movement, of the stretching and contracting of the knees, decides the period and launching speed of the biped. These two attributes determine the amplitude and period of sinusoidal kicking/sinking motion at the ankle joints.

4.2 Results

The result of calculation of the amplitude and period parameters tells us that the parameters will almost equal and beyond the changing of the slope angle. This is contrary to our initial intuition; this can be explained using the law of momentum (MV'–MV=FT). Consider the case, going up. The speed of the supporting leg length changes at the knee, is low compared to the velocity of motion of the upper body and that the reactive force is almost symmetric, between before and after the mid stance posture. The periods that the upper body exists in each section (before and after the mid stance) are almost same. As well as the integration of both side of the floor reactive force vector are almost same. The horizontal component of the integrations of impulse (FT) will cancel. Therefore, the momentums at the initial and ending have same magnitude, which means, the speed of the upper body is the same at the initial and ending instance. This result tell us that the slope angle will not affect so much of the kicking speed of the biped; therefore, the result of the simulation is true that the kicking speed is mostly the same beyond the changing of slope angles. Fig.7s are the graphs of the calculated parameters for sinusoidal kicking movement from the simulations of Basic Movement.

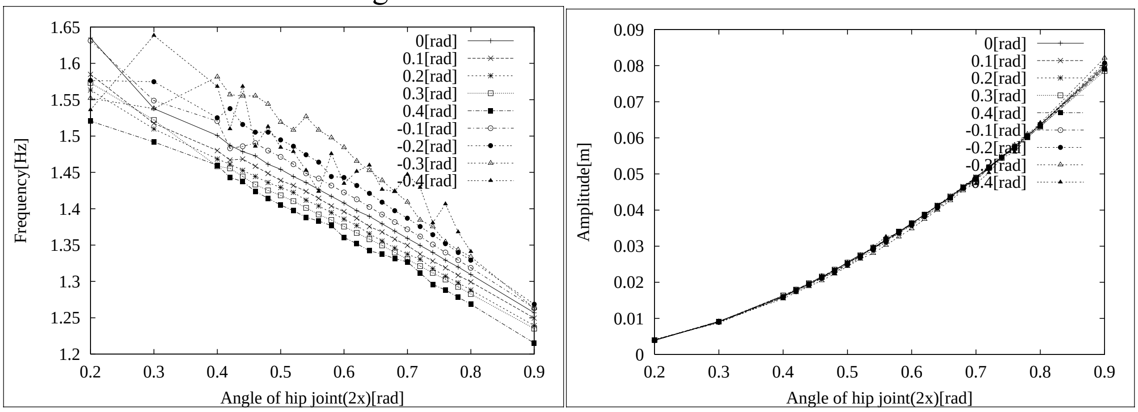

Fig. 7. Kick parameter change vs. slope angle

The result here shows the merit of this simple motion pattern. If the needed kicking speed will not change so much along with the different slopes, allowing us to keep the actuator at the ankle joint without further consideration to slope angles. If the velocity at touch down phase of motion does not increase so much on a steep slope, the durability of the walking machine shall intrinsically increase. This invariance of the parameters allowed us to derive a simpler controller while still achieving our initial goal – producing human-like walking motion.

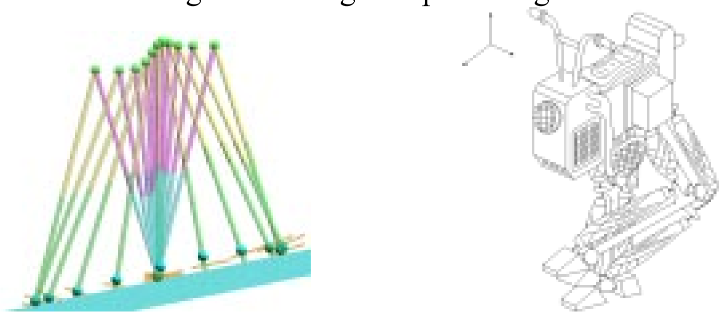

Fig. 8. A step of climbing up motion and biped bike

Fig.8 is shows our biped model going up a slope 0.2 rad at θ = 0.27 rad.
Fig.8 shows a sketch of a biped bike that we wish to build in the future.

5 CONCLUSIONS

In this paper we proposed a simple bipedal model, which shown to possess human–like biped walking characteristics. The resemblances are: (1) similar step length for stable walking motion,

(2) similar duty factor for single/double support phases, and (3) similar pattern and magnitude of floor reaction force.

We extended our model to walk up slopes. The extension is by adding a prismatic joint to each knee, and using a simple sinusoidal motion pattern. This extension does not induce any additional parameter changing of different slopes within a certain range. This characteristic is ideal for the design of biped locomotors for working in a variety of terrains.

For further work we wish to extend our current model to a more realistic 3D environment while keeping to a similar control scheme as the one introduced in this paper.

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