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REVIEW THE METHODS AND APPROACHES FOR PLANNING TRAJECTORY BIPED WALKING BIPED ROBOT AND INTRODUCE A NEW CONCEPT FOR MAINTAINING THE HIGHEST SAFETY FACTOR ON UNEVEN TERRAIN DURING DYNAMIC WALKING

Abstract: Biped robot expected to achieve stable walking on uneven terrains. For that, we should have some different algorithms to achieved generation robot trajectory with stable walking and controlling balance in different error patterns.

In this paper presented a novel concept to solve the problem of finding the absolute position of foot of biped, in Cartesian coordinates with the largest stability margin, and then control the joint angles to obtain the desired absolute position at big angular momentum during dynamic walking of Biped Robot on uneven terrain.

Keywords: biped robot, walking robot, planning trajectories of biped robot, stability, uneven ground, reaction force distribution, zero moment point

Introduction

Many of works presented the different method for generating trajectories of biped robot in offline or online mode. Many of these methods based on the most common principles like Sensor Control Reflex, zero moment point (ZMP) trajectory and others works. We analyses different works in next section of this paper, however a little of those works presented methods for generating trajectories of robot with considering online balance controlling at unexpected changing of angular momentum, in cases of uneven surface, so in this paper, suggest a new concept to solve problem generating trajectories at big angular momentum.

Analysis of other works

In article [1] which was mainly based on the work of S. Kajita et al. Where authors introduce the notion of the preview controller and the Three- Dimensional Linear Inverted Pendulum mode (3D-LIPM) to generate the trajectory for a biped walk [1]. The performances of stable walk are limited by the size of the obstacle, also not able to walk on a slope above 5° without sliding or falling over [1]. Where another research, was focused on swing leg from single support phase (SSP) to double support phase (DSP), for this was proposed three methods [2]. The first one include

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designing polynomial functions for the hip trajectory during the complete gait cycle, satisfying the constraints and continuity conditions, second method suggests employing a simple dynamic model for the biped robot denoted by the linear inverted pendulum mode (LIPM), and Third one suggests describing a suitable center of gravity (CoG) acceleration during the DSP satisfying continuous conditions at the instance of the transition. But, wasn't considering the effect of variable ZMP at the SSP and its effect on the speed of the biped and its stride. In other side in the work of Thomas Buschmann [3] presented a hierarchical system for real-time walking control. In experiments and modeling used Johnnie and Lola robots. Novel aspects include a trajectory generator based on spline collocation and a stabilizing controller based on hybrid position/force control. Author proposes a hierarchical control system that divides the control problem into smaller tasks that can be solved in real-time. Nishiwaki also proposed a similar structure for real-time walking control for the robot H7 [3].

Another research was considering the Modeling, Simulation, and Control of Biped Robot AAU-BOT1 [4]. One of the different strategies that is used is using the angle trajectory for each joint like hip and foot joint, which means that there is no control on the absolute position of the robot, for experiment AAU-BOT1 was used. However, authors mentioned that control system tested on the actual AAU-BOT1 but the simulation test results indicate that it is possible to use the designed control system on the actual AAU-BOT1. In addition, this work does not consider about the surface type or the environment around the robot.

The evolution of a dynamic walking gait of biped robot is presented in another work [5], this walking algorithm was verified and tested under Yobotics and RoboSapien, biped robot. Some of work [6] focused on stable and reliable walking for a biped robot. The summarized results as follows:

1) A walk control consisting of a feed forward dynamic pattern and a feedback sensory reflex was proposed.

The dynamic pattern is a rhythmic and periodic motion, considering the whole dynamics of the biped robot. The sensory reflex is a quick local feedback control to sensor input requiring no explicit modeling.

2) The sensory reflex consists of a ZMP reflex, a landing-phase reflex, and a body-posture reflex. These reflexive actions are online hierarchically organized to satisfy the dynamic stability constraint, to guarantee to land on the ground in time, and to keep a stable body posture for biped robot walking.

3) The effectiveness of proposed method confirmed through walks on unknown rough terrain, and in an environment with disturbances by a dynamic simulator and an actual biped robot. The experiments showed that with dynamic pattern and the sensory reflex, it is possible for the biped to walk rhythmically and to adapt itself to the environmental uncertainties [6].

Conclusion of analyzing

Based on the analyzing works where different methods used for planning trajectories for biped robot. The most promising methods are based on the following principles: Sensory Reflex Control, ZMP trajectory, optimization-based gait, COG-based gait and interpolation-based gait, 3D-LIPM. Despite the advantages of the applying methods for the stabilization of the cases of stabilization, walking balance, swing phases, and uneven terrain, but applying those methods for online controlling in case when uneven terrain and when the surface is slippery and choose the best path to reach the target and avoid obstacles is not effective. For that, to solve one of the actual problem in planning trajectories, unsolvable by these methods, specifically planning trajectory of Biped Robot at uneven terrain with online controlling, including complicated balance system with stabilization at big angular momentum. In addition, controlling system which based on ZMP, center of pressure (CoP), CoG, force points (FP), and analyzing the reaction in FP between the foot and surface. In view of the relevance and the novelty of the concept, the purpose of this publication is the planning trajectory of walking Biped robot on uneven terrain.

Related Work

Biped robot research is an active field, last years a lot of researcher developed and present a different method in planning trajectories field. Some of this research became well known. Like D. Humennyi work [7], [8] and others.

Planning Trajectory of biped robot

The planning trajectory includes basically two parts, one part is the trajectory for each joint that ensures that the robot is walking forward, the second is a trajectory of the ZMP to ensures that the robot is in balance during the walk [4].

a) Online Trajectory Generation

The purpose of online trajectory generation is to calculate the optimal trajectory at all times dependent on the current posture of the robot and its surroundings. A change in the terrain or backlash in any joint would cause the optimum trajectory to change. If online trajectory generation is used such changes would not be a problem as the new optimum trajectory would be calculated and the robot would react in correspondence to it. [4]

b) New concept for of planning Trajectory

In this paper, introduced a new concept to solve the problem of finding the absolute position of foot of biped robot, in Cartesian coordinates with the largest stability margin, and then control the joint angles to obtain the desired absolute position at big angular momentum during swinging phases SSP to DSP at dynamic walking of Biped Robot on uneven surfaces.

Novel concept includes analyzing the force pressure at the FP between the foot and surface. Related method presented for DSP phase [7], that present a method of control balance for biped robot at DSP phase. So depending on the simulation results in related work, I present new concept for online generate trajectories and balance controlling of biped robot on dynamic walking.

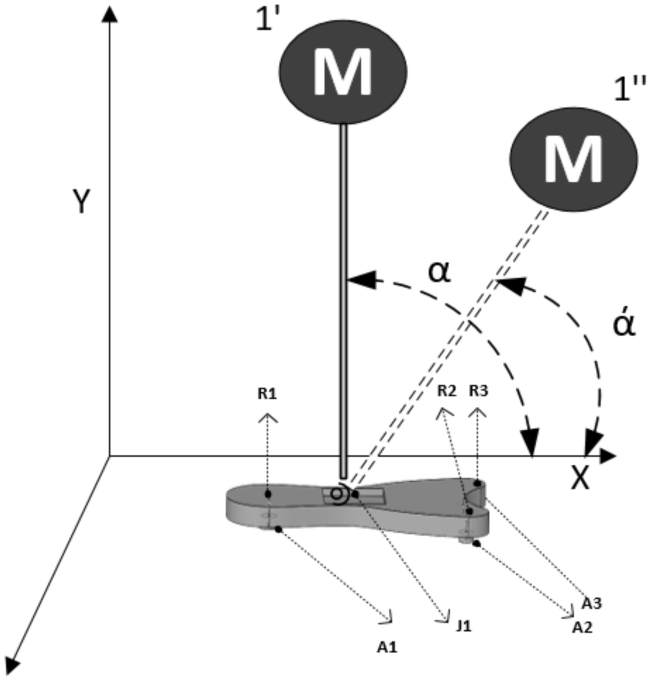

Fig. 1. New concept for analyzing forces and reaction on foot, ά angular momentum, A1, A2, A3 Force pressure at the contact points, R1, R2, R3 reaction of each FP, M: mass of body (X, Y, Z) Cartesian coordinate, J1: joint actuator fixed on foot

We have a five walking stages that are required to control the biped efficiently in various situations [9]. In each stage, we can easily recognize the current movement and then predict the next movement. Stages 1–4 are repeated during walking. Stage 5 is the period of standstill pose.

These stages are described below referring to Fig. 2.

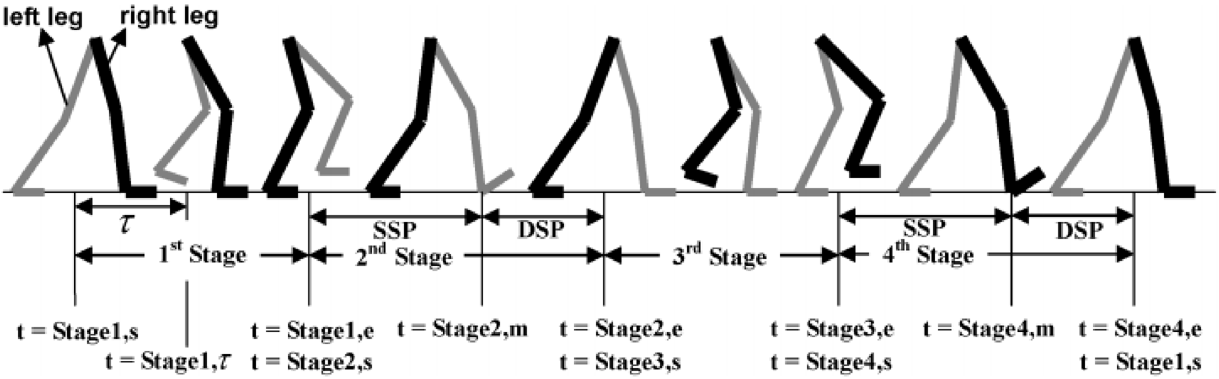

Fig. 2. Walking stages and timetable, Stage 1: lift the left leg to its maximum flexion and height, Stage 2: lower the left leg until it makes complete contact with the ground, Stage 3: lift the right leg to its maximum flexion and height, Stage 4: lower the right leg until it makes complete contact with the ground, Stage 5: Follows after Stage 1 or 3 and brings the robot to the stop pose with both legs landed on the ground

In Fig. 2 , we grasped the features of dynamic motion and then developed the appropriate controllers for stable walking, Table 1 shows the time schedule of the online controllers.

Table 1.

The time schedule of online controllers Control

Control scheme	Online controller	Stage 1	Stage 2		Stage 3	Stage 4	
			SSP	DSP		SSP	DSP
Real-time balance control	damping controller	√	√		√	√	
	ZMP compensator	√	√		√	√	
Walking pattern control	soft landing controllers			√			√
	pelvis swing amplitude controller			√			√
	torso pitch/roll controller			√			√
Predicted motion control	tilt over controller	√			√		
	landing position controller		√	√		√	√

SSP and DSP stand for the single-support phase and the double-support phase, respectively.

For this and depending on a different Stages in Fig. 2, the new concept suggests to use 3 force points A1, A2, A3, Fig. 1, to determine the vector of direction and position of foot at big angular momentum, by choosing more force points in study give us greater accuracy in determining the position of the foot.

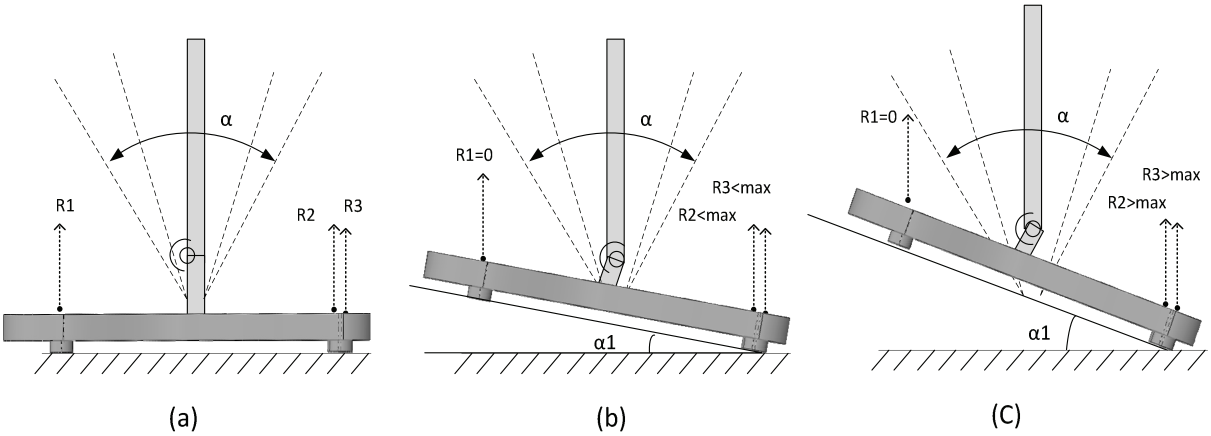

Fig. 3. Disturbances can change the contact state of a biped, (a) Stable status when R1 = R2 = R3 at flat surfaces The position force points, (b) normal slope with angular momentum α, (c) big slope with large angular momentum α. α1 pitch angle

So we will have, we have three statuses of values for R1, R2, and R3.

- *First status* at stable phase where the reaction of FP that is mean
  the robot in stable phase at flat surface and ready to make next step with. Fig. 3(a)
- *Second status* when R1 = 0 and R2, R3 < max (max is the maximum range of values where robot still in stable walk) Fig. 3 (b)
- *Third status* when R1 = 0 and R2, R3 > max that mean robot lost balance going to fall forward. The opposite of this status when R2, R3 = 0 and R1 > max. Fig. 3 (c).

This Concept will be useful for the third status because we can control balance and control joints angle to swing the leg and ensures that the biped robot is stable, by the way there are no absolute criteria that determines whether the dynamic walking is stable or not [10].

c) Dynamic walk

In dynamic walking of biped robot, the COG move outside of the support region for limited amounts of time. If the robot has active ankle joints and always keeps at least one foot at on the ground, then the ZMP can be used as a stability criterion. The ZMP is the point where the robot's total moment at the ground is zero. Dynamic walking is achieved by ensuring that the robot is always rotating around a point in the support [10].

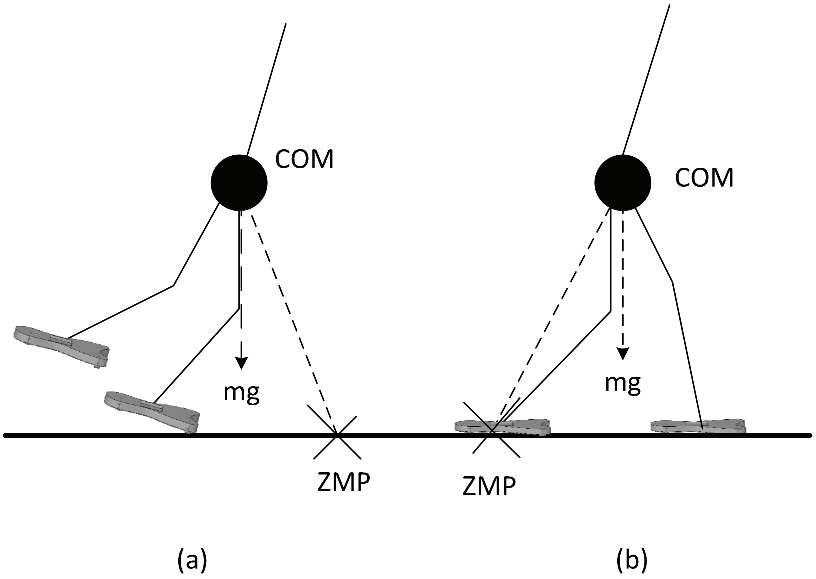

Fig. 4. Dynamic walking statuses (a) unstable position, (b) stable walking

The stability of the ZMP is often considered in the trajectory generation and control for biped robots, so we can simulate several possible trajectories and then choose the one with the highest stability [4]. The best trajectory can have defined in many ways depending optimal largest stability margin. To determine the best trajectory. However, the stability margin defined as the minimum distance from the ZMP to the convex hull defining the Support Area (SA), as shown in Fig. 5 [4]. For the dynamic walking robots, CoG can be outside of the support area, but the ZMP cannot [10].

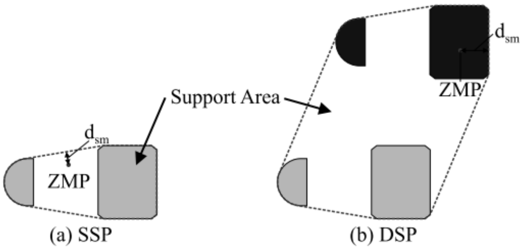

Fig. 5. Definition of stability margin, d_{sm}, The minimum distance from the ZMP to the support area (SA) is the stability margin, i.e. the larger the number the better. If the ZMP is outside the SA it indicates that the situation is unstable

d) Controlling Balance

The purpose of the control system is to track a trajectory that ensures static balanced gait. We can to use the absolute position as a way to design the posture control in Cartesian coordinates, of the robot and then we control the joint angles to obtain the desired absolute position [4].

In traditional biped robots, stability maintained by having at least three contact points with the ground surface at all time. There are some techniques to implement a balance control for a biped robot, like using soft computing or artificial intelligent techniques [10].

The output from the balance controller is a compensation angle that added to the reference for the posture controller. The balance controller controls the x- and y-coordinates of the Ground Center of Mass (GCoM) according to a reference for the GCoM specified by the trajectory [4].

To maintain the balance in dynamic walking the ZMP point must be in the foot convex area, in contact with the floor as shown in Fig. 5.

The procedure of the trajectory simulation is illustrated in Fig. 6 The illustrated procedure is utilized to get a result from each of the trajectory variations, which means it is a single iteration of the entire search for the best trajectory. Note that in static gait, assuming that the ZMP and GCoM are identical, the GCoM used in the further design of the trajectory due to the easier computation.

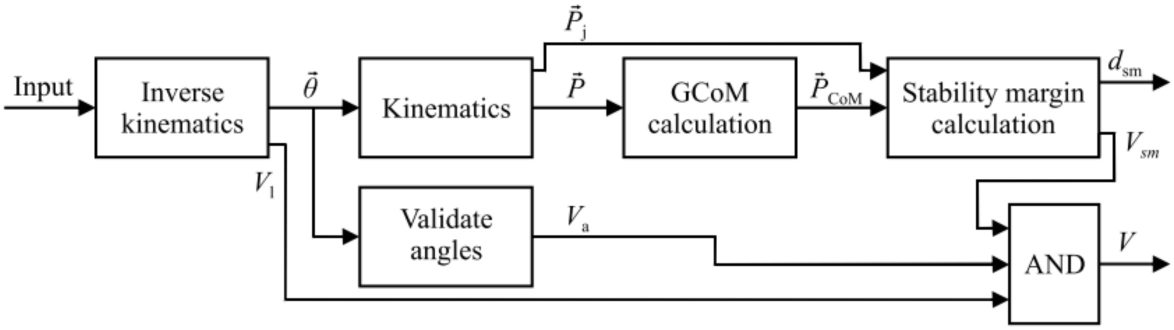

Fig. 6. The procedure for a single one of the trajectory simulations. The procedure here is repeated for each of the simulations. For input, we give the coordination of target

Critical assessment of own work

This concept under testing, but depends on the simulation results of Humennyi work [7] [8]. This concept will be very useful.

Conclusions

In this publication presented the new concept to solve one of the actual problems in planning trajectories process, specifically planning trajectory of Biped Robot on unknown, uneven terrain with online controlling, including complicated balance system with stabilization. And controlling system which based on ZMP, COP, CoG, force points, and analyzing the reaction in force points between the foot and surface.

Based on the works analyzing before where different methods used in planning trajectories for biped robot. but applying those methods for online controlling in case when uneven terrain and when the surface is slippery and choose the best path to reach the target and avoid obstacles is not effective.

The new concept solve problem of determine the absolute position of foot of biped, in Cartesian coordinates with the largest stability margin, and then control the joint angles to obtain the desired absolute position at unexpected big angular momentum during dynamic walking of Biped Robot on uneven surfaces.

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