Towards Fast Walking based on ZMP Control and Central Pattern Generator

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I. MOTIVATION

Humanoid robots are designed with high mobility capabilities. Due to the huge controller design space, as well as being an inherently nonlinear system, it is difficult to maintain the balance of humanoid robot walking, especially when a robot walks fast.

Many researchers, up to now, have modeled the biped walking by considering the height of Center of Mass (CoM) as a fixed constant, other biomechanical studies show that the CoM height is variant during walking and running[1]. The shape of CoM height trajectory is important for energy consumption, and it varies differently for various speeds and step length ranges [2]. Although linear inverted pendulum model (LIMP) is widely used in robotics, but robots often need to keep their knees bent in order to keep the height of CoM fixed, as the constraint of this model. Therefore, the change of the CoM height is important for walking and running.

II. STATE OF THE ART

The ZMP [3] criterion is widely used as a stability measurement in the literature. For a given set of walking trajectories, if the ZMP trajectory keeps firmly inside the area covered by the foot of the support leg, the given biped locomotion will be physically feasible and the robot will not fall over during walking. Biped walking can be defined as the modeling of the predefined ZMP references to the possible body swing or CoM trajectory. The possible CoM can be calculated by a simple model, approximating the bipedal robot dynamics, such as Cart-on-a-table or inverted pendulum model [4]. Kajita has presented an approach to find the proper CoM trajectory, based on the preview control of the ZMP reference, which makes the robot able to walk in any direction [5]. This method cannot handle the motion of the CoM in *Z* axis.

Nishiwaki have proposed an approach to generate walking patterns by solving the ZMP equation which can consider the CoM movement in Z axis numerically [6]. Designing the vertical CoM trajectory is mainly studied in the context of biped running, not in humanoid walking. Kajita studied the height trajectory of the CoM that can create and modify the hopping motion [7]. In another study, the vertical trajectory is designed simply and heuristically [8]. The study of designing vertical CoM trajectory is simple up to know, and to the best of our knowledge, there is no study focused on the designing of the optimal hip height trajectory generator, particularly with respect to generate fast and stable walking.

III. PROPOSED APPROACH

In this study, the height trajectory is considered as the periodic movement. The CoM vertical trajectory generator is designed using the partial Fourier series [9]. Evolutionary optimization algorithm applied in order to find the optimal hip height trajectory generator with respect to fast and stable walking. In order to have a smooth change between different height trajectories, Bio-inspired Central Pattern Generators (CPGs) based on Hopf oscillator is used, which can prepare online modulation and increase basin of stability of walking. Hopf oscillator is the self-sustained oscillators and has the stable limit cycle.

In order to generate the position of the reference CoM in a biped walking, first the position of the foot during walking is planed and defined. Then, based on support polygon, the ZMP trajectory can be designed. In the next step, the position of the CoM is calculated by solving differential equation of the ZMP numerically [6][7]. In order to test its performance, the proposed walking reference generation system is applied to the simulated NAO robot.

IV. CURRENT RESULTS

The walking parameters, such as step length and period, are optimized together with parameters of the height trajectories in two different optimization scenarios. First, the height is considered as a constant value. In second scenario, the height trajectory are varied and generated by Fourier series which is bounded to second harmonic. Using the genetic algorithm, the walking is optimized with respect to the speed and stability. The results of the two optimization scenarios are presented in table 1.

TABLE I. WALKING SCENARIO PRAMETERS FOR THE MAXIMUM SPEED

Parameters	Fixed height	Varied Height
Step Period	0.2 s	0.25
Height of CoM	0.19 m	[0.20.. 0.215] m
Step Size	0.09 m	0.15 m
Speed	0.45 m/s	0.6 m/s

The CoM position projection on the ground plane for the walking scenario, which has the movement of the CoM in *Z* axis, is shown in fig. 1. The optimized vertical trajectory of the CoM is also shown in fig. 2.

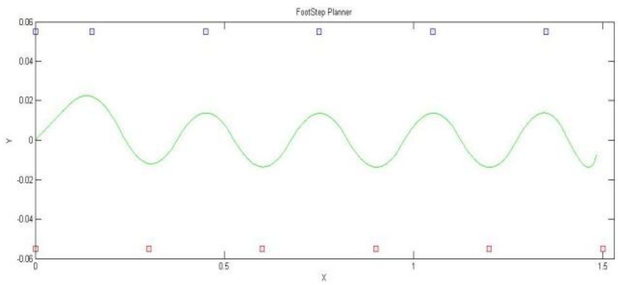

Fig. 1. COM projection on the ground plane

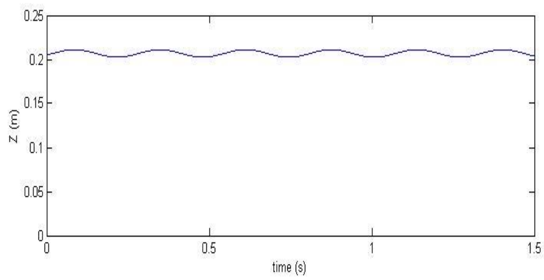

Fig. 2. Height trajectory of the CoM

V. BEST POSSIBLE OUTCOME

In future, we want to implement and test the results of the simulation on the real humanoid NAO robot. In order to have the smooth change of different height trajectories, caused by changing the speed and direction of the walking, CPGs will be applied and tested.

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