Towards the Enhancement of Biped Locomotion and Control Techniques - Walking Pattern Classification

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Abstract: A new walking pattern classification method is proposed for uneven floor walking of 5-link 7 DOF biped robot. This method extracts the patterns as per the stance foot's current floor position and swing foot's transitioning floor conditions during locomotion. When a global path composed of stairs, obstacles, etc. and certain walking parameters, such as the speed of walking and total walking time, are given to the system, the guidance controller unit determines footstep trajectory in terms of step patterns by using a genetic algorithm based optimization technique while ensuring biped's stability criterion. The demonstration of biped for different pattern classes is realized by a dynamic simulator.

Keywords: Walking pattern classification, biped locomotion, uneven floor walking**.**

I. INTRODUCTION

Reference gait trajectory generation is one of the critical issues and another challenging problem in the biped locomotion and control study. The biped reference trajectory synthesis is hard due to the fact that it necessitates a complete comprehension and analysis of the system characteristics. In the past 40 years, considerable improvement has been realized in the biped reference trajectory generation and in the literature, many methods have been proposed. Most common ones used are gait generation by analytical [1], [2], [3], center of gravity (COG) based [4], [5], [6], Zero Moment Point (ZMP) based [7], [8], [9], computational intelligence based [10], [11], [12], measured human walking data based [13], [14] and optimality based [15], [16] methods.

In this paper, full kinematical and dynamical model for 5-link 7 degrees of freedom (DOF) 3D biped robot, derived by analytical calculations and Lagrangian method, respectively, is used to implement and test the proposed method. The overall system is composed of a guidance unit (high level controller), trajectory planner unit (reference trajectory generator), supervisory control unit (low level controller) and biped model [17].

When a global path is given to the system, guidance unit plans the footstep trajectory by using genetic algorithm based optimization technique, while ensuring the stability of the system by using ZMP as a stability measure. The generation of footstep trajectory is realized by finding energy optimal foot step parameters of each walking step, such as step length, step speed, etc. for a given desired global path as per the different environmental conditions.

Implementation of optimal footstep planner is realized by using the classified walking patterns identified for the motion in uneven surface, as explained in this paper in detail. Note that the biped motion in this context is not necessarily periodic motion. The footstep planning is realized to ensure that dynamic stability measure (ZMP) is satisfied for non-periodic locomotion on uneven surfaces, such as walking on an environment with obstacles or stairs. After designing the optimized footstep trajectory formed by the sequence of walking patterns, the hip point and swing foot ankle point reference trajectories in sagittal and frontal planes of biped robot are obtained by using 3rd order (cubic) spline interpolation and then, the reference joint angle trajectory is calculated by inverse kinematics, for each sequential step's pattern class. In the supervisory control unit level, PID and Computed Torque Control methods are implemented successfully. The overall system, including the forward dynamics integrator, high level controller, trajectory planner, low level controller and 3D biped dynamic animator is implemented in MATLAB.

II. WALKING PATTERN CLASSIFICATION

The aim of the reference trajectory generation in this paper is to generate walking pattern classes so that the desired gait trajectory of the biped system can be generated similar to natural human locomotion. For this purpose, a systematical method to generate reference gait trajectory for a 5-link 7 DOF biped robot on different floor conditions such as walking on even surface, stepping over obstacles, stepping up and stepping down motions which results in a natural human-like walking is generated. The proposed method is a pattern classification method for the biped locomotion, whereas these patterns are chosen so that they cover stepping motions on different floor conditions, such as even floor walking, stepping over obstacles, stepping up and stepping down motions including staircase walking.

The pattern classes are extracted as per the biped's current and next steps' floor conditions in sagittal plane. In other words, the patterns are designed depending on the stance foot's current floor position and swing foot's transitioning floor conditions. The pattern classification composes of 9 patterns as shown from Fig. 1 to Fig. 9 in detail. Note that stepping over an obstacle directly corresponds to Pattern 1 with proper step height adjustment.

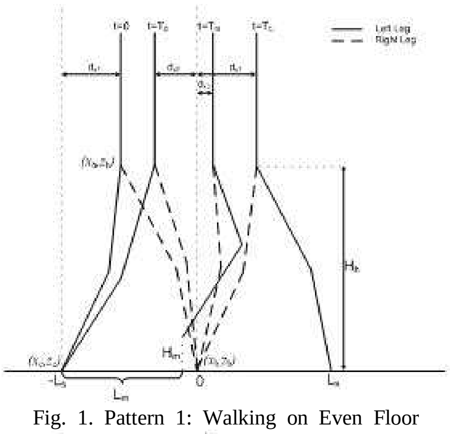

Fig. 1. Pattern 1: Walking on Even Floor

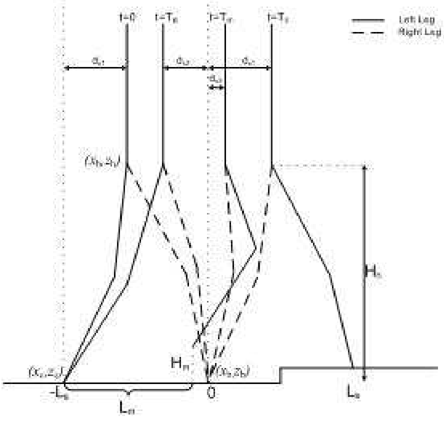

Fig. 2. Pattern 2: Stair Up - First Step

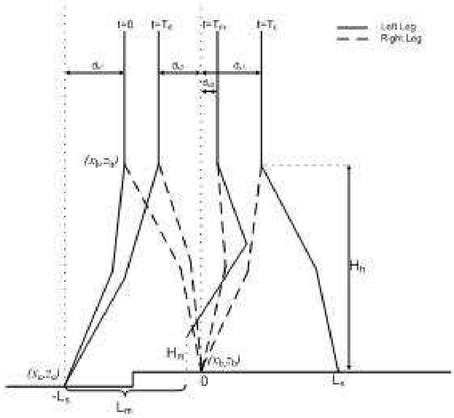

Fig. 3. Pattern 3: Stair Up - Second Step

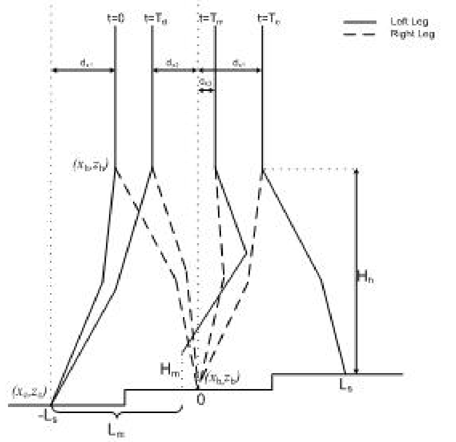

Fig. 4. Pattern 4: Stair Up - Second Periodic Step

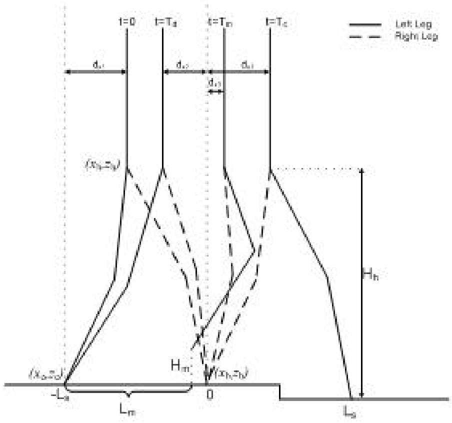

Fig. 5. Pattern 5: Stair Down - First Step

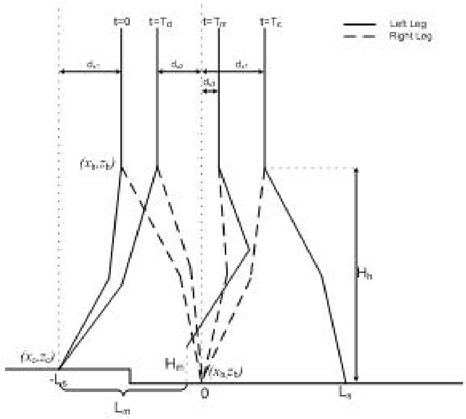

Fig. 6. Pattern 6: Stair Down - Second Step

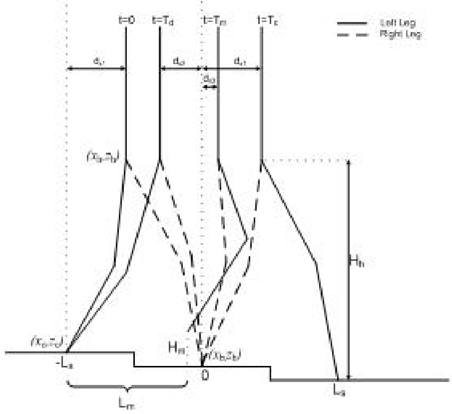

Fig. 7. Pattern 7: Stair Down - Second Periodic Step

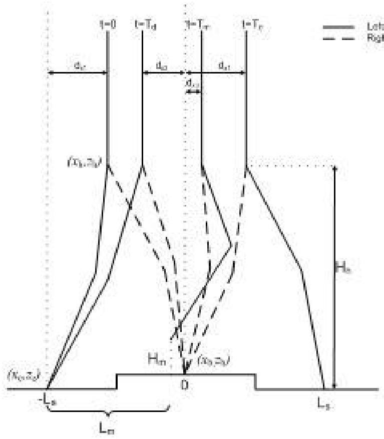

Fig. 8. Pattern 8: Stepping on Up

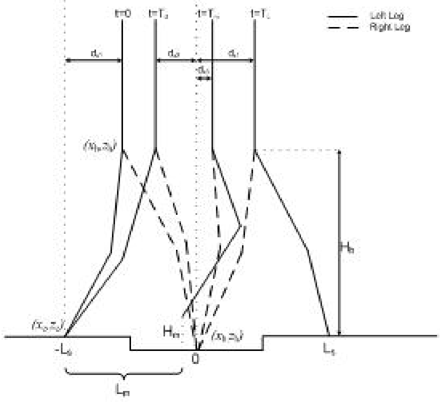

Fig. 9. Pattern 9: Stepping on Down

III. SIMULATION RESULTS

The walking is classified into 9 patterns, as per the environmental conditions that robot interacts taken into account. The simulation results of the biped walking for Pattern 2 are presented in Fig. 10 to Fig. 12. In Fig. 10, the joint angle trajectories are given; in Fig. 11, the joint angular velocity trajectories are depicted and in Fig. 12, the simulation snapshots of the biped walking are shown for Pattern 2. To further elaborate the walking patterns, the periodic staircase motion is also investigated and the results for the periodic stair up case are presented in Fig. 13 to Fig. 15 by means of joint angle trajectory, joint angular velocity trajectory and simulation snapshot of the biped walking.

IV. CONCLUSION

In this study, we developed a systematical method that classifies the biped walking patterns into 9 classes for a 5-link 7 DOF 3D biped robot. It covers the walking of biped on uneven surfaces composed of rectangular shape obstacles and stairs. The ultimate purpose is to generate enough walking patterns so that the walking steps of biped can be designed systematically by only using the sequences of these patterns for any given environment to achieve a successful biped walking. To achieve a complete pattern classification, this work will be extended to cover the inclined surfaces so that design of biped reference trajectories for any given environment will be achieved.

VI. ACKNOWLEDGEMENT

This research work presented in this paper is conducted in Middle East Technical University with Prof. Dr. Kemal Leblebicioglu.

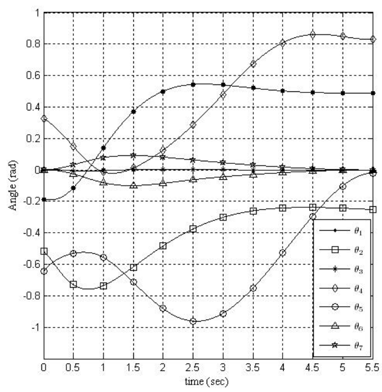

Fig. 10. Simulated trajectory joint angle profile for Pattern 2

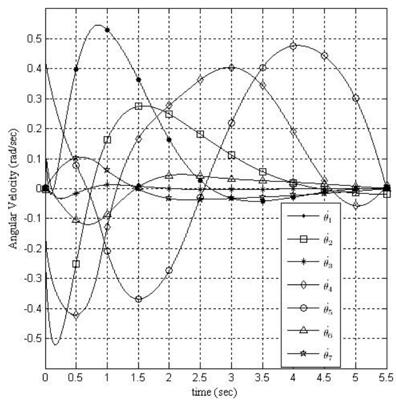

Fig. 11. Simulated trajectory joint angular velocity profile for Pattern 2

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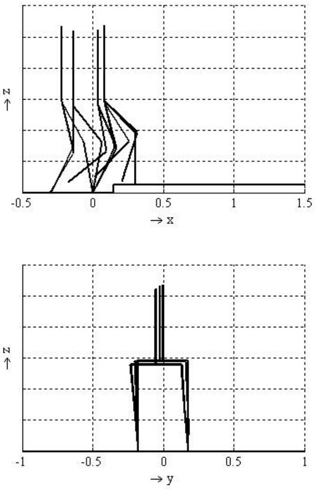

Fig. 12. Simulated trajectory walking snapshot - sagittal (top) and frontal (bottom) plane views - for Pattern 2

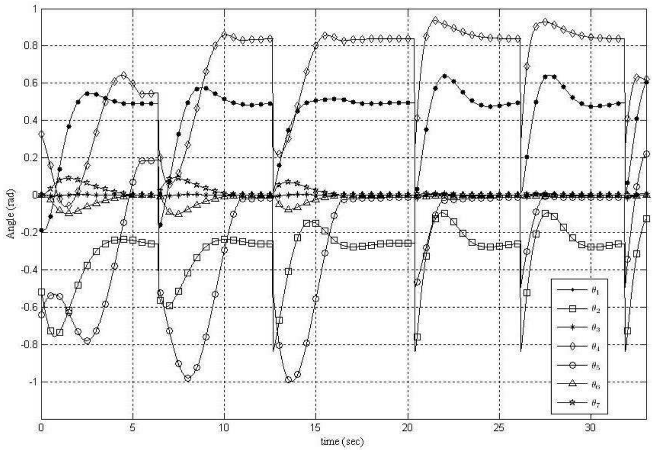

Fig. 13. Simulated trajectory joint angle profile for periodic stair up walking

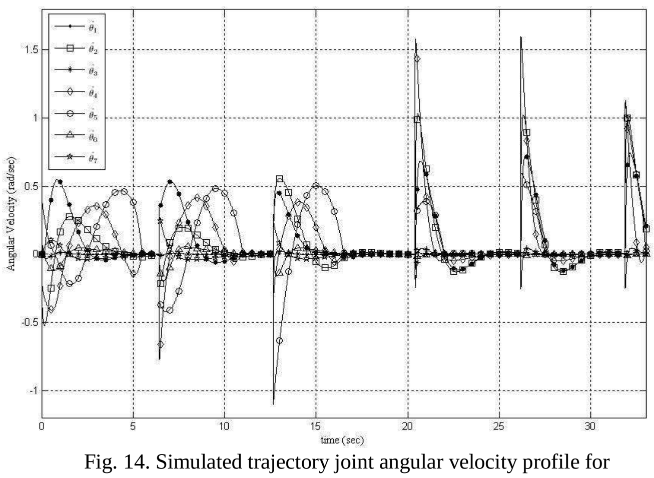

Fig. 14. Simulated trajectory joint angular velocity profile for periodic stair up walking

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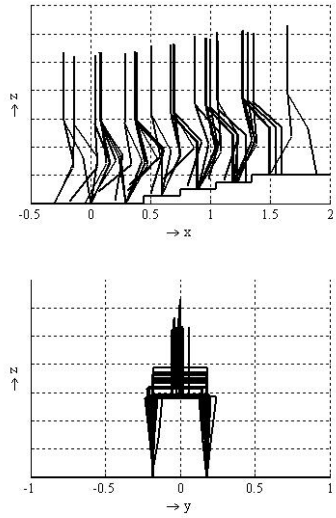

Fig. 15. Simulated trajectory walking snapshot - sagittal (top) and frontal (bottom) plane views - for periodic stair up walking

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