Double support phase analysis and ZMP calculation from restriction forces

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1 Motivation

Among all the articles of human robots there are very few dedicated to the double support phase. A lot of researches consider this phase as an instantaneous transition between the single support phases for one leg to another in the biped gait. So we decided to focus our work in this direction and study the over-actuated system that arises from the sub-actuated free-flyer humanoid with restrictions on both feet.
The other focus is the ZMP concept, which has been very controversial since it was presented. Specially some questions arise:

- What happens when the ZMP is outside the support polygon?
- What happens with the ZMP in the flying phase of a biped robot?
- How to use the ZMP in uneven terrains?

There has been a notable effort in generalize this concept in the late decade, but we think no one had achieved it in a definite way.

2 State of the Art

On the other hand since the implicit presentation of the ZMP concept in 1969 by Vukobratovic et al [6], the concept has suffered various polemics among scientist. First of all, some authors claim that because the normal component of the moment generated by the inertia forces acting on the biped is not necessarily zero [6], the concept should be ``zero tipping moment point'' [7]. And the second issue is the existence of the ZMP outside the support polygon. Vukobratovic claims that the ZMP does not exist outside the support polygon and for that case the ZMP becomes de ``fictitious ZMP'', Goswami introduces de FRI concept for that cases [8]. In [7] there is an explanation of the CoP-ZMP and the use of a virtual version for the case of uneven terrain or virtual surface" to respect the original CoP-ZMP concept. The FSW (Feasible Solution Wrench) is another criterion proposed in [9] for uneven terrain and also extended to multi-legged robots. They define a "Wrench Plane" which contains an observation point of a resultant force and moment and where they obtain a kind of CoP (ZMP). Finally it becomes clear the need of the ZMP generalization within [10], where a "Universal Stability Criterion" is proposed based on [9]. But still we think it can be defined a generalization without a polyhedral convex cone abstraction.

3 Own Approach

Our interest on the double support phase is how to change the CoP from the back foot to the front foot in order to initialize another step in a single support phase. The approach used is to generate a time dependant trajectory of the torso in the operational space and then to move the feet accordingly with the assumption that there is sufficient friction to avoid the robot from slipping. Thus there exist a relationship of the torso movement with respect to the inertial frame and the movement of the feet with respect to the torso. The control scheme also considers dependence of the general coordinates between the two legs, which is mapped through the Jacobians of the feet.
The control used is a operational space PD, but also a dynamic compensation scheme has been analyzed for the over-actuated system and it's under test.
We consider a restriction in the horizontal plane, so the ZMP criterion is good enough to guarantee the dynamic balance preservation. The difference of this work is that the ZMP is calculated directly from the restriction wrenches given by the dynamic equation. If we calculate the whole forces and moments that restrict one foot of movement we can locate the ZMP in the single support phase and we can also extend this notion to the double support phase. With this approach it became plausible that the concept of ZMP can be extended to a three dimensional space with a geometric shape of a line. But we don't have any strong prove yet.
Finally the trajectory generated in the simulator is tested on the Bioloid humanoid robot at a speed control level and without any information of the forces acting on the restriction.

4 Current Results

The 24 DoF robot has been successfully simulated with restrictions in both feet and we obtain a smooth transition of the CoP from the back foot to the front one in the double support phase. Figure 1 shows the evolution of the ZMP transition from the back and right foot to the left and front foot in lateral and frontal view. At the bottom we present the ZMP graphs as the transition is made.

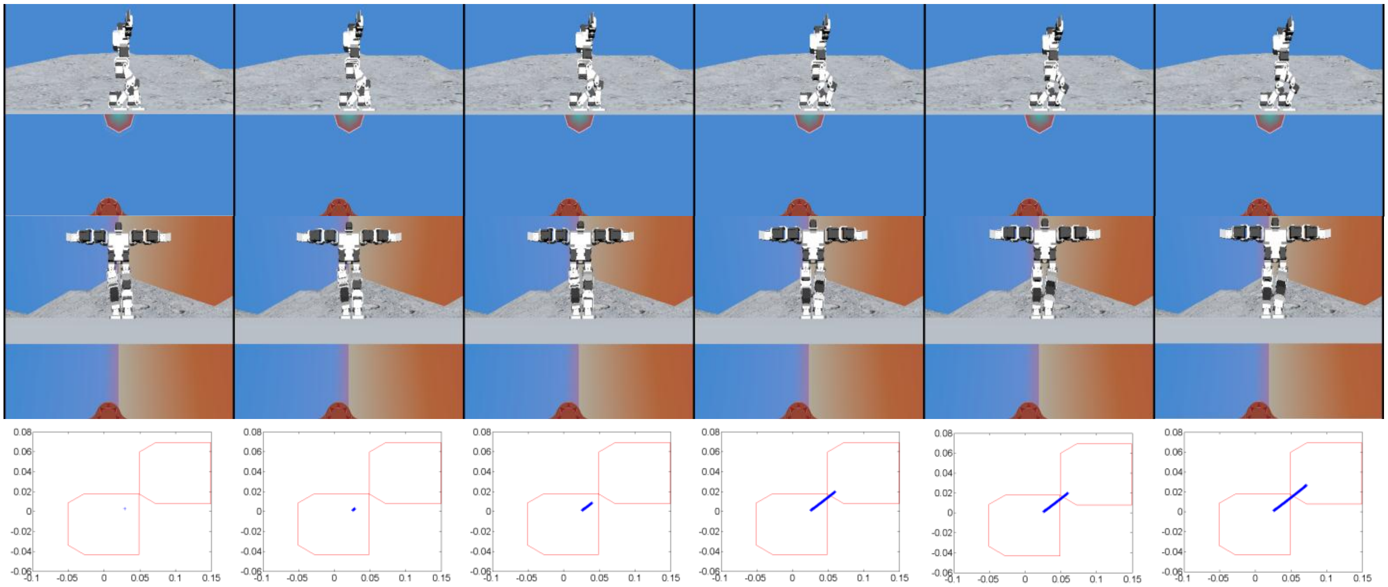

Figure 1. Simulation of the CoP transition in the Bioloid double support phase.

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Also the experiment with Bioloid has been achieved using the simulation data and normalized for the servo interpretation, but results are not shown.

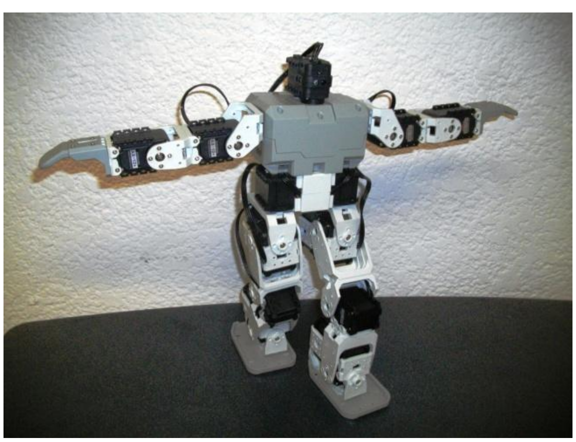

Figure 2. Experimental platform: Bioloid.

5 Best Possible Outcome

The extension of the ZMP concept to a 3 dimensional space is our goal. The idea may be similar to the "Universal Stability Criterion" of Hirukawa et al, but we think the physics principle is different. We think this definition could give us the idea of what happens with the ZMP during the flying phase and how to predict the foot landing position in order to extend the analysis in running cases.

Acknowledgement

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