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Experimental Error Compensation of the Linear Inverted Pendulum Model for humanoid robot TEO.

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***Abstract*— In the robotic field, the most versatile but complex machines are humanoid robots. The complicated architecture, high degrees of freedom, and balancing requirements make difficult the control task. Then the humanoid robot is usually represented by means of simplified models that enable an easy way of designing controllers. Taking parameters of the robot as the mass, location of center of mass and inertia, many approximate models of the robot can be established. Models allow to decouple the controller design into sagittal (x-z) and lateral (y-z) planes. But models are never totally accurate and feedback becomes essential in the design of the robot controller. Kajita proposed to model a biped robot as a 3D Linear Inverted Pendulum (LIPM) and this model is still being used in humanoid applications.**

Walking through rough or sloped terrains, avoiding obstacles placed in the robot environment, carrying an object itself or collaborating with a human are complex task for a humanoid robot. In all of them, the robot has to be ensured not fall over. However, it is necessary taking into account different mechanical requirements like distribution of the robot, an unknown weight or the center of mass. Therefore, these parameters lead to the use of one particular model of the robot.

The aim of this work is to improve the performance of ZMP computation using the classical LIPM described by Kajita. This improvement is performed by adding system and external error corrections. As mentioned before, model simplifications are not accurate and have errors. Because of the linearisation of the model, the ZMP equations are linear and the system are not completely ideal. These definitions introduce system errors. Also, there can be external errors. The measurement deviations in the Force-Torque (F-T) sensors due to calibration errors, or in analogue to digital conversions. Other systematic errors as the flexibility of the structure (due to the height of the robot), loosenesses between mechanical parts (as transmissions or unions of pieces), and small irregularities in the ground are not considered. All of these errors have no positive effects when talking about a model-based controller.

From the control point of view, the real humanoid mechanism is slightly flexible because of the legs length. Due to they are relatively long, the mechanical structure suffers from flexibility. Because of this compliance, the humanoid robot exhibits the characteristics of a lightly damped structure. For example, in a static case and under position control for the ankle joint, a pushing external force can easily excite an oscillation. This oscillation exists even when the position error in every joint is zero. Therefore, a control mechanism allowing ZMP fast correction must be implemented.

However, using the compliance joint model mentioned above, the ZMP error can persist. To accomplish the ZMP positioning requirements, this paper develops an improvement of the linear inverted pendulum presented before. Our objective is to modify the previous model. So system errors are taken into account in the robot model. To complete the final model, a spring k_s and a damper B have been added to the previous inverted pendulum. These mechanical elements try to compensate the errors induced in the system.

First, the robot movement is performed by its ankles like an inverted pendulum. So, a relation between the ankles angle and the measured ZMP is obtained. Giving to ankle joints angles from 0 to -5 degrees, in 0.5 decrease, the measured global ZMP has a linear relation with the set angle. Five tests carried out and taking the average relation.

Due to the intrisic deviations introduced by the mechanical system, the relation between ZMP and ankle angle is not reversible. That is, the ZMP obtained from the sensors is different from the ZMP determined by an ankle angle. Several step response trials have been performed and the ZMP data obtained has been used to adjust a second order polynomial equation. Being this polynomial equation nonlinear, the error is not constant for each working point. Then, the way selected for reducing the error in the balance controller has been based on the "Gain Scheduled Matching" method. In control theory, a gain-scheduled method is used to select automatically discrete parameter for adjusting gains or errors. Gain scheduling is a common strategy for controlling systems in which its dynamics change depending on the working conditions.

In our case, ZMP errors are organized as a "gain scheduling map" for every working point. The ZMP error matching process reduces ZMP deviations. In this case, the "gain" parameter is the error of the ZMP. Therefore, for each value, an adequate error will be considered in the control loop. Then B and k_s parameters will be obtained according to control specifications as settling time, overshooting, and others.

To check the feasibility of the proposed model, it has been tested experimentally in several tests. The error correction has been performed according to ZMP error matching described before. For each operating point of desired ZMP, the measured ZMP is corrected by introducing the modelled error.

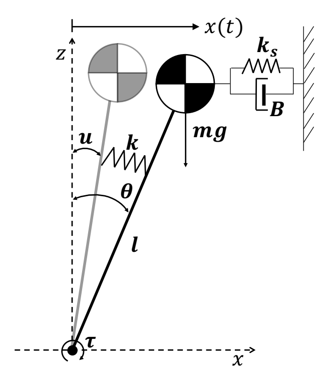

Fig. 1. Proposed compensated inverted pendulum model

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