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Biomimetic Internal Model for Limit Cycle Walkers?

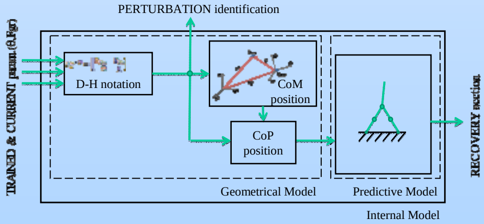
E.A. Turowska, A. Forner-Cordero, J.A. Gallego, J.C. Moreno, and J.L. Pons

Once the perturbation is detected recovery actions can be taken. An important issue is to check if taken actions are taken correctly what is equivalent to a statement that the used method is a right one or it is not. Due to that the trajectory tracking and the position in the next Double Stance is provided.

Walking in non structured environments and under perturbations is an important issue for bipedal robots. It lead to gait pattern changes and stability losses. Human beings seem to be able to tackle different types of gait perturbations successfully, [1].They choose a limited repertoire of recovery strategies that are modulated to suit the contextual demands. Hence, selection and implementation of the right recovery strategy poses a relevant question in bipedal walkers. Humans seem to use an internal model to predict the consequences of a certain action.

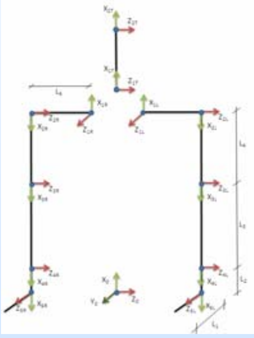
An Internal Model approach

The Internal Model consists of two parts: the Geometrical Model and the Predictive Model.



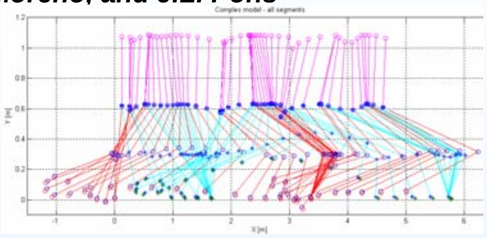
1) **The Geometrical Model (GM)**

The goal of this model is to calculate the COMs, CoPs, and joints position of the biped. These parameters are used by other blocks of the control structure (perturbation identifier, predictive model). Outputs provided by GM are used to detect perturbation and how the biped should behave in case when the perturbation occurred.



Denavit Hartenberg (D-H) notatnion.

	Frames	alpha	a	d	theta
Origin-pelvisR	0-1	-90°	H	Y	th_pr
pelvis-hipR	1-2	+90°	0	-L5	th_hr+180°
hipR-kneeR	2-3	0	L4	0	th_kr
kneeR-ankleR	3-4	0	L3	0	th_ar
ankleR-footR	4-5	+90°	L2	0	th_arf
Origin-pelvisL	0-1	-90°	H	Y	th_pl
pelvis-hipL	1-2	+90°	0	L5	th_hl+180°
hipR-kneeL	2-3	0	L4	0	th_kl
kneeR-ankleL	3-4	0	L3	0	th_al
ankleR-footL	4-5	+90°	L2	0	th_alf
Origin-pelvisR	0-1R	-90°	H	Y	th_pr
pelvisR-trunk	1R-1T	+90°	0	0	th_t
downTrunk-upTrunk	1T-2T	0	L6	0	0



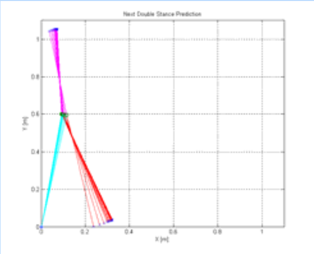
To calculate the COM's and the joint position, the forward method of the Denavit Hartenberg notation was used. The bipedal robot was modelled with 11-links and 9 joints: trunk, hips, upper and lower legs, ankle and feet.

To estimate the CoPs the robot was represented as a two-legs model with the mass of the whole body concentrated in one point, [2]. However calculations are provided just for 'the leg' which is with the contact with the ground. In that case we can say that the body is represented as a simple inverse pendulum.

$$y_{COP} = \frac{-\dot{H}_x - y_{COM} \cdot F_{gr\_y} + M_{EX} - L \cdot M \cdot a_{COMy}}{F_{gr\_y}} \qquad z_{COP} = \frac{\dot{H}_y + x_{COM} \cdot F_{gr\_y} - M_{EY} - L \cdot M \cdot a_{COMz}}{F_{gr\_y}}$$

2) **The Predictive Model (PM)**

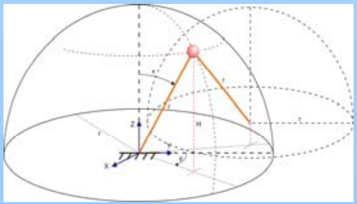
The Predictive Model predicts the body configuration in the next double stance. It forecasts if the next robot configuration is stable, stabilizable or may lead to a fall. The configuration is defined by: step length, step duration and the trunk inclination angle. In each instant of time the prediction of the double stance is calculated to see if the recovery action [3] was taken correctly. If not, it should be changed in the next instant of time.



Simple model (3-L) for the Predictive Model

Determine the position of the biped in the next double stance from the equations of motion. Once it is known, determine if it is stable or not.

Calculations are provided for a simplified, computationally inexpensive model represented in a sagittal plane with three links (2x leg, trunk). Is this enough?



Representation of the whole body taken into account while the CoP's position was calculated.

References:

[1] A. Forner Cordero, H.F.J.M. Koopman and F.C.T. van der Helm, "Multiple step strategies to recover from stumbling perturbations", *Gait and Posture*, 48, 47-59, 2003.

[2] Hof, A.L., 2007, 'The equation of motion for a standing human reveal three mechanisms for balance', Journal of Biomechanics, (40):451-457.

[3] A. Forner Cordero, H.F.J.M. Koopman and F.C.T. van der Helm, "Mechanical model of the recovery after stumbling", *Biological Cybernetics*, 91, 212-220, 2004.

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ESBiRRo

Ctra. Campo Real, Km. 0,200
28500 ARGANDA DEL REY (Madrid)

Tfno.: +34 91 8711900
Fax: +34 91 8717050

http://www.iai.csic.es/gb
E-mail: turowska@iai.csic.es

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