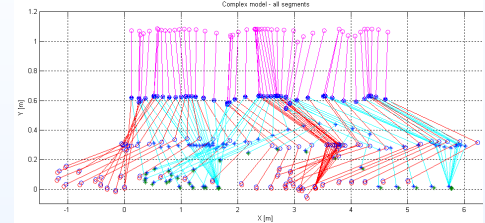


## Biomimetic Internal Model for Limit Cycle Walkers

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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.

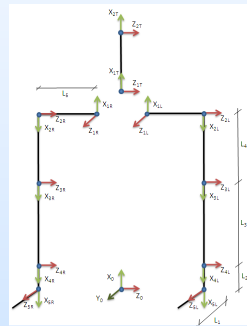


To calculate the COM's and the joint position, the forward method of the Denavit Hartenberg notation was used. In that case the bipedal robot was considered as a 11-links model (11 segments/9 joints: trunk and pairs of hips, upper and lower legs, ankle and feet).

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.

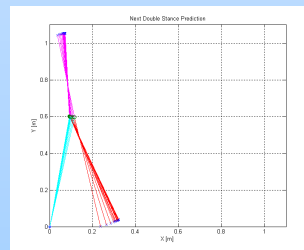
$$\gamma_{\text{COM}} = \frac{-\dot{\theta}_{\text{tr}} - \gamma_{\text{COM}} \cdot \dot{\theta}_{\text{tr}} + \dot{M}_{\text{tr}} - L \cdot \dot{\theta}_{\text{tr}}}{\dot{\theta}_{\text{tr}}}$$

$$z_{\text{COM}} = \frac{\dot{H}_{\text{tr}} + x_{\text{COM}} \cdot \dot{F}_{\text{tr}} - \dot{M}_{\text{tr}} - L \cdot \dot{\theta}_{\text{tr}}}{\dot{\theta}_{\text{tr}}}$$

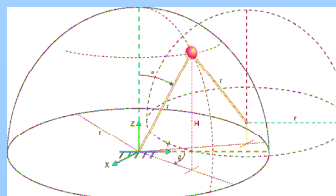


Denavit Hartenberg  
(D-H) notation.

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



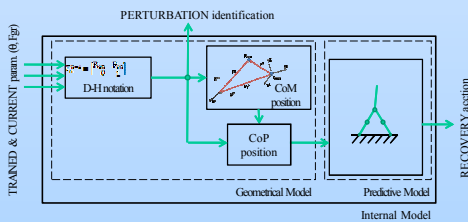
Simple model (3-L) for the  
Predictive Model



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

### The Internal Model

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.

Thanks to the Commission of the European Union that gave financial support to this research under contract IST-61-045301-STP.

### 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.

To know the position of the biped in the next double stance angles of all articulations are calculated from the equation of motion. Once they are known, the position in the next double stance are estimated.

Calculations are provided for a simplified, computationally inexpensive model represented in a sagittal plane. It consists of three links (2x leg, trunk).

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.