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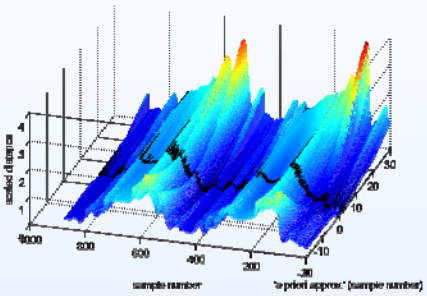
Perturbation Detection in Limit Cycle Walkers

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

The first step to avoid a fall during walking is to detect quickly that a perturbation is happening. We propose the Nearest Neighbour Gait Index to find out how much the walker deviates from its Limit Cycle. This allows to build a Fuzzy System that determines if a trip is happening and estimates its magnitude.



Calculation of the Nearest Neighbour. The mesh represents the distance to the actual state of the robot. The solid line the distance to each Neighbour.

Walking on irregular surfaces is a challenging issue in humanoid robotics: neither ZMP nor Dynamic Walkers have succeeded in handling perturbations. However, humans reject them naturally and efficiently. They rely on sensory organs that trigger a certain reaction determined by the perturbation type and magnitude, and gait phase[1]. We follow a similar approach for walking robots: the Nearest Neighbour Gait Index, observes the state of the robot and, if necessary, triggers a recovery action.

The Nearest Neighbour Gait Index

The Nearest Neighbour is the point in the Limit Cycle that best represents the current state of the robot: the algorithm tells us where the walker is with respect to its Limit Cycle.

1) **Definition of a Reference Limit Cycle** (RLC) that describes the normal gait. The RLC is a curve in a *2n*-dimensional state space, calculated as the mean trajectory of the *n* joint angles and velocities after normalizing to stride percentage. The mean stride duration is also obtained. Noise and artifacts are filtered with the Benedict-Bordner filter[2].

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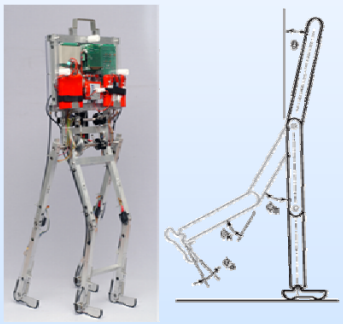
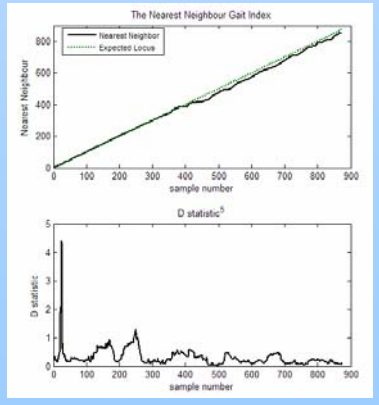


Limit Cycle Walker META[3] (Delft UT). It has 7 DoF. Incremental encoders and a IMU provide joint angles and velocities.

2) **Selection of an interval of candidate neighbours** based on the (quasi)cyclic nature of dynamic walking.

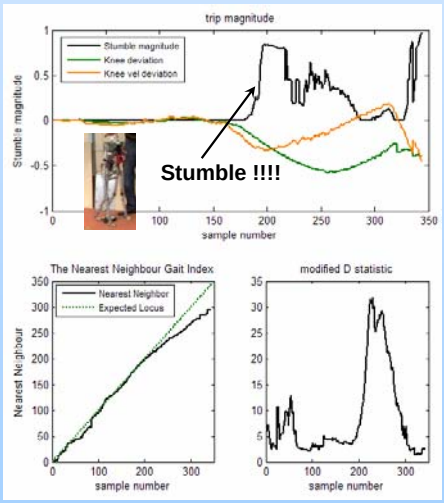
3) **Calculation of the Nearest Neighbour[4]**. It is defined as the least Euclidean distance in the *2n*-dim. state space. All variables are scaled with respect to its maximum.



The Nearest Neighbour Gait Index for one stride. We use the D-statistic[5] to quantify the deviation from normal gait.

Fuzzy Stumble Detector

Observing the trajectories of all variables during a trip, we concluded that knee angle and velocity were enough to detect and quantify a stumble. A fuzzy inference system permits to quickly implement this "knowledge" and test it on the walker's tripping data.



Fuzzy stumble detector. It detects that META suffered a trip. We also see an increase of the modified D-statistic[5].

References:

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[3] D.G.E. Hobbelen and M. Wisse, "Swing-Leg Retraction for Limit Cycle Walkers Improves Disturbance Rejection," *IEEE Trans. Robot.*, 24(2):377-389, 2008.

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[5] J.G.D. Karssen and M. Wisse, "Fall detection in walking robots by multi-way principal component analysis", *Robotica*, (available on-line).

ESBiRRo

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

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

www.iai.csic.es
E-mail: gallego@iai.csic.es