Internship proposal

Modelling and verification of human gait

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Location and team  LIX, Bâtiment Turing, campus Ecole Polytechnique (Palaiseau). Within the Computer Science Laboratory of Ecole Polytechnique (LIX), the intern will integrate the Cosynus team, whose research axes are the semantics and analysis of (possibly distributed) programs, hybrid and cyber-physical systems.

General presentation  From a modelling perspective, human beings can be thought of as physical objects which interact with physical space in ways that are mediated by forces, masses and inertias, and can be described, to first approximation, by ordinary differential equations. To this extent, human beings can be considered as dynamical systems.

A major challenge in fields such as robotics, control, health etc. is to find models of human gait motion which can replicate actual human’s motion. A recent study [2] validated a gait model, in a 2D configuration (refer to fig. 1(a) for the planes of motion), on a large number of subjects which is based on a previously employed walking patterns ([3]) for the design and the control of humanoid robots. The latter model considers the motion of the center of mass (CoM) in the sagittal plane such that the center of pressure (CoP) remains strictly within the convex hull (also known as the base of support) of the stance foot during the walking process [3]. While motion in the frontal plane is not considered, in the transversal one the CoM position is taken constant and corresponds to the human’s height, which in some cases can be a strong hypothesis. Also, 3D models for human walking process are proposed in the literature, and [1] presents an interesting survey on such models.

Human gait models are fundamentally hybrid due to the presence of continuous phases, discrete transitions, and unilateral constraints arising from the contact forces between the feet and the ground. A hybrid model of a gait motion is constructed by enumerating a list of dynamic models corresponding to allowed phases in the gait along with the possible transitions among phases, as represented on fig. 1(b).

The cycle of gait naturally has two continuous domains, corresponding to single support (SS) on the left and right legs (case in which one foot is on the ground while the other is above), while the double support phases (DS) can be supposed instantaneous. Roughly speaking, the hybrid model achieves the cycle of gait motion with repetitive sequence of phases (each depending on dynamical aspects, as illustrated in fig. 1(b)) which move the body forward while simultaneously maintaining stance stability and while possible transitions between phases occur.
Objectives of the internship  The challenges of this internship can be:

1. Propose a gait motion in a 3D configuration, which can be an extension of the 2D model proposed in [2].

2. Formulate the 3D gait model—proposed at 1.—as a hybrid model in which each phase occurs due to a transition (e.g. temporal logic constraints).

3. Check the critical component of the walking process e.g the stability, under a variety of assumptions. Some suggestions may be the consideration of different walking velocities, step positions and durations, time for each of the gait phases, different CoP base of support, small model disturbances related to the human’s anthropometric parameters (mass, height, foot length and width etc.) or desired behaviours (velocities, positions etc.) at the end of the motion.

4. Check the never stopping property of the walking mechanisms, at a certain speed, under a variety of assumptions. This implies checking more general temporal logics formulas than the ones in the item above, such as: there is a never ending cyclic sequence of events (SS), (DS) all within some time slot etc.

For the verification part, we suggest to use first some tools that implement some form of monitoring, falsification, reachability, or even requirements mining calculations such as:

- Breach (using Signal Temporal Logic (STL)), see e.g. [4]
- Taliro (using Metric Temporal logic (MTL)), see e.g. [5]
- Flowstar (for reachability), see e.g. [6]

For the stability part, it may be difficult to use an existing tool, and this should be attacked at a more theoretical level. It may require analyses that account for both time and movement [7] or analysis via Lyapunov exponents [8].
References


