Space Gaits

Type of activity: Standard study

1 Background and study motivation

Legged locomotion is an efficient solution for mobility on unknown and possibly rugged planetary terrains. Research on walking robots has seen substantial progress in the last few decades (cf. [1-6]). Studies already focus on the application of walking robots in space, e.g., [7]. The authors of [8] even draw inspiration from the jumping movements of the astronauts that landed on the moon in order to make an initial design of a jumping robot taking advantage of the moon's low-gravity environment.

While the studies mentioned above (and many more that are omitted here) are pioneering, a general approach to the design and selection of appropriate walking gaits for legged robots is lacking. A possible starting point could be to automate the gait design using evolutionary algorithms [9-11] or other methods of reinforcement learning [12] (see Figure 1). Such automatic, rather unbiased, designs of gaits would allow the solutions to be mostly determined by the problem structure (including the environment, body and controller). The optimised gaits could then be analysed by means of the classification methods popular in biological research, leading to generic insights into the relation between the environmental conditions and the emerged gaits. In this study, we are mostly interested in the relation between walking gaits and environmental conditions such as gravity level and soil type.

Figure 1: *Left:* Evolved morphologies under different task descriptions, from [9]. *Right:* Robot used for evolving walking gaits in [10].

Milton Hildebrand pioneered the scientific analysis and classification of gaits [13]. Following his work the movement of each limb is partitioned into a stance phase, and a swing phase. In the first, the foot is in contact with the ground, while in the latter the foot is lifted and moved. Each leg completes a cycle in the same length of time in order for a steady pattern to occur. Thus, any gait can be described in terms of the beginning and end of stance phase of each limb with respect to each other (see Figure 2).

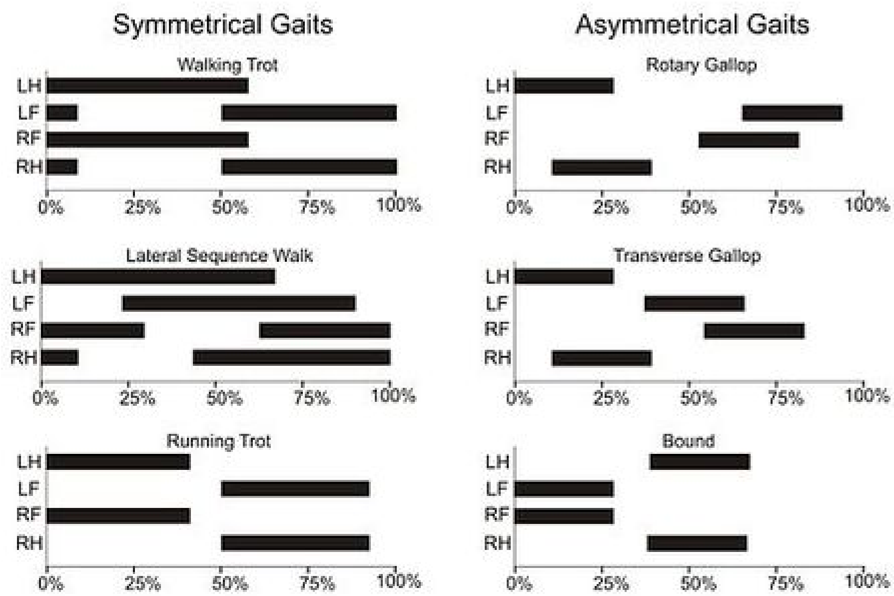

Figure 2: diagrams for analysing different gaits, as introduced by Hildebrand [13].

Early work on six-legged robots used the Hildebrand methodology to analyse the walking gaits [14,15]. For example, in [14], this scheme has been used to analyse the evolved walking gait of a hexapod.

More complex and detailed ways of analysing gaits than the Hidebrand diagrams are used today, both in biology and robotics. For example, newly studied features include the contact forces (cf. [16]). The use of such more complex analysis methods is encouraged in the context of this project, as long as the information on the gait present in the Hildebrand diagrams is preserved. Namely, that information captures gait properties that are essential to the project, such as whether the robot is walking or hopping.

2 Study objective

The goal of the Ariadna project is to systematically use Hildebrand diagrams or some equivalent methodology to analyse walking gaits emerging from an optimisation process in order to verify whether behavioral switches / bifurcations exist with respect to parameters such as gravity and soil type.

3 Proposed Methodology

The following methodology is proposed for this study, and should be discussed in the proposal, though argued alternatives are welcome as long as they promise to achieve the project goals.

1) A set of experiments tailored to gathering data on optimised walking gaits for different gravity / soil conditions. The experimental set-up (dynamics, body morphology, soil) has to be proposed having in mind its relevance to space exploration. The range of gravities studied should cover different scenarios, ranging from asteroid- to Jupiter-like environments and beyond. Of course, the relation between robot mass and gravity is an essential aspect that needs to be discussed.With respect to the set-up, the proposal will have to address the important issue of the trade-off between the simulator's speed and realism. Clearly, to reach the project objective many evolutionary runs have to be performed, requiring a fast simulator. However, the dynamical model implemented also needs a certain level of realism, so that the optimized gaits are plausible. For example, this may have implications for the modelling of the soil and contact with the soil.Universities are encouraged to address this in the proposal, for example by discussing the complexity of simulating specific soils versus coarse soil categories (e.g., dust, sand, silt, clay, solid). The terrain type could also be of interest (e.g., flat, undulating, rocky).

The proposed set-up will also have to include an objective function for the optimization process. While in many robotic studies only speed is optimized, it is important to keep in mind that in space applications energy efficiency is a critical parameter as well. The emergence of behavioral switches and bifurcations, and the critical values of gravity and soil parameters these will occur at, will depend on the selected objective function.

2) An automated classification scheme to classify gaits, for instance based on the Hildebrand methodology. The classifications may relate to classes as recognized in the biological literature. However, methods can also be proposed that automatically recognize relevant regularities in the different evolved gaits, for instance as in [16]. Another option would be to perform unsupervised clustering of the gaits.

3) The application of the proposed scheme to the evolved gaits as to locate switches and bifurcation with respect to a gravity parameter, and other parameters describing soil properties.

The study can be performed on fixed morphologies (bodies) as well as on morphologies that are, themselves, the result of the optimisation procedure (as in [11]). If the latter option is chosen, a degree of realism has to be ensured on the employed morphologies so that the simulated robots are physically plausible. In addition, in such a case, the proposal has to specify how the effects of the environmental conditions on the evolved morphology and on the control can be separated.

This Ariadna project proposal is addressed at research groups with expertise in any of the following domains: walking robots, animats, artificial life, evolutionary robotics, biologically inspired robotics, biomimetics.

4 ACT Contribution

Researchers in the ACT will provide space knowledge and perform gait optimisation in parallel with the proposing group (using the same common simulation platform agreed). This will result in larger quantities of data and also form a test of the reproducibility of the methodology.

The analysis of the evolved gaits will also be set up (and performed) in collaboration with the ACT researchers. The project PaGMO / PyGMO could be used for the optimisation part of the project, in which case the ACT will also provide support on the possible software integration with the simulator.

5 Bibliography

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