Spider attachment for space applications

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Firm attachment between loose objects is a critical issue in the absence of gravity like, e.g. on-board a space station. This fundamental issue of space travel led to the success of the bioinspired Velcro which is based on a statistical anchoring between a "hook" surface and a "loop" surface. Together with the increasing use of extra-vehicular activities, a system working on a broad variety of surfaces, e.g. the hull of a space station, is needed. Robotic devices need to locomote freely and safely on the outside of spacecraft. On top of that, complexity of the system must be kept at a minimum.

Recent research on geckos and spiders, *Evarcha arcuata*, led to the description of an even more astonishing mechanism of so called dry attachment via van der Waals forces. Contrary to the gecko, the spiders control attachment passively via the kinematics of their legs. Their locomotive apparatus is highly versatile allowing for walking, jumping, and object handling. In the study presented here, we analyzed the attachment systems of *E. arcuata* and geckos and together with existing data on spider kinematics we conceptualized a legged walker suitable for space applications, for example working on the outer surface of a space station.

Simplified leg kinematics

For space applications dry adhesion offers a broad range of application since there is no need to cope with the interaction of any sticky fluid with the variety of harsh environmental conditions, be it in the almost vacuum of an orbit or the unpleasant conditions of planetary surface. This initial decision points to two remaining groups of model organisms, geckos and spiders (e.g. *Evarcha arcuata*). Both employ similar physics for adhesion and the gecko is by far the more thoroughly studied model. However, the absence of active articulation and actuation in the spider tarsus offers a simplification of any potential biomimetic legged robot. Two principles

contribute mostly to adhesion control, (i) the spring mechanics of the adhesive device, the tuft, and (ii) the kinematics of the leg which control the orientation of the asymmetrically shaped adhesive terminal ends of the setules in respect to the substrate and hence the strength of adhesion. In the present account we focus on the replication of leg kinematics which perform walking and include adhesion control without the need for additional sensing, control, and actuation.

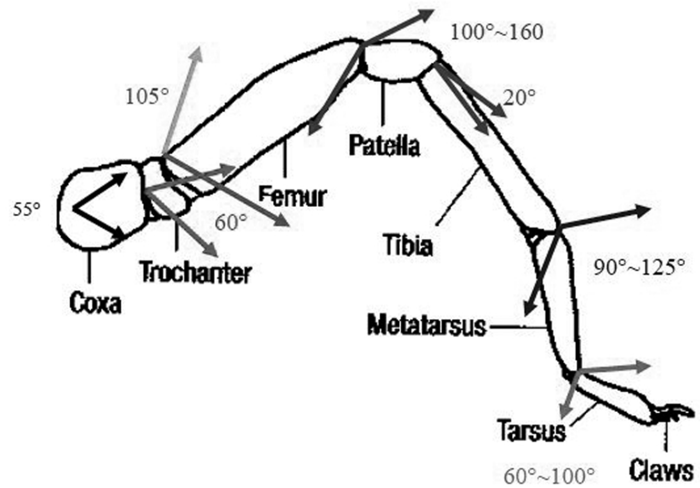

Fig. 1: Generalized model of a spider leg using literature data from various sources.

The first goal of the project was to identify a kinematic model of the leg which is highly simplified on the one side but also capable of controlling adhesion via tarsus orientation on the other side. Any animal uses its leg for more tasks than purely walking and hence, the - from the engineering point of view superfluous - extra degrees of freedom allow for behaviours such as probing, jumping, fighting, mating, etc. and hence, can be neglected for our concept.

From a generalized model of a spider leg (Fig. 1) we derived a technical limb with two monocondylar and one bicondylar joint allowing for motion with seven degrees of freedom (Fig. 2). Six degrees of freedom are necessary for locomotion purposes, the seventh allows controlling the angle between tarsus and substrate and in consequence, the pull-off force of attachment hairs with asymmetric terminal ends as found in, e.g., *Evarcha arcuata*.

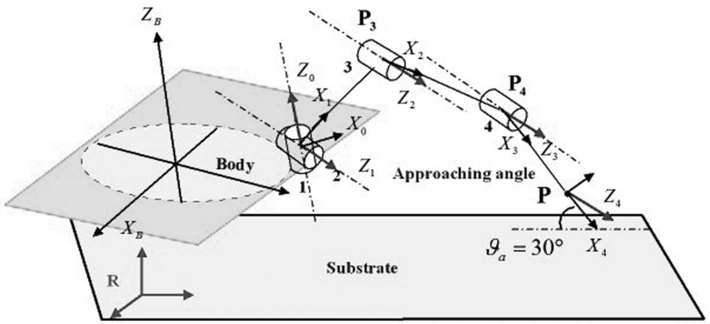

Fig. 2: Simplified technical leg with 7 degrees of freedom.

Leg controler and walking simulator

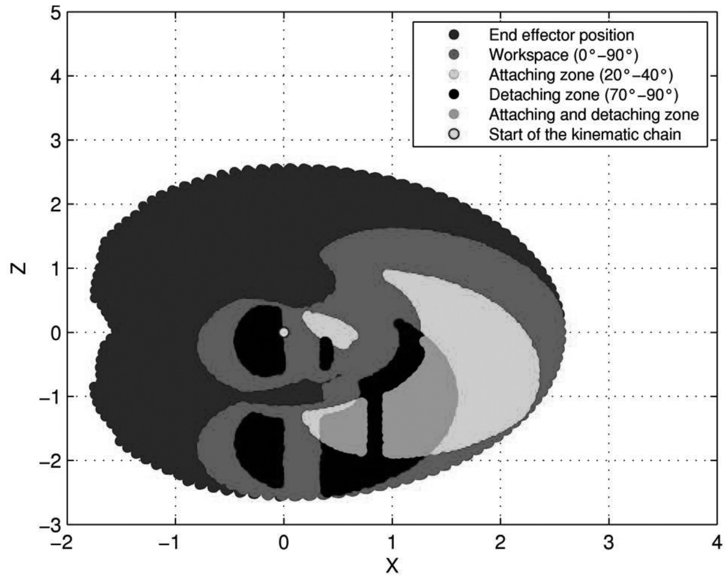

Fig. 3: Workspace of 7DoF leg in dorsal view. The green areas show end-effector positions with good approach angles, the black with good pull-off angles.

In the following step, we determined the dextrous workspace of the technical limb for reasonable tarsus-substrate angles between 20 and 90 degrees including those for optimal approach (20 - 40 degrees) and lift-off

(70 - 90 degrees). The leg controller has to be able to control adhesion to the substrate through controlled navigation within the workspace of the end-effector (Fig. 3).

The next necessary step was the implementation of the single leg controller into a hypothetical robot. We choose a rotary symmetric setup with eight legs. This setup removes the need of implementing a steering algorithm at this stage as the robot just chooses the direction in which to walk to next without prior body alignment. In addition to that, the eight legs give the system a desired flexibility for future implements of capabilities such as handling of objects and safe transitions between differently oriented surfaces.

The simulator (Fig. 4) was implemented in Matlab and forward locomotion was achieved via slight inclination of the substrate. In the simulation the controller was able to locomote on flat substrate as well as on vertical substrates and in overhead configuration controlling attachment via the angle between tarsus and substrate.

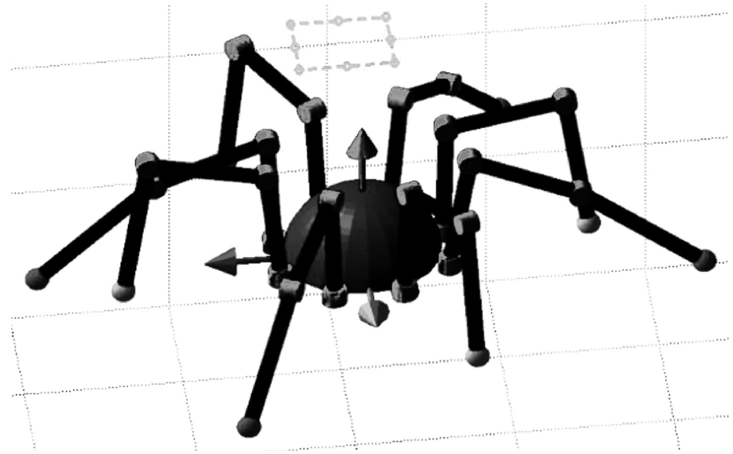

Fig. 4: The final result is a kinematic simulator integrating the model of the simplified leg and control. The model robot is able to walk and keep attached on surfaces of all orientations.

Outlook

In the present account we present the results on the kinematics and control of a technical spider leg which implements locomotion and attachment control in one single controller without the need for additional sensing and actuation. In consequence, we realized a significant increase in robotic functionality without increasing mechanical complexity. The central assumption is that it will be possible to reproduce the behaviour of, e.g., the model animal's tarsal tuft to a high degree, especially the asymmetry of the terminal ends which allow for control of pull-off force via tarsal orientation. Another focus of this project indeed lies in mechanical simulation of these attachment devices and a subsequent formulation of the requirements in terms of material and structural compliance (Gasparetto et al., in prep.).

Further reading

Gasparetto A, Vidoni R and Seidl T (2008). Kinematic study of the spider system in a biomimetic perspective, Proc IEEE/RSJ Intl Conf Intel Robot Sys, Nice, France, Sept, 22-26.

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Kesel AB, Martin A and Seidl T (2004). Getting a grip on spider attachment: an AFM approach to microstructure adhesion in arthropods. Smart Materials & Structures, 13:512-518.

Project website: http://www.esa.int/gsp/ACT/bio/op/DryAdhesion.htm