**Biomimetic Spider Leg Joints: A Review from Biomechanical Research to Compliant Robotic Actuators**

**Stefan Landkammer \*, Florian Winter, Daniel Schneider and Rüdiger Hornfeck**

*Abstract:*

*Due to their inherent compliance, soft actuated joints are becoming increasingly important for robotic applications, especially when human-robot-interactions are expected. Several of these flexible actuators are inspired by biological models. One perfect showpiece for biomimetic robots is the spider leg, because it combines lightweight design and graceful movements with powerful and dynamic actuation. Building on this motivation, the review article focuses on compliant robotic joints inspired by the function principle of the spider leg. The mechanism is introduced by an overview of existing biological and biomechanical research. Thereupon a classification of robots that are bio-inspired by spider joints is presented. Based on this, the biomimetic robot applications*

*referring to the spider principle are identified and discussed.*

*Summary*

As an introduction, the author highlights the requirements of effective HRI (human-robot interaction), emphasising the risk of injury when using rigid robots for direct interaction, and hence the avoidance of such situations in modern industry. The potential benefits of effective HRI for industrial and care sectors has fuelled research into soft robotics and intrinsically compliant actuators, often through observing how biological systems avoid damage through compliant limbs, tendons etc. In most current systems, compliance is active, achieved through expensive and computationally demanding sensors, hence the drive to create passive compliance in robotic systems.

Most mammals and insects utilise antagonistic muscle systems to generate movement; interestingly however, arachnids function through a combination of flexor muscles and hydraulics. The benefits of this system to arachnids, such as sensitivity, low weight and strong actuation, could also yield huge benefits to robotic systems, and an investigation of this potential forms the focus of this paper.

Section 2 describes previous biological research into the arachnid leg, leading on a description of the current understanding of spider leg actuation; muscles within the exoskeleton connecting different leg sections allow the contraction of the legs, whilst fluidic pressure (of internal ‘blood like’ fluid) is increased to expand a bellow like structure, and consequently extend the leg.

Research displayed here also includes analysis of structure of this bellow like structure on the inside of the joint, revealing the points of pressure that are reinforced with tendons, as well as the folding mechanism upon the pressure being reduced.

It is revealed that a lack of muscles for extension allows for almost all of the space inside the leg cavity to be utilised for contraction muscles, hence the strength when holding prey, climbing and rappelling. Interestingly, pressure increases that extend the leg do not seem to be isolated to a single joint; individual muscles must be tensed to prevent extension.

The section overall highlights the phenomenal complexity of the arachnid actuation system, with much still unknown about the complex fluid dynamics and antagonistic relation between hydraulic pressure and flexor muscles.

Section 3 moves onto the technical applications of the aforementioned research, beginning by defining which class of robotics the spider leg model fits, namely that of rigid body robotics with soft actuation. A summary of the current usage of soft actuators demonstrates the common use of antagonistic actuator pairs (replicating many biological systems), as well as highlight the difficulties with control due to the nonlinear dynamic behaviour of these actuators (force varies with contraction/expansion). It highlights also the current tendency towards *only* fluidic actuation for compliant systems.

Also summarised are the benefits of fluidic actuation, such as high energy efficiency, and the (particularly interesting) feature of almost negligible energy consumption when holding a position, through use of stop valves.

The author then moves to a discussion of previous research, in which the actuator design was based explicitly on the principles of spider leg actuation. The various attempts are described in brief, with the capabilities outlined, and the potential applications emphasised.

Only one of these displays the previously mentioned antagonistic extensor/flexor system that is present in arachnid legs, utilising an experimental set up remarkably similar to the biological system that inspired it, and displays a high power to weight ratio and efficiency, essentially mimicking the biological actuators.

The author concludes by emphasising the potential advantages of replicating these systems, whilst admitting that there is still a vast amount still unknown with regards to how the spider leg functions with such fidelity. In particular, the complex fluid dynamics caused by changing internal volume (due to muscles expansion) and pressure is very much an open area of research, and understanding this is integral to understanding how to control such systems effectively.

*Review*

The paper is a particularly interesting read, in part due to the focus on an actuation method that is somewhat novel not only in modern robotics, but also in nature, and one that is still not fully understood. It provides an effective introduction to the topic for newcomers to the field, and contains citations to many of the most prevalent pieces of research into spider biomimetics. It is effectively communicated that such systems could greatly improve the capabilities of future robotic systems across many applications, and should serve to inspire further research into the field.

I feel the author was particularly aware of the potential for a review paper such as this to become rather tedious, especially when listing the various devices created, along with their individual capabilities; this seemed to have been mitigated by a brief, interesting discussion of the potential applications for each device, along with a well-crafted diagrammatic representation of the various systems explored.

One criticism I do have is with the early discussion of the exact definition of biomimetics with regards to biological example of the spider; it felt excessively involved, and did not feel like a particularly relevant piece of information with respect to the overall theme of the paper.

@Article{,

author = {Stefan Landkammer \*, Florian Winter, Daniel Schneider and Rüdiger Hornfeck},

title = {Biomimetic Spider Leg Joints: A Review from Biomechanical Research to Compliant Robotic Actuators},

journal = {robotics},

year = {2016},

}