Rossiter, J. (2020). Spinning artificial spiderwebs. *Science Robotics*, *5*(44), [eabd0290]. https://doi.org/10.1126/scirobotics.abd0290

Subject: biomimetic robotics

Title: In a spin with robotic spiderwebs

One sentence abstract: Artificial robotic spiders webs demonstrate spiders-like capabilities of sensing, capture and self cleaning through novel electrostatic actuation and dirt-shirking coating.

Jonathan Rossiter[1*]

Engineering Mathematics and Bristol Robotics Laboratory, University of Bristol, BS3 1NJ, Bristol, UK

*Jonathan.Rossiter@bristol.ac.uk

Arachnids have long been the focus of study for materials development and robotics: spiders employ a unique hybrid locomotion system, using hydraulic pressure generated in the prosoma organ to power their powerful-yet-thin legs (1); their webs have amazing self-tensioning behaviours, exploiting the surface tension of water droplets (2); and spider dragline silk has a specific tensile strength five times that of steel at around 1.3 GPa. In addition to these amazing characteristics, spiders, as carnivores, use high fidelity sensing and filtering coupled to their web structures to sense and locate prey and to determine when to attack. Scientists have long been fascinated by arachnid biology and have sought to mimic spider actuation and sensing, and the sophisticated structures and materials of spider silk and spider webs. Writing in Science Robotics, Younghoon Lee and colleague have brought together the fields of biomimetics, electrostatics and smart materials, to develop a new ionic spiderweb material and to replicate essential behaviours of spiders' webs in self-sensing, self-cleaning and prey-capturing artificial ionic spiders webs (ISW) (3) (figure 1). This adds new capability to robotic systems, with wide potential applications from climbing robots to self-cleaning coatings.

Traditionally researchers have targeted the strength of spiders' webs through mimicry of the silk extrusion gland (4). This is extremely challenging because the spider has evolved a highly optimum chemical extrusion process involving multiple stages of pH changes, ion infusion and mechanical fibre alignment. Lee and colleagues have taken a different approach and have developed artificial spiderwebs that, while not as strong as artificial silks, exhibit novel functionality that is inspired by the materials and structures of spider webs. They have noted that smart materials have limitations in their abilities to actuate, sense and grip objects, and that controlled electrostatics offers a technology to overcome these limitations. Operating at the intersection of these fields, they present a composite coaxial fibre made of ionically conductive and stretchable organogel, encapsulated with silicone rubber to form a strand, which is then perfluorinated using a conformal coating to reduce surface energy. They use this composite fibre to form a range of ISW structures which resemble the classic planar spiderweb. By applying and sensing the electrical potential between pairs of ISW fibres they generate three behaviours. Firstly, electroadhesion can be induced between the web and an object by establishing an electric field between adjacent strands of the web. Secondly, objects making contact with the web generate an electrical response in the ionic conductors, which can then be used to initiate the adhesion process. Finally, by applying a time-varying electric field between pairs of ionic strands they can be made to vibrate and thereby, with the help of the hydrophobic coating, throw off contamination. By demonstrating these three characteristics of ionic spiderwebs, the authors have enabled the possibility to make artificial spiderweb-like structures that can operate in natural, and often dirty, environments.

The value of the work presented by Lee and colleagues extends beyond their immediate use as artificial spiderwebs. Flexible and stretchable ionic conductors could act as substitutes for conventional conductors, including wires and liquid metal channels, for future electroactive artificial muscles. This could have great benefit to the growing field of soft robotic wearable assist devices for people who are disabled or elderly. The growing topic of soft electroadhesion is also likely to benefit. Much work is currently underway to develop morphing structures that can also electrostatically grip and manipulate delecate objects (4), and ISW materials may enable new gripping structures and enhanced sensing functionality. By demonstrating an attractive combination of active (via electrostatically-induced vibration) and passive (by dirt-repelling surface coatings) self-cleaning, this work also hints at future applications in active surfaces that clean themselves, either for aesthetics or for function. For example, wall-climbing robots that employ electroadhesion are currently limited to clean surfaces and dust-free environments (5), and developments deriving from the ISW could liberate them from these constraints. It would also be extremely interesting to develop the spider analogy further, potentially seeing how spiders could work with the ISW in their natural environments, providing new insights into biology.

The ionic spiderwebs presented are not without limitation. Improving the robustness of the web fibres under repeated stretching is a challenge, and the capability of the web to detect proximity of non-charged objects has yet to be demonstrate, although both will doubtless be addressed by the team and also by other scientists. The ISW can be seen as a generic technology that is applicable well beyond the mimicry of arachnid webs, and it remains to be seen how far these materials can be developed and adopted across soft robotics. Notwithstanding, the contribution of this work by Lee and colleagues to the fields of electrostatic actuation and controlled soft gripper is noteworthy and exciting.

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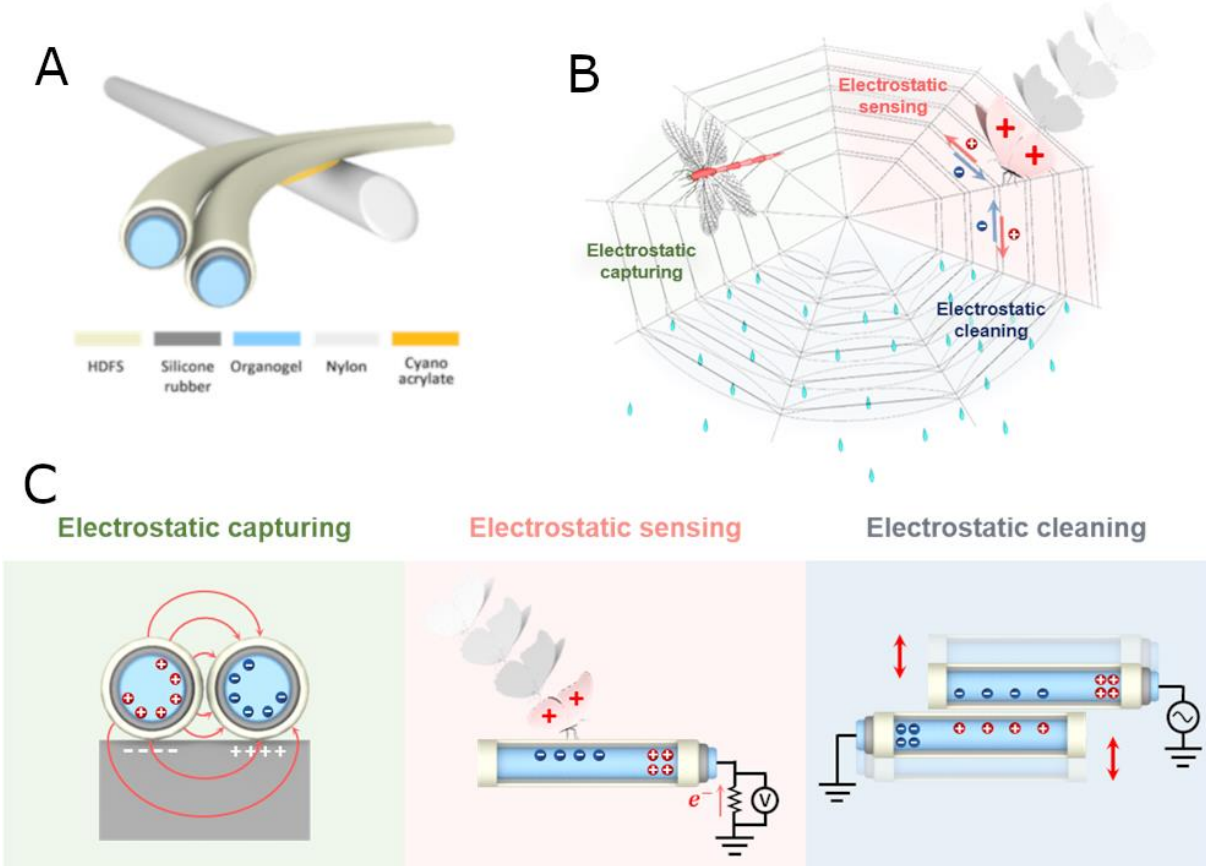

Figure 1. The ionic spider web. (A) Conductive, compliant web fibers are made from ionic organogel encapsulated in silicone elastomer and coated with a low-surface-energy material. (A, concept) and (B, mechanism) The ionic spiders webs mimic the natural web and exbibit capabilities of object sensing and capture, and hybrid self-cleaning. (edited figure derived from figure 1 in manuscript)

Alternatively, figure could be stylish stock photo of spiders web, showing droplets of water/dew, or one with a spider on the web.