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Fishing for artificial muscles nets a very simple solution

Geoffrey M. Spinks
University of Wollongong, gspinks@uow.edu.au

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Abstract
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Fishing for artificial muscles nets a very simple solution

AUTHOR

Geoff Spinks
Leader, Manufacturing Innovation Global Challenges Program at University of Wollongong

The humble fishing line. Flickr/derfian

Sometimes in research the answer is right under your nose.

In our case, we spent nearly two decades developing exotic materials as artificial muscles – to now show in a paper published in Science today that the best performing systems can be made from ordinary, everyday fishing line.

Or sewing thread, if you prefer.

Not only are these materials cheap and readily available, they can be converted into high performance artificial muscles easily – just start twisting!

Polymer coil muscles.

We attached one end of the fishing line to an electric drill and hung a weight off the other to apply some tension. We stopped the weight from rotating as we used the drill to twist the fibre.

At first the twisted fibre shortened but maintained a uniform shape. But at a critical point, a loop or coil formed in the fibre and further twisting produced more coils. Before too long the whole fibre was a spring-like coil.

To set this shape we applied a little bit of heat using a hairdryer and let it cool. If we then hung a weight off the polymer coil and applied some more heat, the coil contracted.

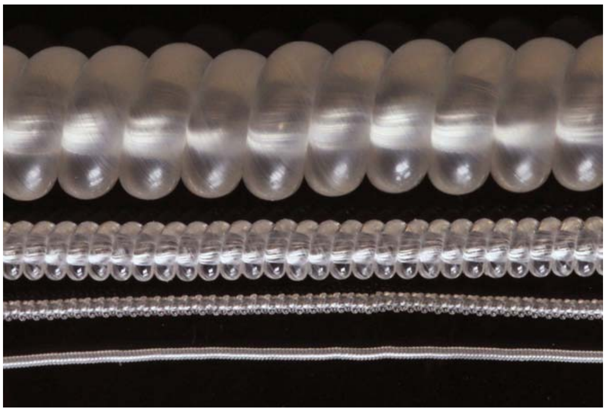
For more convenience and better temperature control, we wrapped a conductive material around the fibre and applied heat by passing a current.

Muscle-like performance

The amount of contraction and the force generated can be impressive and in most respects compare favourably with our own muscle.

In one example, we used a 16cm length of coiled Nylon-6 fishing line 0.86mm in diameter to lift a 500g weight about 20mm in 2 seconds.

A similar sized natural muscle would also contract about 20mm in slightly shorter time (~1 second) but lifting only 150g.



Comparing ‘muscles’ made by coiling (from top to bottom) 2.45mm, 0.86mm, 0.28mm and 0.15mm Nylon-6 monofilament fibres. Science/AAAS
Click to enlarge

By optimising our coil structures we can easily achieve 50% or more contraction in length and increase contraction speed to 7.5Hz.

Our polymer coil muscles also last a long time – we gave up testing after 1.2 million cycles where the muscle reversibly contracted 10% in length in 1 second per cycle.

Power textiles

One application that we are pursuing with the polymer coil muscles is in our massage sleeve designed to reduce the effects of lymphoedema, a condition that affects around a third of women diagnosed with invasive breast cancer.

Lymph sleeve animation.

Breast cancer-related lymphoedema (BCRL) is the swelling of the arm caused by the build-up of lymphatic fluids and leads to heaviness, swelling and discomfort for patients.

Massage is an effective treatment and the “lymph sleeve” is meant to be worn by BCRL patients during their daily lives. The lightweight actuating fabric will detect swelling and then respond by “squeezing” the arm to enhance lymph flow.

A twisty tale

The discovery of the polymer coil muscles is the outcome of more than five years of collaborative effort from researchers around the world.

The work started with the discovery by University of Wollongong PhD student (and now ARC Discovery Early Career Researcher Award Fellow) Javad Foroughi of a “torsional” type of actuation movement in electrochemically charged carbon nanotube yarns.

Subsequently, our collaborators at the University of Texas at Dallas (UTD) – who make the yarns – also found that similar torsional actuation response could be produced by filling the yarn pore volume with candle wax to make hybrid yarn muscles.

Heating the wax generated the torsional or twisting movement. It was also observed that overtwisting these yarns generated coils and that these coils contracted by up to 10% in length when the wax was heated.

Old theories still help

At that stage we did not know why the coiling amplified the length-wise tensile actuation.

But our most recent collaboration has revealed more on the coupling between the torsion and the coil contraction by applying the mechanics theory that had been developed for more than a century and applied to helically-coiled springs.

Finally, we also discovered that similar effects occur in highly oriented polymer fibres when they are twisted into coils.

The pathway to discovery was by no means obvious. If we had not been investigating exotic materials – such as carbon nanotubes – then we would not have observed the very large torsional actuation in these materials.

That work led us to investigate further the effect of twist and the discovery of overtwist-induced coiling. From there we were able to produce high performing contractile muscles from both overtwisted carbon nanotube yarns, and more recently, ordinary polymer fibres like fishing line.

What’s next?

While it’s impossible to predict what the next breakthrough will be, we do know the areas where improvements are needed.

Efficiency is well below that of muscle. Approximately 20% of the input chemical energy for muscle is converted to mechanical work.

Our muscles convert about 2% of electrical heat energy to muscle work, similar to shape memory alloys.

We would also like to use stimuli other than heat and our preliminary work has shown that movement is possible with light or chemical agents.