A leaf out of nature’s book

Wageningen biologists are working with Delft technologists on a drone with flapping wings that is as nimble as an insect. Seahorses, tree frogs and octopuses have also provided inspiration for useful applications – for surgery among other things. ‘Thanks to millions of years of selection, natural designs are full of ingenious techniques.’

TEXT NIENKE BEINTEMA **PHOTO** TU DELFT

The honey bee – which weighs only 100 milligrams and is loaded with nectar – lands with utter precision on a flower that is dancing in the wind. An extraordinary display of flying skills, which engineers would love to be able to emulate.

The honeybee, already heavily loaded with nectar, approaches the flower on a light side wind. It quickly corrects its course for a puff of wind, slows down, hovers briefly and lands precisely on the flower head as it sways in the breeze. An incredible demonstration of flying skills, certainly for a 'design' weighing 100 milligrams. Many engineers would love to manage something like that in their laboratories. They cannot do so as yet, but they are well on the way. Scientists at Wageningen University & Research and the Technical University of Delft are jointly developing a drone that flies like an insect: it is manoeuvreable, light and has flapping wings. They have already made a series of prototypes of their DelFly. The latest version was the subject of an article in the top journal *Science* last September.

'The robot helps us understand nature better'

'We are not aiming to imitate nature precisely,' says Johan van Leeuwen, professor of Experimental Zoology in Wageningen. 'And that would not be possible: those natural designs are so full of ingenuity, the product of millions of years of natural selection, that you can't copy them. What we want is to understand the mechanisms at work in nature and to get inspiration from them for the design of useful applications. We call that bio-inspired design.'

BROWSING

He cites a few classic success stories by way of example: velcro, which is based on the hooks on the burrs of the great burdock plant. Paint that is waterproof and dirt-repellant thanks to nanotechnology, a trick played by the lotus leaf. Buildings designed and positioned just like termite hills so as to catch the wind and ensure air circulation. 'This approach to design has really taken off in recent years,' says Van Leeuwen. 'It used to be very difficult to get funding for this. Now that there are more and more examples of successes, everyone thinks it's logical: browsing through the natural world in search of handy new ideas.'

The research is highly interdisciplinary. 'You use knowledge from zoology, mechanical and fluid dynamics and aerodynamics. We've got an engineer on our team with a background in Aerospace Engineering.'

That engineer is Florian Muijres. He works in Wageningen, where he is studying insects' flight strategies. His equipment for that includes a 3D camera setup which takes 13,500 frames per second. He has been working on the DelFly since 2014. 'That came out of a Delft student competition 13 years ago,' says Muijres. 'Students of Aerospace Engineering were given an assignment to design a flying robot based on nature, supervised by biologists from Wageningen and engineers from Delft. This resulted in the first DelFly, with propulsion based on that of flying insects.'

MANOEUVRABLE

'In the new prototype, the DelFly Nimble, it is not just the propulsion that is bio-inspired,' says Muijres, 'but also the manoeuvrability. Insects, birds and bats are very good at that. Just watch a hummingbird in action. It can fly both fast and efficiently, and hover and manoeuvre very deftly. You can only achieve that combination with wings that flap. The way they manipulate the air makes optimal use of the air currents.'

For a long time nobody knew how insects actually do that. A lot more is known about that now, partly thanks to modern camera techniques and computer models. Muijres: 'Once the biological knowledge was there, Delft colleagues could build it into a robot.'

The engineers also wanted to know exactly how an insect can find its way around. 'The nice thing was that we could start researching that using the robot,' says Muijres. 'If we programme it with what we think happens in an insect's brain, we can then test it to see if we're right. And you can keep on adjusting it a bit at a time and see what happens then.'

At that point you are moving from engineering territory into that of science, Muijres points out: 'The biology helps the engineers to design a robot, and then that robot helps the biologists get a better understanding of nature. That interaction is incredibly interesting. That's what makes this project so unusual and so valuable. And it's what makes a scientific journal like *Science* take an interest in a drone.'

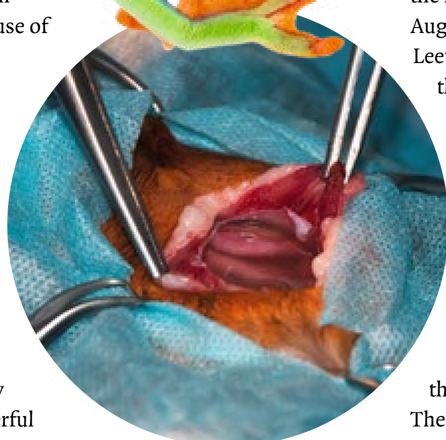
The tree frog's flexible foot soles can stick so closely to a surface that molecular attraction probably takes place. That provides the inspiration for soft tweezers with which you can take hold of fragile tissue.

'Just look how elegantly a bee lands on a flower,' says Guido de Croon, scientific head of the Delft Micro Air Vehicle Lab. 'The lower it gets, the slower it must fly. We want to build that self-steering capacity into the robot.' Biologists came up with the idea that the bee responds to an image of the flower, which gets bigger and bigger. The bee seeks to keep the rate at which the image grows bigger constant, explains De Croon. The closer it gets to the flower, the slower it must fly to keep that expansion steady. 'But if you programme that into the drone, it doesn't work,' he says. 'At a particular distance from the target, the drone starts shaking. The reason turns out to be that there is always a bit of delay in the system.'

The biologists took another good look at the way bees land. It turned out that during landing they always make a little hop at a certain distance. 'Our current hypothesis is that the bee notices that it is starting to shake, and adapts its flying behaviour instantly,' says De Croon. 'We can make use of that moment to unfold the legs.'

SMALL FINS

Van Leeuwen sees the same sort of interaction between biologists and engineers in other bio-inspired projects in Wageningen. Research on swimming seahorses has provided inspiration for the development of an underwater robot. The seahorse has an unusual method of propulsion, pushing water away mainly with its small fins. It only uses its powerful tail to hold onto aquatic plants. In cross section, the tail is not round like those of other animals, but square. The tail consists of hard, angular discs ingeniously hooked up together: a system that makes it both sturdy and flexible. Perfect for a robot that moves over the seabed and wants to hold onto plants. 'We are working on this with the group led by Frans van der Helm – professor of Biomechatronics and Biorobotics at TU Delft,' says Van Leeuwen.



Another Wageningen-Delft project focuses on the tree frog's legs. The tree frog has complicated structures on its fingerpads and toepads, as Wageningen PhD candidate Julian Langowski discovered. The skin cells form little hexagonal pillars there with a network of tiny fluid canals between them. The top of each cell is in turn covered in hexagonal 'nanopillars' separated by fluid canals.

This structure makes the tree frog's foot sole very flexible and the skin can stick so closely to the surface under it that molecular attraction probably takes place. The tiny pillars and fluid canals also facilitate capillary action, meaning the kind of force that will keep two panes of glass together if there is a thin layer of water between them. If you combine those principles, wrote the researchers in *Frontiers of Zoology* at the end of August, you can develop new adhesive materials. Van Leeuwen: 'Together with Delft we are trying to apply this principle in soft tweezers with which you can get a grip on objects with wet surfaces, such as vulnerable tissue during an operation'.

The medical world stands to benefit from bio-inspired design in several areas. 'We have already patented the system based on the octopus tentacles,' says Paul Breedveld, professor of Biomechanical Engineering in Delft. 'That has grown into a major line of research in Delft, leading to the finest steerable surgical instruments in the world, all inspired by Johan's octopus tentacle. The spinoff company DEAM is now producing them. We expect them to be launched on the market at the end of 2018.'

STEERABLE NEEDLE

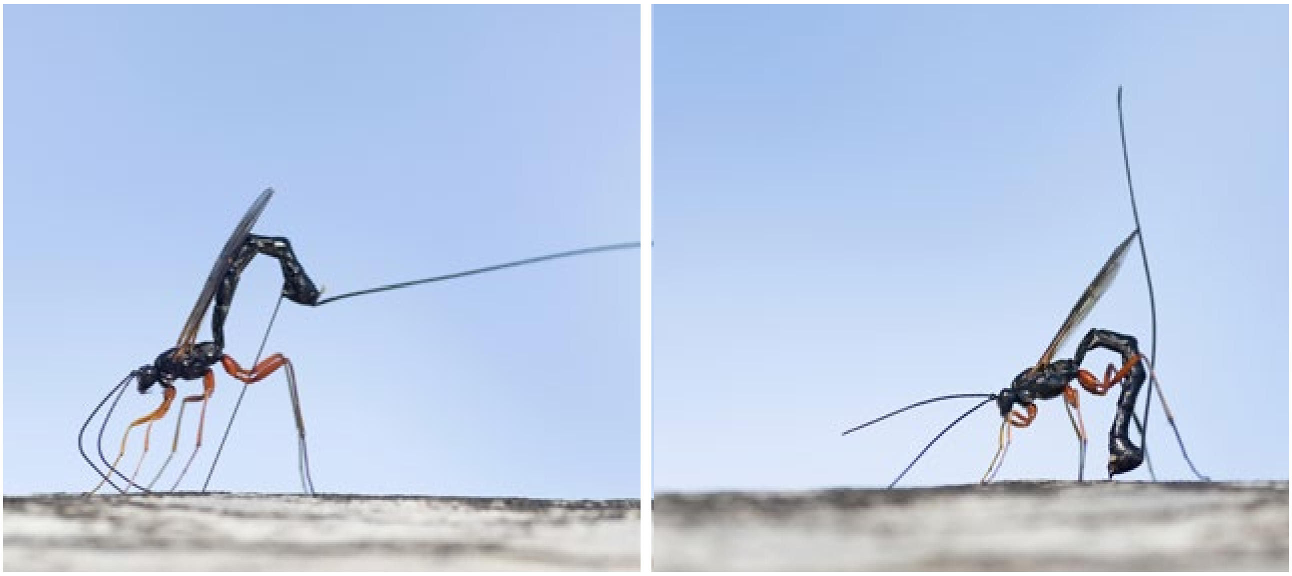
Something else doctors dream of is a flexible, steerable needle, explains Johan van Leeuwen: 'A needle that can go round a corner or even take an S bend.' This would make it possible to avoid vulnerable nerves or blood vessels when injecting a drug very locally, or when >

> ‘Fine, steerable surgical instruments are being based on octopus tentacles’

aiming to remove fluid or tissue. Van Leeuwen: ‘The ichneumon wasp has a solution to that.’ Ichneumon wasps lay their eggs in plants or the larvae of other insects. Some do both: using their ovipositor they drill a hole in a plant, or even in a tree, at a place where a larva is hidden. They lay an egg in the unfortunate larva, which then serves as food for the ichneumon wasp larva. ‘The ichneumon wasp can change the direction of the drilling as it goes along, explains Van Leeuwen. ‘That is possible because the ovipositor consists of three elements which hook up together lengthways.’ One of the elements forms something like rails, which the other reaches around with an extended groove. If you push one of the elements a little bit ahead of the other, the shape of the head of the ovipositor changes, causing it to go in a different direction if the head moves forward. This changes the bend in the tube. ‘Our PhD researcher Uroš Cerkvenik has filmed this at length in transparent gels,’ says Van Leeuwen. ‘They are beautiful pictures, which show that the female can drill underneath herself

ILLUSTRATION TU DELFT / TIM KRUGER PHOTO ALAMY

Wageningen research on octopus tentacles led to the development in Delft of fine, steerable surgical instruments.



PHOTOS BUITEN-BEELD

The ichneumon wasp can drill beneath itself in all directions, without changing its own position. The system inspired engineers to develop a flexible, steerable needle.

in all directions without changing her own position. Imagine what you could do with that, in relation to tumours or in brain surgery, for instance.'

Paul Breedveld adds: 'The wasp uses a system with ridges which can't shoot out of the grooves because of their shape. We have a different solution, which is technically much easier to make: we just put a couple of little rings around our needle that keep the loose rods together.' For nature it is probably easier to make grooves than tubes, but for humans it is the other way round. 'The strength of bio-inspired design doesn't lie in imitating nature precisely, but in using nature as a source of inspiration and not being afraid to combine natural principles with smart solutions thought up by humans.'

DRILLING AROUND TUMOURS

It will take some time before doctors will be working with a needle that resembles an ovipositor. 'We've got to be realistic about that,' says Van Leeuwen. 'In the medical world there are strict safety criteria, so the testing phase is lengthy'. The same spinoff that makes instruments based on octopus tentacles is developing this concept further now too. 'After that, it's the turn of larger companies. It will undoubtedly take quite a few years, but I am sure that needles inspired by ichneumon wasps are on the way.'

The creators of the DelFly are similarly confident: they are sure there will be flapping drones flying around one day. 'For carrying out inspections in places that are hazardous or inaccessible, for example,' responds Florian Muijres, 'such as in a factory hall, or to inspect crops in greenhouses. Standard drones are not as suitable for those tasks: they are much heavier and noisier, and they are more dangerous if they fly into people.' ■

'Needles inspired by ichneumon wasps are on the way'

www.wur.eu/bio-inspired-design