Sue Nelson
Hello, I'm Sue Nelson and welcome to the Create the Future podcast, brought to you by the Queen Elizabeth Prize for Engineering. Celebrating engineering visionaries and inspiring creative minds.
[Music]
A few years ago, I visited Delft University of Technology, TU Delft in the Netherlands. And while I was there, I saw a flying robotic insect, weighing less than 30 grams, with four flapping wings, about 30 centimetres across in total, and it was called a DelFly. The DelFly could do some pretty nifty aerial acrobatics, and was being demonstrated in the university's Faculty of Aerospace Engineering. And today's podcast guest is a Professor of Micro Air Vehicles within that faculty at the Micro Air Vehicle lab, or MAVLab. Guido de Croon works on drones, and robotic insects, his academic background focused on artificial intelligence, but now he combines AI, engineering and biology within his work on small autonomous robots. As a child, he enjoyed playing football and reading, but there was one nature project he undertook, that gave a hint of what was to come.

Guido de Croon
I think I was eight years old or something and I was really intrigued by these ants in our garden, how they were walking about, and I was like, “Okay, I'm going to study them”, you know, so I took this like a notebook, and a pen and I started to make observations. And I noticed that they were, of course, you know, carrying food up and down. So, “okay, let's start with honey, they must love to that”. So I actually put the pool of honey somewhere in the basement, and I saw the ants walking into this honey, and they were just drowning. I felt so bad for them. And that was the end of my career as a biologist actually.

Sue Nelson
I don't think we've started a podcast before with mass destruction, but there we go. What sort of observations were you making? How many drowned?

Guido de Croon
No, no, I guess I thought they would take it to somewhere else. It was not very smart thinking, of course, that they would take it with them. So, I wanted I guess, to observe, how do we organise and take food with them. But honey was, of course a very unhappy choice, especially for the ants, but also for myself, I guess. So then I stopped that kind of line of research. And then when I was a bit older, my brother started to programme. So, we had this like, Commodore 64, like really old computer now. But we had that at home, you could play games on it. But you could also programme a bit on it. So, I started to programme, play some games. And these games, of course, you had opponents, and they were typically computer opponents. So not like the online games that you have now where you play against other people. And yeah, often, of course, these computer opponents were not super smart yet. And that was the kind of thing that really triggered me to start thinking about artificial intelligence actually. What I looked at, specifically during my PhD was visual perception. Because vision is very important in nature, mainly because you can see things pretty far away already. And you can look at things in quite a high detail. And we as humans, we have the impression that the world around us is coloured and highly detailed. And actually, this is not the way we see it, if you really look at the eye, we only see at a very high resolution in a central area of our view, which is called the fovea. And we actually move our eyes around a lot. And by moving our eyes around, we can sample the environment and we look at things and we think we see them, and we see them in high detail. But the images we make are actually pretty bad, you know, especially towards the periphery. But we don't experience the world like that. And that is because for one we look around a lot with our eyes. So roughly three times per second, you notice this, if you ever get hurt in your eye muscles, because they you then you feel like ouch, ouch, ouch, all day long. So we do look around a lot. And we see what we expect to see in a sense. And then we move our eyes to sample and to confirm that we actually see what we think we will see. So, I don't know if this is very vague. But that's what I worked on during my PhD.

Sue Nelson
And makes sense. As you were talking actually, I was sort of looking ahead and then looking at my periphery vision and then realised “yeah, it is slightly blurred. I hadn't really noticed that before”. When did you go from human beings to other types of creatures?

Guido de Croon
During my PhD I was working on efficient vison algorithms and how they could, for example, find objects in images by moving around a kind of fovea and artificial fovea. I made algorithms that were much more efficient than the algorithms that were using till then, because people were going over a full image. And it's every pixel looking, for example, if you look for a face, is there a face here? No, go to the next pixel. Is there a face here? If you think about a human, if you look into the sky, you think, “Oh, yeah, that's the sky” and there's probably not going to be a face there. So, you look down. And this is the kind of thing that I learned my computer vision algorithms to do. And it led to very efficient vision. And then I started to really think about robots as small robots. And during a research stay that I did during my PhD in Switzerland, I got in touch with drones. And I was fascinated by them, because they cannot carry a lot of sensors, they can carry only very little processing. So, my conclusion was here, if you go to really small flying robots, then they need to be super-efficient in their sensors, but also their brain. So you really need this kind of efficient AI and natural artificial intelligence that I like to study and that is when I decided to go to Delft to work on such small flying robots.

Sue Nelson
Now I've been to the University of Delft, and I've seen your rather amazing Faculty of Aerospace Engineering and it felt like I was entering a playground. There were people with drones, there was sort of parts of aircraft. It was huge describe it for me what's actually inside that enormous space?

Guido de Croon
The bigger context is that there's many groups doing all kinds of experiments, different engineers play with what they like most. So, some people are playing with lasers.

Sue Nelson
Feels like play.

Guido de Croon
Yes, yeah, I mean, I hope that they have the same kind of feeling I have, when I do research with drones, it really feels like, also, it's like playing, it is very nice. So other people work with like materials, new kinds of materials that they are testing with big machines trying to rip them apart, or, you know, seeing when fatigue starts to come into play. We also have student teams that make actual planes, so and also new types of planes that should be much greener than current aeroplanes, they then make skills versions of course. So there's a lot happening in that whole, from very different departments, from materials everywhere, they look at the new kinds of materials to new kinds of plane designs. And what we have there is what we call our Cyber Zoo, which is like a big black cube. On the inside, you have some artificial grass to make it look a bit natural to our robots, walking robots and flying robots in there. And our dream is a bit that we will have robots in there in the end that are functioning day and night. Also, when we're not there, then it becomes a little bit like a butterfly garden or something, if you step in. We have a motion tracking system in that black cube and that's why the cube is black as well, to block out daylight, which sometimes has a lot of infrared in it. And this motion tracking system is dependent on infrared. So, we don't want external sources or too much. We use a system mostly to track what our drones do for scientific articles. But we work on techniques that allow drones to really fly completely by themselves. So, they're definitely able also to fly outside this cube. But we do want to track them during the experiments.

Sue Nelson
I must say a little bit about the DelFly the drone that I saw when I was there. And we heard a little bit of it's buzzing a movement at the beginning of the podcast that I'd recorded on that visit. I was astounded when I saw it because it looks like an insect, a large insect. It flaps its wings, which you sort of don't, I didn't expect anyway. But what got me the most, the sort of wow factor was how nimble and nifty it was. And the speed at which it could change direction. I mean, you made it look easy. But I'm pretty sure it wasn't to get to something like that?

Guido de Croon
Oh indeed, the DelFly project in which we developed these flapping drones started already in 2005, led by some colleagues of mine and the student team to make the first version. So, that was before I arrived as well. Yeah, it hasn't been a long development in which we always wanted a flapping wing drone that would be able to fly, but also observe the environment, so that you could do an observation mission, but later so that it could look itself at the environment and fly by itself. And what we noticed at some point is that the kind of flapping wing drones were making initially got into trouble when there was even the lightest drafts of for example, on air conditioning. This was because it was flapping, but it was steering with a tail a bit like a plane does. Yeah, surfaces, say control surfaces. So, in 2018 one of our postdocs succeeded in making a model that actually steers with the wings, as insects do. So, if an insect wants to turn to the right, then it can flap harder on the left for example, you know what I mean?

Sue Nelson
A bit like rowing?

Guido de Croon
Yeah, exactly. Yeah, exactly like rowing. Actually, these small flapping wing drones, especially insects, they fly at a smaller scale, and the air becomes more viscous. So for them it’s a little bit more like swimming than flying almost, in the sense.

Sue Nelson
So what sort of size is at the at the moment then?

Guido de Croon
Yeah, so the DelFly which is actually called the DelFly Nimble, the one you saw. So, it's very nice that you characterised it as nimble. It has a 33 centimetre wingspan, it weighs 29 grams, you would see it as quite a big prehistoric insect, if you see it, but yeah, it looks very natural, like you say, like a big butterfly. Yeah, this new one, because it steers with the wings, it's very agile.

Sue Nelson
So you work with biologists, as well as engineers and incorporating AI so that you have this whole multi-disciplinary package effectively in one drone?

Guido de Croon
Yeah, definitely. So we work with biologists, I think it's very nice because I get all kinds of inspiration when reading biological articles or articles about biology, but also talking to the biologists. And sometimes they come with new findings that we then try out. But typically, what we find is that when we try out the things that they think happened in the brains of insects, then we actually find also novel things that may not have looked like a problem to the biologist, because a biologist when he or she looks at the, for example, a landing honeybee. The

honeybee knows how to land, you know. So, they look at what it does and get her data and think like, “Oh, it's following this strategy”, for example. But then if we try that out on a drone, we run into all kinds of problems that the honeybee is actually solving, but which are not visible to the biologists necessarily.

Sue Nelson
What are the possible applications of the DelFly or, or similar drones?

Guido de Croon
These drones, they're very lightweight, so they're very safe. That's a very important feature. They're also beautiful by the way. So this leads to a number of new applications. So one application is that after COVID passes, hopefully, we will have shows again. You already have swarms of drones being used in shows for lights, or whatever. But these flapping wings can give extra nice visual effects. So we think for shows they will be very popular. But we also think about more serious applications in the sense, like applying them in greenhouses. In the Netherlands, we have huge greenhouses, in which we grow all kinds of crop. And there are really many tasks for which drones could be used inside these greenhouses. In these greenhouses, you have people working there, walking there. So, they need to be safe at any point, I would say, and it would be best if they don't need to adapt to the drones. Because I know there are companies actually working on drones in greenhouses. But then the drones are typically a kilo or heavier, they are pretty big. They have fast turning rotors, these drones, you know, do pose a risk in terms of safety. And it means that you would have to lock off a part of the greenhouse when it's flying there, things like that. And this is to me is simply unacceptable. And so that's why we believe that this kind of new, very lightweight, safe, soft, the wing, if it touches you, it really doesn't do any damage. It's like you being hit by an insect.

Sue Nelson
What would you actually do in the greenhouse?

Guido de Croon
It would look at the crop. That's one of the first things I think it could do, so also there, I see all paths towards the future. But the first thing I think drones will do is look at the crop in order to timely detect diseases or pests. This is a huge problem to a greenhouse, typically they detect it quite late. And then they need to throw away a large part of the plant. You can prevent if you detect them earlier. But if you've perhaps never been to a greenhouse like that. But you have really big rows of plants where often you cannot walk in between them. So you have to look at the distance. What they actually do is they put up sticky papers to see if there's a flying form of the pest, but you would like to detect them much earlier in the crop. So detection pests, diseases, looking at, you know, how well the plants are growing. Because you can evaluate that with normal light cameras, but you can also look with different spectra at plants and see whether they're stressed whether they need more water or, but later, they can actually start acting. So they can, for example, not only detect that there is a pest somewhere, but then also drop larvae of natural enemies of these pests, they could actually help in pollination at some point, I think, but then we're talking about a bit longer in the future.

Sue Nelson
So it's really is using what you've done throughout your career, which is looking at AI and the vision aspect of it. But really this miniaturisation so that the technology can fit on a very lightweight, robotic drone?

Guido de Croon
Exactly, yeah. And that is fairly, very challenging. And if you look at the state of the art in artificial intelligence for robots, for example, self-driving cars, what you see is that most engineers try to represent the complexity of the task in the head of the robot. And so that's very nice, of course, but you know, it requires very high

resolution, heavy power hungry sensors. It requires big computers that make large maps maintain them, and keep them in memory. And if you look at insects, they actually try to solve tasks in a simple a way as possible. So by not representing this complexity in their heads, but by following your simple behaviours to solve complex tasks, and that is what we try to do with our robots as well.

Sue Nelson
So a bit like how you were interested in ants as a child, the sort of next stage is getting these robotic insects working together in swarms?

Guido de Croon
Exactly, yeah. So, this concept works at all levels. So, for example, one thing we also work on is odour source localization, or gas source localization. So, suppose that you have a gas leak in a building, it would be nice if you could send robots in, that can sense the gas, and then find a leak for you, and then at least can indicate you immediately the leak is here. Now, this is a thing that engineers have worked on. And what they then try to do is they make, again, a map, and they model the diffusion of this gas in the head of the robot. And this becomes, again, you know, a very computationally complex problem. Well, if you look at nature, this is something that animals do all day long. For example, I now have an orange on my table and, you know, fruit flies, I don't know if they'll come to the orange itself, but they definitely come to my bananas. They find this fruit by following odours for a large extent. So they don't need to make any complex map or be calculating what the airflow will do in their heads, they just, you know, use simple behaviours that will solve this task. And in swarms, it's the same and then the concept is that the individual insects or robots are very limited. But together, they can take all these more complex tasks and what you were referring to with the anta and what I guess I tried to study with the honey is that if ants carry food back to the nest, they leave a kind of pheromone that other ants can perceive and smell and so ants that are outbound, that are going to find food, they actually follow a path with more pheromone with a higher probability. In this way, they find the shortest path to the food. And the reason is that this pheromone that gets left on the ground, let's say, but it evaporates over time. If you take a very long path home, then much of your pheromone has already evaporated by the time you get home. But if you take a short path, then the pheromone is still quite present on the path.

Sue Nelson
And so, what for you then would be your ultimate aim with the research that you're doing now?

Guido de Croon
Yeah, that's, that's a good question. So, I would love to get closer to the capabilities of such insects. Because sometimes people say like, "yeah, the idea of swarming, and this kind of intelligence is that the robots should be stupid". No, I mean, you know, insects are actually quite intelligent. But the type of intelligence is, I think, amazing, because if you think of a fruit fly, it weighs close to nothing. It's super tiny. It has around 100,000 neurons, that's very tiny. We have like 68 billion neurons in our in our minds, but it's able to fly, avoid obstacles, find food, shelter, socially interact with other fruit flies, it's able to learn, etc. So, it has a huge repertoire of behaviours, which it does very successfully. And that's much more than our drones can do now. And as robotics researchers, we typically take one thing like landing, you know, and work on it for a long time. And even then we don't land as well as fruit flies do. My goal is to better understand this kind of intelligence, and then harness it for us to be able to make tiny, lightweight, safe robots, as capable as these little insects and perhaps go beyond as well.

Sue Nelson

Could you take these drones and say, instead of putting big heavy rovers on the surface of Mars, for instance, in the future, might people rethink and send lots of miniature flying drones, each with their own particular sensor on instead?

Guido de Croon
Yes, I think that's a great thought. And the European Space Agency is actually working on that. I spent some time in Delft, and then I went to the European Space Agency, because actually, the problems in space are a bit similar to the problems on drones, because you want to take as little weight as possible into space. And the kind of processes they have typically need to be space hardened, which means that they're much less fast than what we're used to on Earth. So basically, they also have a desire for lightweight, low computational solutions. And where today, they sent big rovers that are very well engineered, so that they, you know, and that have many tools on board, like a driving laboratory. In the future we may go to missions where you have many tiny drones, for example, and we had at the first unmanned helicopter flying on Mars this year. And there's also always this risk, right? So, for example, I once talked to one of the engineers of one of the rovers and he said, “yeah, it's always a tension between the scientist and the engineer, because the scientist is like, ‘oh, I want to look over that cliff’ and the engineer is like ‘yeah, there's no way I'm going to drive it clear near to the cliff’”, right? Because if it falls in there, you cannot just go and repair it. But with a swarm, you know, you may be able to take a little bit more risk. Because if you have, indeed, a swarm of many of these tiny things, and a few of them get lost, that is acceptable. That is actually also one of the changes in mentality that we need in order to make swarm robotics successful, is that people should realise that we will be able to do complex tasks with the tiny drones, but they may not always do the optimal thing. And some of them may get stuck a little bit like the fly that you see flying into your window, you can say “stupid animal”, but yeah, this is the kind of thing we will see with this kind of insect AI. And that should become acceptable as well.

Sue Nelson
Now, before we go, we often like asking for advice that you would give to people who have got that inkling that they might want to become an engineer, of whatever form, what would your advice be?

Guido de Croon
Even if you may not think you're a typical engineer, it doesn't mean that you cannot, you know, advance things in engineering. Personally, I studied AI, which is kind of like a computer science study, so I'm just saying that, also people that are perhaps different from the engineering prototype, you know, you can definitely contribute by taking a different angle on engineering problems. I think it can be very refreshing and give a lot of progress. And it also makes engineers more diverse. So that's, then again, it's a bit like a self-reinforcing effect, right, because we have a certain image of an engineer and then you know, people that don't think they fit that image, they don't choose to do engineering, but then you still get that same group of people doing it. So, nothing against that group, of course, but I'm just thinking that if you don't feel that you fit this exact picture of what an engineer is, I would definitely still stimulate you to, you know, try out engineering things and see if there's anything you like, there, because it can actually be very valuable.

Sue Nelson
And great fun, from the sound of it?

Guido de Croon
So, yeah, keep close to what you love, I would say.

Sue Nelson
Professor Guido de Croon, thank you very much for joining me on the Create the Future podcast.

Guido de Croon
Thank you very much for inviting me.

Sue Nelson
Find out more about the Queen Elizabeth Prize for Engineering by following @qeprize on Twitter and Instagram, or visit qeprize.org. Thanks for listening, do join me again next time.