

Disruptive: Bioinspired Robotics (pt. 2)

Host Terrence McNally interviews Robert Wood. Podcast published July 27, 2015.

McNally:

Hello, welcome to DISRUPTIVE the podcast from Harvard's Wyss Institute of Biologically Inspired Engineering. I'm your host, Terrence McNally.

The mission of the Wyss Institute is to: Transform healthcare, industry, and the environment by emulating the way nature builds.

Our bodies — and all living systems — accomplish tasks far more sophisticated and dynamic than anything yet designed by humans. By emulating nature's principles for self-organizing and self-regulating, Wyss researchers develop innovative engineering solutions for healthcare, energy, architecture, robotics, and manufacturing.

They focus on technology development and its translation into products and therapies that will have an impact on the world in which we live. At the Wyss, folks are not interested in making incremental improvements to existing materials and devices, but in shifting paradigms. In this episode of DISRUPTIVE, we will explore: BIOINSPIRED ROBOTICS.

Many of the most advanced robots in use today are still far less sophisticated than ants that "self-organize" to build an ant hill, or termites that work together to build impressive, massive mounds in Africa.

From insects in your backyard, to creatures in the sea, to what you see in the mirror, engineers and scientists at Wyss are drawing inspiration to design a whole new class of smart robotic devices.

We're going to explore this exciting territory in a three-part episode of DISRUPTIVE, featuring three members of the Wyss faculty, CONOR WALSH, ROBERT WOOD, and RADHIKA NAGPAL.

Wood's Bio

Today's guest, ROBERT WOOD is the Charles River Professor of Engineering and Applied Sciences in the Harvard John A. Paulson School of Engineering and Applied Sciences, founder of the Harvard Microrobotics Lab, a founding core faculty member of the Wyss Institute, and co-leader of its Bioinspired Robotics platform. Wood completed his M.S. and Ph.D. degrees in Electrical Engineering and Computer Sciences at UC Berkeley.

In 2010, Wood received the Presidential Early Career Award for Scientists and Engineers from President Obama for his work in micro-robotics and in 2012 was selected for the Alan T. Waterman award, the National Science Foundation's most prestigious early career award.

Welcome, Robert Wood to DISRUPTIVE...I mentioned a few biographical highlights, but before we jump into your work, in your own words, can you tell us a bit about your path?

[02:20]

Wood's Personal Path

Wood:

I guess my interest in robotics started as a graduate student. I was trained classically in electrical engineering, but my interests branched out beyond a single disciplinary track and so robotics was a natural fit. I'm also a tinkerer. I've been building ever since Legos and model airplanes and all that. All of my model airplanes ironically have ended up in the top of a tree.

So with that in mind, and just serendipitously when I was at Berkeley looking for projects that caught my eye, one was in its infancy, which was this project called the Micro Mechanical Flying Insect Project that my would-be future mentor Ron Fearing was just starting at the time. It turns out to be the predecessor of a lot of the things we do, in particular in the robo-bees project.

That was just starting and it caught my eye as really opening up a huge number of challenges that would be taken for granted for other types of engineering and robotics projects. Like for example, if you're going to make a little flying robot then there's nothing off the shelf which is going to give you the types of things that you need, the components that you need for these devices. How do you make them? How do you power them? How do you control them? What sensors? What computation? What power? All of these were open questions that had no solutions. And so that struck me as a very rich bath of problems that we could dive into.

And to get a little bit more specific, one of the things that I wanted to do is figure out how to control air flight. My adviser, Ron, more or less said they don't exist yet, so you've got to go build them first. So that sort of had this natural path to it that led to a lot of our work in how do you build complex devices at these small scales.

McNally:

One thing I hear is - you're a child with your dad...remote control airplanes, and now here you are in your career - smaller, tiny and so on but still things that fly.

Wood:

Actually I recall wanting to be an aerospace engineer but my dad felt that was not lucrative enough, so I had the choice of electrical or mechanical. But yeah, it all sort of came around, and it's not necessarily flight *per se*, it's just these complex multi-disciplinary systems that you have to develop solutions that span some of these disciplines.

[04:47]

Why Study Bees?

McNally:

One of the things that I keep finding when I'm talking with folks at Wyss is of course the biological inspiration, the whole platform that you're in and so on. So here's a simple but big question - Why do you study bees?

Wood:

Bees specifically are just a metaphor. The devices that we make are more fly-like than bee-like, but the bees are supposed to be a metaphor for the collective behavior of these insects. So one of the big aspects of this project is that we're collaborating with Radhika Nagpal. She is leading this question of how these things would work together such that the whole is bigger than the sum of the parts, just like a bee colony, for example. But in reality what we make are more like flies.

Okay, but that aside, why would we look to nature for inspiration? Well, it's, for these types of systems where there's so many unknowns. If you just say build me something that's a tenth of a gram that can fly around the room and do something interesting, where do I start? Well I can start with something that's a tenth of a gram that can fly around the room. And so that was one sort of anecdotal aspect.

The other one was, at the inception of the Micro Mechanical Flying Insect Project, my adviser was working very closely with a group of biologists who were just on the cusp of understanding how insects fly. I know it sounds odd that it would have been in the late 90's and we haven't figured this out yet, but they did this remarkable work in really understanding the aerodynamic basis for how flies and other insects achieve the agility that they have. That was, I guess, the first and one of the most memorable examples that I have of biologists and engineers working together to mutual benefit, and that stuck with me all along.

[06:25]

The Robo-Bee Project – A Series of Challenges

McNally:

So you've been working on flying insect robots for nearly 15 years, right? And robo-bee is the first insect-sized winged robot to demonstrate controlled flight. Can you tell that story? And by that I mean, what was the problem, what was the inspiration, what were the big challenges, what were the breakthroughs? The narrative of how you got to that flight...

Wood:

With robo-bees, I guess it started in my lab at least shortly after I arrived at Harvard, and a lot of the work that I was doing as a graduate student was figuring out some of the core questions, like how do we develop motors, if you will, the little actuators... these things, given again that nothing is off the shelf. How do we think about how we build devices of this scale that can, for example, flap wings around? So we had a little bit of that in place and I just tried a few crazy ideas and demonstrated that indeed it was very feasible to start to make things which could actually get off the ground. Extremely uncontrolled and unpowered and tethered

and all of this, but that just gave us enough ammunition to put together this larger project, this robo-bees project, and start to attack these problems one by one.

So some of the problems that we had at first started from - how do you build? You know everything that we were doing before that was - it might have produced working prototypes but at great expense and time and very tedious and required a great amount of skill - it was very hand-sort-of-assembled stuff. So how do we overcome all of these challenges to make many repeatable high performance prototypes with future sizes ranging from roughly about the diameter of your hair? So how can we do that? That was one, so we spent a lot of time figuring that out.

Next we moved on to, well if we can do this, then the design space for these types of things is enormous. Even if you go by what we think the insect is doing, there's still so many variables there that we don't know what is functional versus what is phylogenetic. What are the constraints that the insect is being posed?

So we used our processes to try to work through dozens of generations of designs till we got something that could fly, could produce the sort of forces and torques it needs to control its flight.

Then the next challenge is control. How do we think about wrapping a controller around this system? Next challenge after that was sensors. Everything that we were doing previously with control was with off-board sensing so now how do we migrate that onboard? And so the list goes on.

What we're currently working on is taking what we've learned from control and migrating it on-board. Some of our collaborators are making custom-integrated circuits to do some of this. And then also we're working on power, also with some collaborators both within and outside of the Wyss Institute.

So it's just a series of challenges that we try to sort of knock out one by one. And if you ask us, for example, what's the most challenging thing, well it's currently what we're working on.

McNally:

Sure it is.

Wood:

We have solutions for the other stuff.

McNally:

You're doing what 15 years ago was a dream, right?

Wood:

...yeah...

[09:29]

What's Next

McNally:

What's next?

Wood:

Next for us in the robo-bees project, is to continue adding in onboard sensing; to continue adding in onboard control, meaning custom integrated circuits that will do everything that we've been learning using big off-board computers. That also dictates that we need to change our on-board design, it needs more payload, so it's a sort of circular thing.

Really what we want to do is just cut the tether and have everything be fully autonomous. Sounds easy, but it comes back to these challenges with, even seemingly simple things. Why can't you just put a battery on it? Well, yes, if the batteries existed at that scale. Well, do you have to redesign batteries? Well, yes, the chemistry works out fine, it's just a matter of packaging. Some of them - like battery packaging, for example - might seem pretty non-academic and at times pretty frustrating, but these are things that we must overcome.

[10:17]

Pop-Up Assembly

McNally:

I want to talk about potential applications in a second. But if I'm not mistaken, one of the big things was this pop-up assembly. One of the things that you came up with to solve one of these problems along the way may have a lot of other uses and may open some doors. Can you talk about that?

Wood:

Yes, we think that's true. As we were really focusing on how do we build the things, - it's not only biology that we look to for inspiration, we look anywhere we can get it. So the solution that we came up with for how to build things on small scales took inspiration from folding, so assembly-by-folding.

So imagine folding a paper airplane. Now imagine folding a paper airplane that has several hundred or even a thousand little features in it. Quickly that's going to become intractable, so another piece of inspiration that we had is from children's pop-up books - almost like ship-in-a-bottle type things where you pull a little string and you push on something or whatever and out pops this miraculously complex device. And that sort of paradigm really opened up the possibility of making these things more repeatable from one device to the next; parallelized them so you could make 10 or a hundred or whatever at once. That in and of itself was enabling for our research, but we also have several other research lines that have come out of that.

We just recently got a new DARPA-sponsored program to expand some of these capabilities into micro-surgical devices. At least on the surface, to us naively, that seems to make a lot of sense. If you want small scale, you make small scale

articulated actuated sensor-embedded structures, and things like minimally invasive surgery probably makes some sense to try to explore.

McNally:

So in that regard, do they pop-up first, or are you talking about things that you insert into something and then they pop up?

Wood:

It could be either. If you think of pop-up more generically as just deploying stuff, whether it's deploying a final structure that's frozen into place and then used for something or an instance where the deployability is a feature that you want for entering through small lumens, orifices, whatever, and then expanding and doing some function... Either way, it's all based upon the same principles of these folding-based structures.

[12:34]

The Search for Inspiration

McNally:

As you say, you looked to biology, you looked to pop-up books, origami, all sorts of things. How does that happen? How does that kind of looking at all of these different possible sources of inspiration, how does that take place?

Wood:

In reality the strength of the Wyss Institute... is that, how do you solve complex open-ended problems like this? Well, you get good people, that's obvious. You get creative people. You get multi-disciplinary influences all around you, such that maybe a solution from another discipline lends itself to what you're working on. Then really give them both the creative freedom and the infrastructural resources. We have the ability in lab to create almost literally anything, ranging from over nine orders of magnitude in physical scale. So giving them tools to do these types of things and create - and just create, repeat.

Our sort of mantra in the lab is, build and test and build and test. And you expect most of the things that you're going to build will not work, but you learn from them. This sort of mentality, the infrastructure, the personnel that we have in the institute, that's what enables this I believe.

[13:42]

A Robot Who Self-Assembles and Moves

McNally:

One of the things which I know got a fair amount of attention in August of 2014, your research group announced the world's first robot that builds itself and performs a function without human intervention; forms itself from a flat sheet into a four-legged creature that crawls. Self-assembly, locomotion. What's the story behind that one?

Wood:

So this is actually an ongoing project - a really fun collaboration with some of our long-term collaborators at MIT, who work more on the origami side and the algorithm side to study things like what can you make just by using folding? And if you prove that you can make something, then how do you prescribe the sort of fold sequence to achieve that? These sorts of really interesting questions. Then with us thinking about more from the manufacturing side, how can we actually build these devices that will then implement these algorithms?

The robot in this case is not particularly impressive at all. The point is not to build some really cool robot, the point is to embed all of this theory that they've developed for - for lack of a better word - universality. What can you build? How can I build something and then claim that the techniques that I've been using in this particular demonstration can be applied generically across any sort of robot or structure or mechanism? What's really interesting about the robot is that it embeds the core elements that our collaborators said are necessary to show this sort of universality and then it also embeds a method to self-assemble. So those two things are what really got us excited about that.

[15:15]

Origami, Shrinky-Dink - Mixing Old and New

McNally:

I remember when I first heard that story, one of the things that struck me was the wonderful combination of old and new - origami; the Shrinky Dink. It seems like you were taking advantage of all sorts of existing technologies and approaches - and yet at the same time it's cutting edge. Talk to us a little bit about that mix.

Wood:

Again I think it's part of this theme of, we use whatever tools we can. It doesn't have to be something horribly fancy. Like for example, we were thinking about how we could make devices that would fold themselves. What is the basis for this folding? What's actually going to fold? And there's a lot of options; there's a lot of materials which change their properties if you heat them or shine light on them or whatever you do to them. What fell out as the best solution is a kid's toy, these Shrinky Dinks.

The nice thing about these materials, and not just these but a lot of the other materials we made, they've been already engineered for some other application. So they've already been thought out, how they should be processed, how they should be cut and machined, whatever is necessary to use them. All that's been thought out for us with these things. We don't have to reinvent that. So that's really appealing, plus they're cheap and pretty accessible and all of that.

[16:25]

The Wyss Environment

McNally:

You've touched on a couple of times about the Wyss environment and the collaboration and various stimulation and so on. Can you talk about what effect this has on the way you think and approach your work, versus perhaps a more academic arena?

Wood:

Becoming part of the Institute...Now in retrospect I see it was a sea change for me, because as I started off at Harvard, I never really thought about what does my IP portfolio look like at the end of the day. In fact, I remember sitting in a meeting, and (Wyss Founding Director) Don Ingber happened to be there, this was before the Institute started. Naively and stupidly as a fresh junior faculty member, I said something like, "Nobody's ever going to care about what patents I have," meaning they're going to care about what nice papers I write and my citations and all this sort of stuff. Don, of course, raised his hand and immediately objected to this. So, fast forward several years now, five or six years later, and we really think about this.

The Institute has at first forced us, and now we're gung ho about, thinking about translational opportunities and not just producing nice papers. Not just we have this cool demo of this self-folding robot and we have a really nice paper and that's great, but now thinking about what are the next two, three, four steps? Who's going to take this and find the markets for where this will be applicable? Who's going to start the company? Who's going to start to negotiate the license deals? Have we filed a patent on this yet?

All of these questions are instant now for us. And that's a great learning experience for me, but I think it really gives back to our students as well, at all levels, undergrad through post doc and higher. It gives them an edge, a mindset that you don't typically get in an academic institution, and that's likely to pay big dividends.

[18:13]

McNally:

Looking at it from the other perspective, what is it you gain that you wouldn't normally have in a commercial institution?

Wood:

The innovative aspect. I mean, there are so many pressures...Although I should give a disclaimer here, I've never really had a real job, so this is really totally from the outside looking in... There's constraints which don't necessarily exist in an academic institution. Academic institutions are supposed to have intellectual freedom. If something is of interest, is deemed of academic value then you can go explore that, and that's not necessarily the case in something that's more driven by marketability and profit and these sorts of things. Of course, these are obvious statements.

So in somewhere in between, which is where the Institute lives, is this sweet spot, where we still have academic freedom. I can go out and explore topics that I think are relevant or interesting scientifically, but then there will be a team of people behind me just waiting for the technology fall-out and asking me, poking me with

questions like, “So what’s this good for?” and “How can I use this?” and, “What about a biomedical application?” or “Hey, this looks kind of like...”, whatever. So there’s kind of the best of both worlds there.

[19:20]

The Next Horizon

McNally:

What questions right now are the itches you’re just beginning to scratch? What’s on the horizon for you?

Wood:

A lot of our challenges historically - and this is true across I think everything that we do – have to do with actuation and power. So for us as roboticists, if we can use, for example, an electromagnetic motor, just a DC motor or whatever, you probably have no reason not to. But if you’re in an instance where you can’t, whether it has to be something that’s so small that motors don’t exist, or if it’s something that has to be soft so you can’t use metal components, or if it has to be something wearable so it’s too bulky - whatever the application is, then you have very few, if any, choices. So coming up with solutions there... I’ll just draw the analogy of artificial muscle. So that’s one of the two big challenges I see, that, whether we like it or not we are struggling with.

And similarly with power. Batteries are okay, but they’re still, orders of magnitude away from hydrocarbons, these sorts of things which we’d like to get away from, so can we come up with something that’s sort of pushes that gap closer. I’ll just draw the analogy to fat. So if I had muscle and fat, if I had the engineering equivalent of muscle and fat, I think we could build a much broader spectrum of useful robots than we can today.

McNally:

Muscle and fat...As you were speaking I found myself thinking, biology does everything you’re striving to do, and that’s exactly what you’re saying, isn’t it? The closer you can get to biology the better.

[20:45]

The Future

McNally:

Finally, if you could stand in the future, 20-25 years from now, what would see? What roles are robots playing in our lives?

Wood:

I think we get in trouble if we speculate too much because we’re actually just now starting to undo all the damage of the sci-fi movies. If there’s a robot in the movie, that’s not going to end well for the humans. And there’s also undue expectations that come with that...So I want to be a little bit careful with speculating.

Certainly there's going to be more - not just factory automation, but more household automation. There's going to be medical automation - having robots that assist, either in the way that, for example, Conor Walsh is doing with things that you physically wear or things that you just find lying around your house which assist in cooking dinner or walking around playing with your cat. Whatever it might be, you're going to find a lot more examples of that. And I believe that will be driven a lot by some answers to these basic questions in actuation and power that will really enable greater autonomy for these types of systems.

[21:55]

McNally:

You've been listening to DISRUPTIVE: BIOINSPIRED ROBOTICS. I'm Terrence McNally and my guest today has been ROBERT WOOD.

We invite you to listen to the other two segments of this episode - with CONOR WALSH and RADHIKA NAGPAL. We'll talk with Walsh about his work with soft and wearable robots with practical applications from healthcare to the military. Nagpal's team built a swarm of a thousand robots who can without direction organize themselves into the shape of a starfish and Radhika is as passionate about living a whole life as she is about breakthrough science.

You can find both those podcasts at iTunes or SoundCloud.

You can also find them at the Wyss site - Wyss is spelled "W-Y-S-S" and the site is wyss.harvard.edu - w-y-s-s - Harvard.edu You can also learn more there about the innovative work of the Institute. There's an extensive library of articles and videos.

You can also sign up at Wyss, iTunes or SoundCloud to have DISRUPTIVE podcasts delivered to you monthly.

My thanks to Seth Kroll and Mary Tolikas of the Wyss Institute and to JC Swiatek in production, and to you, our listeners. This is our second episode of DISRUPTIVE and if you like what you hear, let us know and feel free to share far and wide. I look forward to being with you again soon.