[Lucy]
And welcome to Coffee and Control, the brand new podcast about control engineering where I find very interesting people from the world of control and persuade them to answer all of my questions. I'm your host, Lucy Hodgins, and my guest today is a professor of applied control at the University of Southampton. So there are two reasons why I wanted to get this guest in particular for my first episode. So firstly, he is my PhD supervisor, which means that if this podcast thing turns out to be a terrible idea, then no one else needs to know about it. But more importantly, he is one of the most down to earth, wonderful people that I know and he gets so excited about control. It is wonderful. So I thought he'd make an excellent podcast guest. You're gonna love it.

Okay, so there are a lot of really cool people mentioned during this episode, both from within Southampton and from other universities. So I was gonna add in sides throughout with more details on those people, but then this podcast would have been way too long. So instead I've put a detailed list of the show notes of who was mentioned, where you can go to find their work. Definitely there are some amazing people that you should go check out.

So in this episode, we discuss iterative learning control, rehabilitation robotics, tremor suppression, multiple model switched adaptive control, control applications in recycling, and why equality, diversity and inclusion is so important.

[Funky theme music]

[Lucy]
Can you start by saying your first and last name and a few sentences introducing yourself and what your research is about?

[Chris]
I'm Chris Freeman. I'm a professor of robotics in ECS. My research kind of combines robotics, control systems, rehabilitation, and more recently, AI and wearables, recycling and other applications as well.

[Lucy]
So here ECS stands for the Department of Electronics and Computer Science, which is within the University of Southampton.
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[Lucy]
Okay, I'm going to start by asking you about your PhD and hopefully work my way through your career to what you're doing now. Okay, so first question is about what led you to pursue a PhD in control specifically? I saw you did your undergrad in electromechanical engineering.

[Chris]

Yeah, this is where my whole career seems rather unplanned because I didn't really think, you know, from what my parents and school didn't really encourage much thought about career, or it certainly passed me by anyway. So was just, so even applying to Southampton, I knew it was very high in that it was number one in electrical at the time, almost still is. And it just seemed like quite a good idea at the time. And it was quite a nice, a nice distance away from home. And then I hadn't gotten any thought about what I wanted to do at the end of the three years. So I just applied and I didn't really, I think we had a career center, but it wasn't anywhere near like it is at the moment. I don't think we really had many internships, we didn't have barely any email, so there wasn't much scholarships. So we weren't really that supported in those days and I certainly didn't take any kind of career directional thoughts. So I just applied, you bought a book at the time and just went through like the big engineering companies and just applied. And I got a couple of offers, one in London. So it was only by getting a job in London and...it being a very bad experience. That was the most useful three or four months in my life for eventually making me see what I wanted to do. So no planning basically.

And then that's when I called up Paul Lewin and asked if he had remembered that he had been talking about PhDs because there was no graduate training in Kvaerner. The company had recently been taken over. So very depressing rubbish environment and it just made me think eventually what I actually wanted to do and a PhD was part of that. But even then I didn't know what really I wanted the PhD in. So this is very badly planned and luckily Paul, of the probably, I'm sure he'd agree the greatest decision of his life was seeing what I was good at and that I've got, I think it was 95% in control systems and he had an open, was a project starting and he had some spare government money. So that was my planned career. And I absolutely seized it.

[Lucy]
So I'm going to ask you about PhD, some of the topics in your PhD. So it was in Iterative Learning Control. Could you very briefly explain what ILC is and why you might use it over other control algorithms?

[Chris]
ILC was sort of invented in 1984, though that's disputed. And it was proposed as a very simple way of learning from experience. So for like production lines, robot doing the same operation again and again, it makes a mistake. You want a very simple way of correcting that. So if it overshoots or it gets there too fast, all you do the next time it does it, you shift the input forward, backwards, to correct for that overshoot. Like really simple one line of code.

But then, and amazingly people haven't really thought of that. And it worked so well that it spun off a whole huge domain of research.

[Lucy]
Okay, so Chris's thesis completed in 2004 was titled, Experimental Evaluation of Iterative Learning Control Performance for Non-Minimum Phase Plants. I want to include a link in the show notes, but the thesis is currently not available online, which is a shame. But if you would

like to read it, then let me know by emailing me, and then I can send it to you and then you can read it because I enjoyed it a lot.

Just a quick extra aside on ILC. The first paper that Chris was referencing was the 1984 paper by Suguru Arimoto titled, Best Operation of Robotics by Learning. And I'm gonna put a link to where you can find that in the show notes.

[Chris]
One of the interesting things I think about iterative learning is it's, I kind of think of it as an umbrella kind of control application because you can basically combine it with loads of other controllers. So if you've got a sliding mode control or, or predictive controller, it does a decent job because it's using feedback, but you then add it to, you add ILC to it and it makes it better. But that makes it quite difficult to get into because the papers you read on iterative learning tend to always be talking about other controllers and also nonlinear and linear and H infinity. just, so I found it very difficult reading about it because it's kind of an umbrella control domain that requires you to master every other control domain. But that's the idea. And so just like learning, so many tasks in the world repeat themselves. The human body is full of processes that have to do with repeating signals and periodic waveforms. But it's the idea of using that error to make it better.

[Lucy]
Okay, so your PhD was on ILC for non-minimum phase systems. Could you explain a little bit about what a non-minimum phase plant actually is, why you might want to control it and then what were some of the challenges that you faced trying to apply ILC to that kind of system, because from what I understand that hadn't really been done much before your PhD.

[Chris]
No. So I think my PhD was dreamed up by Paul Lewin and Eric Rogers. I think the starting point was they saw that people were beginning to do experiments of benchmarking and seeing how good ILC was. Very few people had actually tried out ILC in the early 2000s. Can't remember the exact date. And most certainly no one had done it on what are called non-minimum phase systems. So that's the kind of system that is traditionally difficult to control. I had no idea what one was at the time. I'm not sure we covered that in undergraduate control or I'd forgotten it. And they're systems with a zero in the right half plane. So they're technically stable, but they behave in a slightly weird way. So like a ship turning or a helicopter suddenly changing direction, it goes in the wrong direction to start with and then goes in the right direction. And when you invert the plant, that right-hand side zero becomes a right-hand side pole, which makes it unstable. So it has difficulty doing invertional control, which is when you want to do a task, you're… in one way or another, you're inverting the dynamics. So it makes it quite tricky.

So that was the idea. That was my entire brief. You know, you've got to build a non-minimum phase system and then just try out some iterative learning algorithms. That's basically it and see how well they work on this special type of system. So after struggling for quite a long time with like system analogs, because the starting point was kind of an electrical system and then turning it into a mechanical system, Paul then put me in contact with a guy called Roy Holmes, who had taught me control systems. He came up with an idea, I think it was just on the back of an envelope, which was way simpler than mine. I had a really complicated way of producing this characteristic, but he had a far more elegant, beautiful way of doing it, just with dampers and springs and inertias. And then I just had to make it, and luckily Paul had enough money for me to design it and then build it.

So really nice. I mean, I had very little experience with that. didn't really have, my undergraduate project wasn't anything to do with that and wasn't very useful at all. So it was a big learning curve and I just sort of copied what other people had done and eventually got there.

Then of course the PhD slowly transitioned from not just applying algorithms, but producing new ones. There was no information about how or what they should do. It was just produce some new ILC algorithms. But by that time I was working with James Ratcliffe who had started this project with Paul, Eric and David Owens from Sheffield, which had quite a big budget. And that was all about iterative learning control for robots. So I had a little team and there were some people, a guy called Jari Hatonen, a Finnish guy who was very funny, maybe not meaning to be, but he was excellent. So we sort of created quite a nice support team and I was then trying out some of their algorithms, designing my own and it kind of went from there.

[Lucy]
So in your PhD you discussed a phase lead ILC comparing that to other algorithms and then there was a multiple phase lead ILC that led on from that.

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[Lucy]
Okay so I did terrible job of asking this question but as Chris will explain in a little bit

Phase lead ILC involves using data from future time steps in a previous iteration to improve system performance. What I was trying to ask about here was what I thought was rather ingenious idea in Chris's thesis in which he proposed iteratively adding in little bits of different phase leads to give an optimal trade-off between convergence and stability.

[Chris]
So that phase lead is such a simple algorithm, but at the time people had used like one sample advance. So they kind of got the idea that you do need to look ahead in the trial in ILC because of the non-causal nature of the update system. Otherwise it just becomes a feedback controller, you're not really learning anything because you're not predicting anything. But people at the time, there were only about a hundred papers, but no one had thought about, you know, can you extend that? And so it was just so obvious and it actually worked and it was just wonderful to see. And it was almost, you weren't sure why at the time. I think we've worked it out by now.

But you weren't sure why looking ahead half a second is much more useful than looking at a head point one of a second. But then it goes down again. So I did all these tests to find out and then that … that's elegant because you only need two parameters that you can just tune yourself without having to do a model identification, So the obvious idea was to add some, some more of them and they work really well, but as you can see that there wasn't much maths behind them.

But it was a nice example of application-driven, experimental-driven control. Do what works and then try and work out why.

[Lucy]
Do you have a favorite ILC algorithm?

[Chris]
It always used to be Phase Lead because it's just so simple. It's the one that worked best when we did clinical trials with stroke patients. you can get it just works. What's wonderful about Phase Lead is that it's got one parameter, which is kind of the delay of the system, which for like an arm is quite easy to guess. It's somewhere between 0.5 and one second, the muscle delays. And it's got another parameter that's to do with how fast it all converges. The problem with that is that it won't be stable unless your arm is actually a pure delay, which spoiler, it ain't. But it's good enough.

[Lucy]
So after you did your PhD, you stayed at Southampton to do a postdoc looking at ILC for stroke rehabilitation. So I was wondering, how did this come about and how did you find that whole experience?

[Chris]
I'm getting all misty-eyed. So I think because I've... I'm just thinking dates, maybe people aren't... So I finished fairly early. So I think I submitted in certainly less than three years. But then… Paul had promised me that they'd applied for funding and there would be a postdoc. Looking back, I think that was quite an optimistic claim to make, but I'm very glad he did. And he was absolutely correct. So they'd applied for another three-year grant. Paul had talked to Jane Burridge, a leading figure in rehabilitation and using electrical stimulation.

So about, it was just, think before Christmas, just before Christmas. So I started in April and then two and three quarter years later, before Christmas, I got this promise that they'd applied and it would happen soon. So I stayed around, but then the money, I only had three years funding. It was like 6,800 a year. So I slowly got into debt and then that stopped in the three years, which was like March. And then Paul… very kindly looked for a postdoc position in the HV lab for like another three months. And I think Paul and Eric, think money was probably easier to get in those days.

[Lucy]

Just a quick clarification here that the HV lab is the high voltage lab at the University of Southampton.

[Chris]
It was quite fortunate. My career has some very lucky, I mean, I'm sure I'd have found something else, but that was very helpful. So yeah, I worked for either three months or four five months on other projects that didn't really go very far. One of them was called this, this was an HV project to do with optics, applying high voltages and then light, called the Pockels effect. But in all of my spare time, I was writing up papers that had come out of the PhD. And then my postdoc started in about that summer, I think. Big learning curve.

Jane was really good. So it's mainly working with Jane. I mean, Paul and Eric, even though they're involved in the project, I don't think… they came to some meetings, but they weren't that involved. So that was a big learning experience. That was, again, a very open brief. Am I blessed or cursed? But it was just, you've done some ILC algorithms and they've worked on robots. Here's a human. They can't move their arm out.

Here's something called electrical stimulation, these pads that you put on the skin and they kind of feel a bit prickly and they cause your muscles to contract. My brief entirely was create a system that helps them move their arms. It had to include a robot, but the robot could have been anything, sort of support robot, mainly because we were only intending to stimulate like maybe one muscle. So we kind of needed a robot to support other movements. So I came up with… that. It's really great for me. It gave me a huge amount of scope. Maybe other people might have not liked it because it was just like, it's all on you. So I kind of like that.

[Lucy]
Okay, can you give a brief summary of the problem of stroke rehabilitation and why is it important and how can control help?

[Chris]
So there's in the UK, there's a million or just over a million people who've had a stroke who survived and at least two-thirds of them still have an impairment after six months in their arm movement so they still can't use their arm properly. Usually it's got to do with distal movements, moving your arm away from the body and usually your hand and wrists are very stiff, you can't open your arm and you can't extend your whole arm. There's other problems with walking as well but we're kind of concentrating on the arm.

The problem is… so part of your brain due to a blockage or a burst blood supply has been killed. So those, if that happens in the motor cortex, it means that you don't know how to use your arm. So it's a bit like you have to relearn it just as if you were learning to ride a bike or play tennis or something. But the problem is you can't move. So if you can't move your arm, if you come back from hospital, you start using your other arm, and then your arm that is impaired gets weaker and weaker and becomes even more useless. There might be some other problems as well with it to do with range of movement. So people, the traditional approach is for a physio to come along two or three times a week and then just manually help you move your arm. And you have to sort of try at the same time. At least you're getting some movement. You're helping with the stiffness due to spasticity, but that's not very effective.

So there's still, that's why after six months, so many people still have this problem. So what, what is needed are technologies that help move the arm to get the feedback going, the haptic and proprioceptive feedback and visual feedback going back to the brain, so the user can gradually rebuild that part of their motor cortex by, by slowly contributing, getting the feedback and rebuilding these kind of neurons connections.

There were different ways of doing that. The most popular is FES, functional electrical stimulation, and the other most popular are robots, which tend to be extremely expensive. Early in that project, I had the pleasure of going to MIT and seeing their extremely beautiful, extremely expensive robots. We went with Igo Krebs and Neville Hogan, who who are still leading people in that kind of area of rehabilitation robotics. And we visited white planes in outskirts of New York and Baltimore to see people using these. So there's some nice robots, there's lots of clinical evidence for them, but it only says they're as good as a human operator. So they are gradually being used more and more in clinics, especially private clinics, who can afford these very expensive machines.

But FES has an advantage in that it actively empowers your muscles so it builds strength and it's of course a lot cheaper. But the FES systems at the moment basically are open loop or use very simple triggered stimulation. So it basically is a control challenge. If you can get a system that helps control your muscles to do a movement as close as you would voluntarily do it, then that has the best chance of rebuilding your neurons in your brain as fast and as strong as possible.

[Lucy]
So you've talked already about like robotics, the fact that you had to use robots in your postdoc. I kind of want to ask like, where do you see the place of robotics in rehab and kind of related to that does introducing robot, like robotic systems make control design easier or more challenging than just using FES?

[Chris]
I think there's a… you inevitably have to use robotics because FES can't support all the muscles you need to do, especially with walking and lower limb stuff. It just wouldn't be safe. You can put large electrodes on your quad muscles and the large muscles in your legs, but it wouldn't be safe to use them and they wouldn't provide enough support. some people… only like maybe two thirds of people can use FES. A good friend of mine who had a spinal cord injury like 10 years ago in a car accident, he's tried FES. He's paralysed from the lower back downwards. He's used FES and it just doesn't work with him. So a lot of people need robotics. And you might have seen the big exoskeleton robots. They're extremely clunky. Maybe they'll get smaller with the...

power supplies now trying to get smaller, which maybe electric cars will help with that kind of push. But they're still big and clunky. They're still not compliant. So I see the future going in the soft robotics route. I might be biased because I've had a whole grant on this. So the wonderful people, like Jonathan Rossiter at Bristol Robotics Lab, are doing this kind of work and a lot of other people, additive manufacturers, leicester and places. At the moment, you just don't have the power density, they're just not strong enough. But I think that will change. And as you know, they're doing really good things with battery improvement at the moment. So maybe in the next 10 or 20 years… that grant was all about, like smart trousers. We all went on the radio and promised that they'd be like Wallace and Gromit smart trousers, you just… not just for an impairment, but if you just weren't feeling very active that day, put on your smart trousers and they'd give you a boost. They'd sense what you wanted to do and they'd give you extra power to storm off down the road and overcome impairment or maybe frailty to old age. So there's a big place and they work well together. you want, my ideal system combines electrical stimulation and smart, smart robotics as well.

[Lucy]
So I'm going to ask you a bit about your work on kind of tremor suppression, which is, I guess, different from the stroke rehabilitation problem. Where did this idea of using FES for tremor suppression come from? Had people done similar things before?

[Chris]
I think it actually, first I heard of it, was from Kevin Moore. He was at Colorado School of Mines. So he was my sort of mentor I suppose he was a leading figure and still is a leading figure in ILC so I heard he just mentioned it once as a nice, so as as you know there's there's a very nice relationship between repetitive control and iterative learning control they're both using learning from experience but repetitive control doesn't stop it just carries on and ILC has a has a rest period in between each trial. You think they're almost identical. Theoretical frameworks are actually very different. And so that's why the communities didn't really coalesce for many, many years until a few, some very nice papers that showed that there was kind of an equivalent design framework.

[Lucy]
So I think the paper that Chris is referring to here is the IJC paper called "Internal Model-based Design of Repetitive and Iterative Learning Controllers for Linear Multivariable Systems", which I have read it is an excellent paper. Would highly recommend it. I've left a link in the show notes below.

[Chris]
He mentioned it first and it wasn't until I had some new PhDs starting about 2012 or 13. Well, actually there was I think it was working with health sciences and they wanted a project idea and I suddenly remembered tremor and no one had done it before and it's just, it's just a really nice problem from an engineering point of view. But actually there are hundreds of thousands of people who've had multiple sclerosis or Parkinson's and even it manifests in other conditions as well, other neurological conditions. And you see quite a lot of people with tremor.

So there was a student called Trish Sampson who then did a project. She wanted to trial a system for tremor suppression in her Msc. I didn't kind of realize at the time that meant I didn't have a PhD, this was before I had a PhD student doing it, but I spent the summer making and programming this system myself, I think. But just showing something working and then having a system that then is suitable for a clinician to come in and test with patients are two very different things. So I had to produce this system over the summer that she could then use. We then got a grant from the MS Society and then I've had a couple of PhDs since.

[Lucy]
Yeah, because currently your approach to tackling this is to use multiple model, repetitive control, right? I was wanting to discuss kind of multiple model control a little bit more. So around the time that you were looking into tremor suppression was also, I think, Ollie's PhD, looking into applying multiple model switch adaptive control to FES systems. So I wanted to ask you about the idea of applying framework that had previously been applied to linear systems to a system that's not completely linear. Why did you decide that would be a good idea? Did you think it would work as well as it did?

[Lucy]
Okay, so before we get to Chris's response, I kind of feel the need to include an aside on this, especially because I very much fumbled my way through asking that question. So, estimation based multiple model switched adaptive control is a framework developed in a thesis by Dominic Buchstaller titled “robust stability and performance for multiple model switched adaptive control”, which honestly is an actual masterpiece. Okay, so the basic idea of multiple model switched adaptive control is that instead of having a single model and one controller, you have a ton of different models, and then you design a bunch of controllers to ensure that for any possible parameter variation in your system, there will be a controller that is able to stabilize that. So then you work out which model is closest to your true system and then use the corresponding controller, switch that into the closed loop and you get a stable system.

And there's so much very interesting core maths behind that that Dominic developed, demonstrating that that works and proving that it works for linear systems. So then a few years later, Chris has a PhD student called Oli Brend, and then they applied this framework to FES systems. So I've linked to the relevant papers in the show notes, I would really recommend checking them out. So I think Oli's papers are some of my favourite papers of all time. I read Oli's thesis when I was trying to work out whether I wanted to do a PhD and what I wanted to do it in. And I just remember being sat in my bedroom being like, that is what I want to do with my PhD. Honestly, such a joy to read.

[Chris]
I think Oli's PhD was a wonderful experience because it was working with Mark French, someone who had previously almost exclusively done theory and absolutely beautiful theory it is.

But it's so good. Some people who just do theory have no idea how an experimental system works. they kind of don't want, if it's too difficult, they don't want to use it. But Mark isn't like that at all. So he wasn't put off. He likes the experiments to kind of maybe lead the theory. So no one had done multiple model adaptive control with FES before, to my knowledge anyway.

So it was kind of the simplest setup to see whether it works. So Oli's work is isometric, so the arm doesn't move, which limits some of the nonlinearities from the kind of tendon network nonlinearities. But you can't get rid of the recruitment nonlinearity. Although some groups do assume it's linear anyway, like TU Berlin over a range, maybe with a saturation and a linear gain. So I suppose we could have done that, but we didn't.

[Lucy]
Okay, so here Chris is referring to the Control Research Group at TU Berlin University. They did a ton of interesting work on FES in a range of different contexts. A of their work is very, very cool. Thomas Schauer has a really interesting summary article that he wrote of a lot of this work, which I have linked in the show notes.

[Chris]
We'd used the models that we've been using for quite some time, a kind of S-curve followed by the Activation Dynamics. And then we just took a sort of pragmatic approach to cancel that and slightly update the theory to hold for linear systems and see whether it worked. And as kind of expected, it works very nicely, therefore motivating an extension to the theory. At the same time, there was a PhD student, Abeer, who was then looking at the robust control of Hammerstein systems. So it kind of went quite nicely and was a great learning experience for me as well. I think the best as a supervisor, it's lovely to work with new people and learn new things over a three or four year period.

[Lucy]
Okay, going back to stroke rehabilitation. So a lot of your recent work has been on controlling the hand and wrist using electrode arrays. So whose idea was it to extend, ILC from single pads, which is what you were doing initially to electrode arrays. Because from my understanding, most of the electrode array control strategies before then and also to some extent since have been a lot simpler than ILC.

[Chris]
I remember, so it was at a conference with Jane Burridge, because I hadn't really heard of electrode arrays and I don't think they were very widely used. And this was quite a long time, but maybe 2012 or something like that. She’s … superb networker knows everyone in the FES community.

And at a conference, she introduced me to Thierry Keller, or T-R-E, I can't do the pronunciation, who works at FATRONIK, a kind of independent research company. And they're very heavily involved in EU funding, a lot of companies are. And I wasn't very good at making those kind of connections. And she said, maybe we should look at some electrode arrays, because they're kind of just starting to be manufactured. And so we just go around and find where Thierry is and just say, hey, this is what we could do. Maybe we could do a collaboration. Can you make us some? And he basically said, yes. And then a few months later, I think some turn up with exactly the same design that we're using, we're still using today. So was quite serendipitous, I suppose. I mean, we'd have got around to it eventually, but it's kind of those links that kind of force you into new areas, which is really nice. So we started using them in our...like third trial. And then as you can see, the control possibilities are just beautiful.

My research is sort of built up from a single input linear planar case to like two degrees of freedom, 3D movements. And then we just used like one channel for like wrist, single degree of freedom, wrist control. And then this was, it came at the right time as the next step. What do people actually want to do? Not just move their hand and hit things with their curled up fist, but actually properly extend their wrist. There have been EU grants and Russell Torraj was leading one recently, Wearplex, to try and make more elaborate, more involved electrode arrays. But people doing basic rehabilitation don't think that you really don't, maybe don't obviously see the benefit of control.

They just think, how do you automate what a physio does, the kind of placement of electrodes? We know where the muscles are. Let's do some automation and we should be able to get the kind of basic movements we might get in a hospital if we've got a system like this. So it's kind of joining up those ways of thinking.

[Lucy]
So I guess related to that, what do you think the potential is for surface electrodes in terms of precision of movements?

[Chris]
I think there's huge potential. It's just always out of reach. You can just see in some of the tests we've done, you can just get better. You can get obvious pointing movements. You can get obvious pinch-like movements and open hand movements. When you apply the stimulation, you can even get the little finger and even the thumb as well. You could just see, even though we've only tested things that are relatively simple so far, you could just see the range of movements you could get.

Sadly, it takes half an hour to set up and it changes very quickly. You try it, you try and you can do it yourself with a small, with one person at a time if you've got two hours, but it's all to do with that. That's why you need controllers that work. Either people need more time to actually see it working and to get to use used to it, or you need better controllers that work far faster. So I think it's got huge potential. I mean, I think it's got huge potential for haptics as well, you've seen all the Meta and interviews with Zuckerberg. It's all to do with navigating 3D environments, but doesn't really consider an awful lot of haptics. The best sort of haptics are the sensation of your muscles actually moving. We had talks several years ago with a company who are trying to make virtual reality training videos to help people know how to lift things up.

And they kind of were interested in FES as a way of actually showing a force against your muscle. So it actually feels like you're lifting something up. And no one's done anything like that. That's probably another project.

[Lucy]
Yeah, I was gonna say one of my questions is where do you see FES technology going in the near future and then as far future?

[Chris]
I mean, a lot of people I know were talking about the implanted spinal stuff that, I think people like Elon Musk are pushing and hasn't been terribly successful. It's at such a tiny grade, I think they implanted some electrodes and then some of the tiny connections broke and so it's just extremely expensive. So I think that's one route, the kind of direct implanted approaches. I still think there's a long way to go with the wearables that people like Kai are working on and we're looking at a little bit, and the controllers, and we still haven't quite got to that step. So I can only really see the next like five years.

And then maybe they'll combine with soft robotics. And I know there are EMG, you can use the same technology for sensing EMG as well. And there's a lot to do there, I think. Use it for, like working with Professor m.c. Schaeffel to do with guiding people to use the correct muscles. First of all, encouraging older people to do, to do balance and strength training and then trying to guide people to use different muscles or to do the movement correctly. And I think m.c. has plans to use this for more elite athletes. So the same kind of technology you could use to sense how people are moving and then to give some corrective prodding in the right direction, if you see what I mean. So there's lots of little things like that.

Then, yeah, FES, I mean, so my work isn't just...FES or iterative learning, but there's such a lot of things that seem just within reach. Well, they're really interesting problems, but in some ways it's frustrating that we haven't kind of cracked already. And some of it's hardware and some of it's integrating depth sensing and if the control worked perfectly, then you'd want to help guide people's movements around their homes, of course. So you'd need some sort of AI recognition of objects and path planning as well. And then maybe you could use it for things like production line interaction with robots. So it just leads to all different kind of areas. The problem of getting old or having neurological conditions sadly isn't going away. So I think there's a lot of routes you could take.

[Lucy]
I wanted to talk to you about EDI, so Equality Diversity Inclusion, because I know a few years ago you became head of EDI within ECS. And it seems to be something that you're very passionate about, but it takes up a lot of your time. So I was kind of wondering what motivated your decision to take on that role?

[Chris]

This is kind of building up a trend of me not making decisions. So as soon as I got promoted to professor in 2018, I think without the dust even settling, Paul invited me to a meeting with someone from the Equality Unit. But basically it was Paul's way of saying we need someone to help us with our Athena Swan submission. So I really hadn't shown any interest in this. I've previously been a Deputy Director of the Graduate School, which isn't the most enjoyable task in the world because it's very procedural. Basically the background was we'd been one of the first departments to get an Athena Swan award in 2012, I think, which was led by our current dean. And then they have a four-year plan. And then sadly, we'd been unsuccessful at the next bronze extension. And then we'd had a resubmission, which then had failed. And so everyone was very downcast. They'd started an EDI committee.

So basically I was sort of drafted in as maybe someone enthusiastic who could then help us write our next AthenaSwan application and give us a direction in terms of, work with people, very knowledgeable people to give us a direction of where we wanted to go with EDI. So that was my role. And I really enjoyed it because basically I think, just think of it as it is helping people. It's thinking of ways to support people.

And there usually isn't much arguing. Obviously there are some underrepresented groups that need a special equity who haven't had chances and desperately need more resources and more support. But in general, I think everyone needs support as well. So I've really enjoyed it.

[Lucy]
So why do you think diversity is important within engineering and particularly within control?

[Chris]
Well, there's all sorts of different sorts of diversity, aren't there? There's a huge amount of information about how recruiting people from different backgrounds who think differently absolutely makes you a stronger department. But yeah, it's getting a diversity of opinion and experience, which makes you very strong. And the people who are maybe you think of as more diverse and have different ways of thinking are very, very successful and a huge pleasure to work with.

[Lucy]
Can I ask you some quickfire questions. Are there any other biomedical contexts that you think ILC could be useful?

[Chris]
So, absolutely. So many processes in the body are repetitive, you know, things like breathing, for example. So one of the projects we're doing at the moment, but just finished kind of with with Mike Thompson has been on thoracic pressure control. And that's working with University Hospital Southampton, who've developed tympanic membrane sensors and they require you to accurately track repeating sequence of, of pressures as you blow into a tube.

We used model predictive control in that project but, but because there's a learnt element you kind of needed to to model the human. Well we did model the the human voluntary control system but it, but there is a learning process because the user looks at this repeating reference and then they do learn how to get better. And then the controller needs to know how they've learned to get better. We've kind of cheated at the moment by just not showing them what's going to happen next to prevent them learning. But that's kind of a cheat because you kind of want them to get better. But the controller needs to get better as well. even that's kind of the next step of that would be to embed learning in it so that you… the controller adapts to the way the human learns.

That's one example. Obviously that's to do with voluntary respiration, but there's a whole area of like artificial respirators, which again, it's kind of a more repetitive task, but you could improve the control of them. I mean, obviously things like surgery, like Rujie, what they're looking at, like robotic surgery, I know it is starting to be used more as a kind of assistive aid, but I'm sure in 20 years time, you'll get far more, it'll be more routine to do robotic surgery. And again, that's all about repetitive tasks, dynamics that need to learn from experience. And I think, again, Rujie is doing some control to do with extremely fine needles, to do some very fine kind of brain surgery type control.

And again, everything is repetitive. Everything can benefit from control. And then what we've learned about with what we've been talking about with assistive technology as well, it's intrinsically repetitive in order to build the neural pathways. So I think every biomedical problem in the world is an initiative learning problem or could benefit from learning. And I know a lot of problems of AI is being used, but I just I think we'll see in the future more people embedding more traditional control with AI as people get more familiar with the weaknesses of AI. I think we'll see more solutions combining AI and more traditional control.

[Lucy]
Okay, next question is, who's your role model within control or biomedical engineering or like someone that you really admire?

[Chris]
There's been just so many people with different skills. I mean, people that been very formative in my career, people like Jane, definitely people like Mark French, people who've just opened your eyes to, and giving you the confidence to not just do the same thing. Cause I think careers are all about, you can just do the same thing again and again, or you can meet new people and get yourself out of your comfort zone, which is never pleasant, but it expands you as a person. You don't want to just in 50 years time…but I won't be alive. In terms of this time, you don't want to be doing exactly the same thing. So yeah, pushing yourself outwards.

And people like, you know, working with David Owens was wonderful experience with all that theory. Because I think it's just gradually kind of growing in confidence that you are able to do new areas. Although your first publication in a new area is usually shot down, which puts you off, but gradually you get there. And that's what's nice about being an academic. You can change areas and there's loads of different people to work with. It just requires a bit more effort.

[Lucy]
That kind of links to one of my other questions, which is what is your favourite part of the job or something that you really love about being an academic?

[Chris]
I mean, I really like EDI, not just because it's hopefully helping people and you get to work with some incredibly passionate people like Dorota, and Reena, but because you're getting things done, because you're kind of controlling it. I mean, it's just, you always feel like you're working for yourself and you have a huge amount of freedom to organise your day exactly as you like. And we don't have to, though, I think you're supposed to have like one PhD student. So all the research you do is basically your own decision. So it's this aspect of I'm not working for anyone.

People have said that academics are a group of individuals with a shared grievance over parking. And I think it's probably quite true. It's working with really great people that you really admire. Teaching is, I also really like teaching.

[Lucy]
If you could specialise in an area of control other than ILC or control for FES rehabilitation, what would it be?

[Chris]
I mean, I've got a lot of projects at the moment because of all the activities going on in AI, I'm fortunate enough to have new projects starting, which are combining robotics and AI. Haiming and I have just, and someone from Environmental Sciences have just yesterday put in a new project, a CDT project, to do with recycling and using low-level controllers mixing with AI to help recycling centers better use robots to separate different types of recycling and things like batteries, which has been in the news recently, exploding batteries that aren't kind of found. So it seems to be still the control part, but combining it with AI, hopefully projects with with Rafa to do with control for hybrid robotics that use real muscle that's grown in the lab. So controlling hybrid systems.

I have several projects to do with with AI and reinforcement learning and safe and explainable reinforcement learning and obviously graph neural networks, which were all intended to have a control kind of purpose, you to do the theory and then to use it either to do something involving mobile robotics or echolocation or something like that. But that part never happened, but maybe in the future.

[Lucy]
What is your favourite paper or project that you've worked on?

[Chris]

I think my postdoc. I mean, it was the most hard work. I used to go in in the morning and not leave the ex building, 45 Health Sciences building until six, never coming out. Trying to make this robot work. But then it's just spun out so many papers, so many talks, so many conferences all over the place that people were really interested in it. And I've still got, throwing them away now, but you've got kind of quite a few awards because people were really excited to see the first time it was any model based controller was being used for for rehabilitation. yeah, hard work, especially because I started after only two years of that project. Even though I had a three year postdoc. I then got I then got the lecturing job. So you were having to finish you having to do two jobs at once with no extra pay starting to do lectures whilst also finishing building robots. It's kind of hard work. Maybe it wasn't my favourite at the time, but I think it is now.

[Lucy]
Okay. Yeah, great. Thank you very much.

[Chris]
Thanks Lucy. It's been a great pleasure.

[Lucy]
So in summary, iterative learning control is perfect for actions that are carried out repeatedly and control can be super useful for rehabilitation as well as of course a lot of other applications. I've linked a bunch of Chris's papers down below and also his email address if you want to contact him directly. I've also left my email address.

Please leave comments, rate and review if you have opinions on this episode. I'm very new to this whole podcasting thing and I'd really like to get better. So I want to know what you think. I'm hoping to release an episode on the first day of every month. Next month I will be talking to my other PhD supervisor who is also wonderful, does some very exciting research. I'm very excited to talk to her. It's going to be a great episode. So I hope you have a fantastic month. Hopefully see you then.