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Katherine Kuchenbecker

IEEE RAS Interviews

Q1: So if we could get started with a little bit of personal information. Maybe you could tell us, again, your name and a little bit about where you were born, maybe early schooling, and how you got into the field of robotics.

Katherine Kuchenbecker: Yeah, I'm Katherine Kuchenbecker. I was born in Los Angeles, California. My mom is a research psychologist and my father is a surgeon. I'm really lucky that they valued education and put me in a really good elementary school. I was brainwashed from a young age to want to go to Stanford University because that's where they had gone and studied. It was a wonderful university in the same state in California. So I started there, my bachelor's degree in 1996. I was also lucky to play on the volleyball team and, I studied mechanical engineering. And I loved it so much that I stayed all the way through for bachelor's, master's and PhD. I was the first graduate student of my advisor, Gunter Niemeyer. And, by that time I was fully convinced I wanted to become a professor in robotics and dedicate my career to this great field.

Q1: So what was the first, if you can remember, experience with robotics that you have? What exactly led you to the field?

Katherine Kuchenbecker: My first experience with robotics was actually terrifying. When I was a very small child, my parents took me to a Universal Studio in Hollywood and we went on a backlot tour where you ride on a tram and then they took you into this building where there were mechatronic robot-like, I think they're called Cylons, and they were actually dangerous and terrifying. And they shot at the little bus. Of course we were in no danger. It was a Hollywood set basically, but it absolutely terrified me. And I'm really lucky because my mom noticed that and she didn't want me to develop a phobia of robots. And she systematically worked to help me conquer my fear by helping me understand about machines. Like for example, she took me to the drugstore and we bought a book about robots and read about them. And she bought me a lot of little wind-up toys. And my dad, as a surgeon, he's very good with his hands, and I think he would have been a great engineer. My grandfather, his father, was an engineer. And he also helped me understand mechanisms and devices a little bit from... And so it's kind of funny now that this fear, this early terrifying Hollywood exposure, I was probably too young to have seen this exhibit at Universal Studios. My mom was able to turn it around and turn it into a fascination with engineering, with math, with science, with computers and with programming. But always was a connection to people.

Q1: So what was your first robotics project?

Katherine Kuchenbecker: My first robotics project was in the telerobotics class that my advisor taught for the very first time at Stanford. He had done his PhD at MIT and a quick postdoc with Ken Salisbury. And then he was one of the first employees at Intuitive Surgical,

which was... Surgical is now one of the most successful robotics companies in the world. And when I started working with him in 2002, he had just joined the faculty at Stanford after helping successfully launch the Intuitive Da Vinci robot that was now operating tele-operated surgery in operating rooms minimally invasively. And so he was teaching us this class on telerobotics. We didn't have access to very fancy hardware, but we had inherited a few robots from Ken Salisbury's lab. And my teammates and I programmed a tele-operation system where you could hold one haptic device, one phantom haptic device, and another one would track your motions. And I think we did a silly demo where we put a keyboard under the robot and we could show that you could type and also feel the pushing of the keys. That was our final demo. And I was already committed to doing a PhD with Gunter. I hadn't really decided exactly what I would be working on, but it was really satisfying to see how you could put hardware, sensors, actuators, software together to create a system. But of course, it wasn't doing surgery, but it was operating in the same way as a device that could help doctors, patients, surgeons, and a lot of other people around the world.

Q1: So when you got into your PhD, how did you develop your interest and what did you end up working on?

Katherine Kuchenbecker: Yeah, the very first problem that motivated both me and Gunter back then was adding haptic feedback to the tele-operation, because the DaVinci robot, what was launched and up until very recently, had basically no haptic feedback. So the surgeon moves their hands and the instruments follow that movement inside the patient. They have really good three-dimensional view, but they have no sense of touch. And that's especially dangerous if the instruments are outside the camera and they can't see what's happening or if things are... If they can't... Yeah, if it's occluded. And so from that very beginning, the problem that we were motivated by was how to bring the missing sense of touch into tele-operation. And I'm so lucky that I got to work on such a system, a tele-operation system, because it could then be taken in two big directions. So already in my doctorate, we also started working on haptic feedback for virtual reality or for virtual interaction. So you take away the remote robot and add a simulation and we want you to feel surfaces, contacts, that worked on how to make hard contact feel crisp and real. And then also you can take away the human and just think about autonomous robots and the exact same signals that we want to be able to capture and present to a human operator who's tele-operating a robot. Those are the same signals that we want to be able to measure and analyze in real time for a robot to start doing things autonomously.

Q1: And so that was what you did for your PhD? And when you... Do you want to tell us a little bit about kind of what were the most exciting findings from that? And then what did you carry forward as you went on to your faculty program?

Katherine Kuchenbecker: Yeah, so in my PhD, we only got to like first demonstrations of a human holding a device, a haptic device, and controlling a remote robot and also doing some haptic feedback and virtual reality. I hadn't yet worked at all on autonomous robots. That came

only later. I'm proud of a lot of the things I did in my PhD. The big insight I think I took away was that robotic systems are mechatronic systems. They have so many complicated components. And if you want the whole system to behave well, you must understand every piece. If you ignore, say, the real-time aspect of your code or the time measurements or this sensor, it's likely it may not be interacting with the other components as you intend, especially because these are real-time systems. We were using a hard real-time operating system, taking measurements 1,000 times a second or 5,000 times a second and responding. And so we had very simple code that had to execute quickly and accurately and stay stable. And so, yeah, I did a lot of dynamic characterization of the sensors and actuators and the mechanical system to figure out how it would respond to different inputs so we could predict what the user would feel when we put a certain input into the motors. And then we were able to kind of invert those dynamics, both for the hard tapping on virtual objects and also in teleoperation so that the operator at their hand, they're feeling a very good version of what the remote robot is feeling or what someone would feel when they touch a virtual object.

But I hadn't yet started working on autonomous robots. That really came after I became a professor. I was lucky that I took a faculty job at the University of Pennsylvania in the GRASP Lab. And I think that was the best decision of my professional career. I'm so grateful for the wonderful colleagues. Ruzena Bajcsy founded the GRASP Lab. It's a very interdisciplinary research institution. It's like a cross departmental. So I was hired by the mechanical engineering department, but I had colleagues from electrical engineering, from computer and information science, from biomedical engineering. And we also had really close collaborations with people in psychology across campus. We had a graduate training center. We were having psychology and neuroscience and electrical engineering, computer science students, take classes together and learn from each other and collaborate. And I was so... It was such a flourishing. It was such a great environment for my students and me and my colleagues in this interdisciplinary research.

And that's where I really started getting into autonomous robots. My first PhD student, Joe Romano, he was sitting in an office in the GRASP Lab with several students of Max Likhachev, who is now a professor at Carnegie Mellon. At the time, he was a research assistant professor at Penn. And we were just starting to think about things like machine learning. And Max and I together wrote a proposal for the Willow Garage PR2 Beta program, where we were able to get a PR2 robot at Penn and start working on how to have a labeled robot to do tasks on its own. And we particularly, Joe and I, actually also with Gunter and others at Willow Garage, worked on how to process the tactile signals so that it could pick up unknown objects, set them down or hand them to people or do fist bumps and high fives by responding to the tactile signals that it felt through its tactile pressure sensors, which were quite simple and an accelerometer in the hands.

I also, along the way, was really lucky to do a postdoc with Allison Okamura at Johns Hopkins. And I'm lucky that Penn let me defer my start by one year so that my husband could finish his PhD. He was also a student at Stanford in the same lab. We actually have papers together and we continue to collaborate to this day. But Jonathan Fiedl and I were both able to do postdocs at Johns Hopkins, which is another wonderful collaborative interdisciplinary research

institution they had had headed by Russ Taylor. There had been an engineering research center funded by the NSF called SIST ERC, the Computer Integrated Surgical Systems and Technology Engineering Research Center there. And again, it was even more it was more biomedical than GRASP. And I was able to go into the operating room for the first time and watch DaVinci procedures and talk to surgeons and talk to people who were working on rehabilitation robotics or eye surgical robots. Like it really opened my eyes and got me excited about a lot of other topics and robotics. And so, yeah, that kind of blossomed from there. I've often felt that my research just grows like a tree and it branches in different directions based on what's going on in the field. But also a lot of based on my students interests, what they're passionate about, where their priorities are, which directions they want to take the work. We have a lot of options. There are many decision points when someone writes a fellowship application or when we're deciding what to write about in a grant proposal, or what class project to do, or what new collaborations to start. And I really enjoy that journey of seeing how the research evolves and broadens and intermingles over time.

Q1: That's a really beautiful story of how social research is, and how much it is about the humans, whatever the topic might be. I'm also curious, in terms of deciding on, kind of, what you might want to work on. You feel in your work, are you focusing more on the technical issues that might come with haptics or is it more things that come from an application domain or how do you combine the two?

Katherine Kuchenbecker: It's all of those things. I will. I want to comment quickly on something you said. I definitely believe research is a team sport. And that's why I feel like I have had an advantage by having been a volleyball player. Volleyball is very much a team sport. You have six people on the court. And unlike maybe basketball or soccer, where a single player can score, multiple people have to touch the ball. It's very strategic. You need to. It's very dynamic. It's very quick. And there's a lot of emotions that are involved in dealing with failures, dealing with frustrations. When you miss, miss a hit or your serve goes out, and you have to immediately bounce back. And I feel like those skills have also really benefited me as a researcher, myself, and as a leader, as a manager in my team. Now to transition to the second half of your question, or to your main question, I do like working on the technical aspects of systems. For me, I don't tend to use teleoperation as a way to —It's cool to see that people do these like, what are they called? Where you simulate what an autonomous robot might be by having a human operator teleoperated and control the robot. I think that's very impressive to prove that the hardware can accomplish something. And, but I am usually, in human robot interaction, or, we're not, we're trying not to fake it. I'm usually trying to create a technical system that delivers an experience for a user or an autonomous robot that is operating without kind of like cheating, without getting an assistance from a human operator, depending on—I'm talking about too many things. Let me try to rephrase.

I am personally drawn more towards the technical issues of bringing the systems together. But in the end, they have to work for people. So we are very committed to evaluating them with people. But I like my dream. My ideal papers are— Usually there is a technical contribution, like something novel. We've shown we've been able to do something that we hadn't been able to do

before. But then we also evaluated it in experiments, either a robot doing things in the world or a robot interacting with people or people using our system to do something. Or people interacting with each other with the technology. And I don't want to be too far in either direction. I don't want to only be evaluating technologies that others created, or that are kind of mythical or rely on a human to teleoperate a robot. But I also I don't want to only be building technical systems and be clapping for ourselves of like, oh, wow, look, it works so well. That falls short to me when it's a technology for humans.

I need I really feel very deeply that we need to bring naive people into our labs. And actually, we test iteratively. My students know I'm very committed to demos. So whenever we have visitors, whether that's a grad student who's from another university, who's just a friend of one of my postdocs and one of my PhD students or students from a neighboring university coming by or a professor coming to give the talk, we always give demos of our experiments, demos of our systems, even when they're not fully polished. Along the way, we try to show my own advisor, Gunter, he said, "you should always be ready to show a demo of your work. You never know who's going to walk in the door." Actually, this happened when I was a PhD student at Stanford and I had applied to Penn and they were still processing my application. It turned out that Vijay Kumar, the Dean, now of engineering at Penn and, at the time the chair of mechanical engineering, the department I'd applied for applied to, he walked through the door of the lab where I was working at Stanford with Ken Waldron, who was the professor in the neighboring lab. And Vijay knew I had applied and wanted, thought, "Oh, maybe Katherine's there. And he walked into the lab. I was able to, in just five minutes, try to run up the commands and show him a demo, a hands on demo, so he could feel what I was working on as a PhD student. And I'm very lucky that they invited me for an interview and I ended up getting an offer and accepting it.

But, yeah, you should always be ready to give a demo of your robot, of your system, or at least show it to the people. And, it's not only because your future employer might walk through the door, but also because all kinds of people ask questions. They have different ideas. They see our technologies in a different way. And they may ask us something that we didn't think of ourselves or raise a concern. Like, "Oh, did you think about privacy," or, "Is this a dangerous technology? Could your hugging robot hurt someone?" And I tell my students — we also do open days for the public or girls days. We're bringing kids. We do open houses for the PhD students in our doctoral programs. I always tell them, or we take demos to conferences. I always tell them afterwards, "write down some notes like, what were the main key things? Because you don't want to lose those. You want to write them down and remember them and then bring them to the next meeting with me or your collaborators, so that we have a chance to learn from them, and make sure we're not missing something, making an oversight, because some of those concerns are going to be the same things that the reviewers of our papers, of the future potential users of our systems, our technologies are going to bring up."

Q1: So you mentioned the hugging robot, and you mentioned some others along the way. But could you tell us a little bit about, what are the kind of projects or things that you've done that you feel are your most, I don't want to say interesting, your favorite contributions?

Katherine Kuchenbecker: My favorite contributions are actually the people that I've helped train and I've been able to learn from along the way. PhD students, it's a really great relationship. When you take a PhD student, it's almost like adopting an adult child. If you have a co-advisor, you're like choosing someone together and committing to help raise them in science. And it's so invigorating and it's so exciting to see them develop and see the ideas that they bring and see them, how proud they are. When they're graduating, when they get a faculty job, or get a job in industry. And I have no preconceived notions about whether it's better to have students or postdocs who want to stay in academia or go into industry. Both are amazing ways of contributing. But to see them take those steps forward, like one of my PhD students recently got a job at like a dream robotics company for her. And I was, of course, feeling she was a PhD student with me and now she's been doing a postdoc with me. And of course, when she told me I was sad, as was Mayumi Mohan, that she will be leaving because we actually, of course, we keep doing research. My mom always says the conclusion to all research is more research is needed. But just when our students, our postdocs are becoming like so useful, they're almost OK, they're almost autonomous. They don't really need me as much anymore, but they can't, they shouldn't stay in my lab forever. And so when she told me she got this job offer and they wanted her to start November 1st, I said, "Wow, congratulations. I'm so happy for you. We're going to make a way, figure out a way to make that work. OK, well, maybe Coral is on November 4th to 9th and we're demoing there. So maybe they would accept November 15th." This is for NEURA Robotics, a German robotic startup company.

So, yeah, my first the first contribution that I would say is absolutely, all the PhD students and postdocs that I've had the privilege of training, and especially those who've decided to stay in academia because I get to keep seeing them over the years. Of course, I never review their papers and I actually really try to stay out of the fields that they're carving out for themselves. But I get to see them at conferences. I get to see them win prizes. I just saw Heather Culbertson, who was my third PhD student, the first one of mine to become a professor herself. She's up for tenure now at USC. She just won the Mass Robotics Rising Star Award. Together with Josie Hughes, who's also another amazing professor that I really admire at EPFL. Or, yeah, one of my students just got tenure, Naomi Fitter at Oregon State University. Jeremy Brown, my first postdoc who decided to stay in academia. He's up for tenure at Johns Hopkins this year. And so many of my other trainees. I was just working on a recommendation letter for my PhD student, Rachael Beville Burns, who will start on January 1st as an assistant professor at the University of Tennessee, Knoxville. And it's really fulfilling. So to see them continue on their journeys. And I always tell them, you don't need me anymore. Like, we've had a lot of fun working together, but you should go out and do your own thing, and you'll have more room to think or recruit your own students.

But maybe I should tell you, actually answer your question. I say a few research projects that I'm particularly proud of. One is definitely HuggieBot. And this was the doctoral work and actually the master's thesis work of Alexis Block. She was my first PhD student after I moved from Penn to the Max Planck Institute for Intelligent Systems at Penn. She was doing her master's thesis with me in the robotics master's program there. And we dressed our PR2 up in a soft, fluffy, warm outfit and programmed it to hug people in different ways, either hold on too long or let go too early. And we had very simple tactile sensing, but people liked hugging this robot way more than we expected. And Alexis had several offers for her doctorate and I was glad

that I could convince her to move with me to Germany. And that we planned that she would design and build a new hugging robot that was purpose-built for this application. And actually I talked about it in my talk on Tuesday morning here at ICRA@40.

I think the part of that work that I was the most proud of was the tactile sensing because she, Alexis, made an inflated chest. We called it HuggieChest, and it has a very simple instrumentation, a microphone and a pressure sensor. So many people who do tactile sensing, they try to know where exactly someone's touching the robot. That makes it so complicated by making it inflated, making it a soft robot body and doing minimal sensing. But it was important that we had, not only a pressure sensor, but also a microphone. We had dual kind of temporal bandwidths. This is a theme that comes up over and over in my research that it pays. There's great benefit to be had by looking at both the low frequencies and the high frequencies. There are a lot of detailed information in the high frequencies when it's about contact. And so by training, we collected a data set of what the robot feels in its body when you pad it or rub it or squeeze it or just hold still. And with the support of Hasti Saifi, who's now an assistant professor at Arizona State at the time, she was a postdoc with me at Max Mike.

And so we enabled the robot to recognize in real time what kinds of gestures, when someone does something and react very quickly. And this creates this interactive robot embrace that's uncanny. It's so fun. You just feel like you can nestle in with the robot and it's warm and soft. And when you squeeze it, it will squeeze you back or pat you. And then sometimes if you hold still for a long time, we tested all the possible combinations. There's a very long paper. It's published in ACM, Transactional On Human Robot Interaction. We tested, what does it feel like if you're just sitting still and the robot spontaneously pats you or squeezes you. And people loved that. It feels so fulfilling. Like the robot understands you. Like the robot likes you. Like the robot wants you to be there. And so, yeah, we took this HuggieBot robot to Hamburg for EuroHaptics 2022, and hugged more than 100 people over the course of several days. And we were honored to win the best demo prize because it's surprising. You look at the robot, you think, oh, that looks kind of funny or strange. But then, when it's hugging you, it's like really calming and pleasant. So, that's one haptic experience that I could never could have imagined working on at the start of my career. And we would not have worked on hugging robots if Alexis hadn't gotten really excited about that idea. And it's been a lot of fun. But now I don't work on hugging robots anymore because that's her thing.

I'll say one other thing that I'm really proud of. And it's an insight that goes all the way from the very first work I did in my doctorate and through teleoperation, through the hugging robot and through autonomous robots, and that's paying attention to the higher frequencies present in tactile signals. And here, our work was enabled by MEMS-based sensors, especially MEMS-based high bandwidth accelerometers. Because, when you can buy a chip that's only a few dollars and just tiny, and you can solder it on our board and place it like parasitically on a Da Vinci instrument, on a stylus, inside a robot hand, it's basically like a microphone in HuggieBot's body. Or, you can put this tiny sensor and record these rich details of the 3D contact that that part of the robot or that tool is enduring. And then, you can transmit that feedback to the operator. This is one of my favorite ideas that is not commercially, it's not in the market. It was never adopted by Intuitive Surgical or other surgical robotics companies. But we found that just putting a little accelerometer near the surgical instruments and bringing those signals, those high

frequency signals, to the fingers of the surgeon lets them feel what the robot tools are touching. And that we are often ignoring the higher frequencies and that there are great insights about the transience of contact. And also the skill of the operator, that when the surgeon is experienced, they're much better at bringing the instruments into contact gently and with skill. And then someone who is more new to operating, they're much rougher and they have all these extra collisions. It was one of those insights that just kept paying off in many different directions.

Q1: You mentioned the sensors. Were there other kinds of tools during your work that helped you develop new directions? You also mentioned the CR2, which was one of the early robots that was available for a certain kind of experimentation.

Katherine Kuchenbecker: Yeah, we've used so many different tools over my career. I couldn't possibly list them all. The Baxter Robot from Rethink Robotics was really transformational. My first PhD student, Joe Romano, had worked at Rethink for a little while. He had interned there. And then we had one at Penn. My colleagues and I had one and Naomi Fitter started using it for physical human-robot interaction. So Joe had programmed some initial demos of the PR2 of high fives and fist bumps. And then Naomi did her whole PhD thesis on high fives and also with lots of things, social, physical human-robot interaction. And that actually inspired Alexis to want to work on hugging robots. And even today, we still have two Baxters and we're using them to test a new, actually, Mayumi, the student, the postdoc I mentioned before, has been using them to test a teleoperation, like a kinematic retargeting algorithm that we've built and that we're open sourcing. And they're also doing other studies of human-robot interaction. Certainly, motion tracking of humans, whether that's with cameras typically or wearable sensors, like it's very useful. Or markerless motion capture, we use the capture a lot. Also for human-robot interaction. I mean, back in the day, a Kinect, we had a Kinect and put it on the top of our PR2 and it could see people. That's how we did the high fives and fist bumps. So many different kinds of sensors, so many different kinds of hardware. Yeah. Yeah, those are the main ones.

Q1: Are you, since you're talking about a new, we were talking about hardware, but in terms of other kinds of things, are you interested at all in the developments in terms of generative AI models, or do you think that has a space in the kind of work that you do, maybe not so useful?

Katherine Kuchenbecker: No, I see the generative AI as having a big influence. I don't tend to follow the trends. I don't want to be chasing something that hundreds of other researchers around the world are. Now, if my student came to me and said, "Katherine, this is something we really have to be doing," then yeah, of course. We're using modern learning, we're using reinforcement learning, we use deep learning, we use all sorts of learning tools to process robot sensory data. Things may change in the future, but it's not something that I'm really focused on, but I can't say what we'll be doing in the future. One great way that I think that tree of my research has grown is by co-advising students. I mentioned this briefly before, but it's something I think about half of my PhD students now, I'm co-advising with another professor, and it's usually someone who's not at all close to me. I have a student with Michael Black, who's a computer vision researcher,

who's a real expert on seeing humans, and she's working on sign language. Some of the things she's doing are computer vision, like really cutting edge. We had a CBPR paper last year on reconstructing sign language, all sign languages from very low-res videos that you can just download online by encoding the linguistics of sign language. I would not have worked on this, and I could not have worked on this without a really excellent computer vision researcher and the idea of my student bringing it together, but it has to do with hands and motion, also self-contact. There are some haptics.

Also, I have a PhD student, Iris Andersov, the first student, her name is Paolo Forte. I have a student with Georg Marzius, who's a real excellent machine learning professor at the University of Tübingen. I will see what comes. We also sometimes, when you join a big collaborative research grant or a proposal, that can take your work in new directions. If it's needed for a particular project, I could imagine it being interesting, but there are so many problems that we could study and work on that, yeah, Generative AI, I'm still a little skeptical of whether it's going to be useful for robots, which are such complex embodied systems. But let's see. There have been some great talks here at ECRA@40 that are showing the potential.

Q1: So you've talked a lot about interdisciplinary work and this kind of finding connection in various ways in terms of the positive aspects. What about challenges? Not just in interdisciplinary work, but maybe what are some of the big challenges that you face in your research generally over time? And maybe even some that you haven't been able to overcome or any directions you wanted to go, but couldn't.

Katherine Kuchenbecker: Do you mean like technical challenges, something that we haven't been able to solve or like adversity or like external?

Q1: Both.

Katherine Kuchenbecker: Interesting. I feel like I've been very lucky and I haven't, I've had a lot of good support and I used to, when I was a professor at the University of Pennsylvania, the biggest stress for me was whether I would be able to get enough funding to pay my lab, because of course, we always want our students to have a salary and tuition and it's expensive. And I wrote a lot of grant proposals. I know a lot of faculty do as well. And somehow I always was able to cover the bills. I was always able to pay everyone. I had no gaps in my funding, but that was always there as a stress. And I think none of us does our best work when we're afraid. I mean, a little bit of fear, I think, is a positive incentive, but then it sometimes it could become almost paralyzing. I never wanted to submit a grant proposal that I wasn't actually passionate about or enter into collaborations that I didn't think were going to be fruitful, or force a student to work on a topic that they really didn't want. There's like this magical thing of finding the money, finding the people and the topic at the right time. And I was always able to orchestrate it, but it added a lot of stress. And it was kind of an underlying stress. And therefore, I'm enormously grateful that the Max Planck Society gave me a position as a director at the Max Planck Institute

for Intelligent Systems. And I have full funding for my lab. I do still write grant proposals. My students still apply for fellowships and my postdocs do, but we have a baseline level of funding that I can keep my lab going and we can work on anything that we want. And this is a privilege that the vast majority of professors, researchers don't have. And that definitely took away some of that, and some of the stress that I was feeling as a university professor. And I've been able to, I try to steer that for good. I try to use it to develop really promising young researchers to build new collaborations, to push in directions of the field that I think are promising, but that might not yet be fundable.

Other challenges. The challenge that I'm faced with almost every day is I feel like I don't have enough time. It feels like things are just going faster and faster. I was just going through my email and I think I had six paper review invitations in the last three days. It is not feasible. I could have a full time job just reviewing papers, reviewing grant proposals. And maybe this is a feature of becoming more prominent. I'm so lucky that journals, editors, funding organizations think that I would be qualified to give them an opinion on where this, how this paper, whether this paper should be published, is it valid? How should this money be given to this person? Tenure letters, full professor promotion letters. But I have to say no to a lot of the things. I do feel like I have a duty to contribute to science, to our scientific community. I think anyone who's doing no reviews is not pulling their weight. We all learn something from reading other people's papers, from looking over a tenure case, from writing, for writing an evaluation of a grant proposal. This is part of what makes science, keeps us honest, helps us stay true to make sure our work is being transferred to other people, or hold each other to high standards and learn from each other. But that work could fill everything. So for me, the biggest challenge is figuring out what to say no to, and protecting enough of my time so that I can still sit down with my PhD students, with my postdocs, try our demos, edit our papers.

I edit every paper, like every word of every paper we submit. I really don't want something to go out with my name on it and my team's name with my institution, and go to the reviewers, go to the editors without like being up to the quality bar that I expect. Of course, we all sometimes, a paper's not well thought through or we missed something, we made some typos or we, there's a logical flaw. But like I want to bring the work to a level where I am really proud of it before I send it out to "waste" other people's time, to ask other people to spend time giving feedback. So yeah, for me, the biggest challenge is just finding enough time to do quality work. And that means picking and choosing. I also think there probably are times when my family wishes they saw more of me. And I try really hard to, we cook, my husband and I cook breakfast and eat breakfast together. We cook dinner together with whichever of my stepdaughters who's around. And we try to go on vacations regularly. But as a researcher, there's always more you could be doing. There are always emails in my inbox. There's always someone waiting for something. And I don't know, maybe I'll get some wisdom, more wisdom. But the best thing I've figured out is I need to say no to many things. But if I'm going to do it, I want to do it well.

Yeah. Coming back to research challenges, I don't think I have anything more specific to say. We're working on so many different things. There wasn't one thing that I really ever felt like we were stuck. Sometimes I've had to come back to a problem years later because, with the current technology, with the things we could buy, it just didn't seem fruitful. And so I'll tell a quick example on that, which we actually finally recently made a big breakthrough on. My first

NSF grant when I was a professor at Penn was on wearable haptics. So we used a Kinect to track the movement of a human body. And we put little vibrotactile actuators on the body to try to guide your movement. So I was collaborating with researchers at Moss Rehab. And we were thinking about stroke patients. We had the idea that if we had a therapist, who recorded the arm motions that they wanted their patient to practice on their affected side. So the upper limb, the arm that was less coordinated after the stroke, that maybe if you practiced in a kind of a game-like setting and you not just watch the screen, but also could feel, “oh, I need to lift my elbow up higher.” So we built that system and tested it. And we also had a series of, we tried vibrotactile motors, just little eccentric rotating mass motors. And they have a turn on delay. They don't feel very natural. They're not very localized in the sensations they can provide. And that latency, the latency in them and the kind of diffusion, that it made it really hard to feel exactly where.

So we were able to do enough. My fantastic postdoc, Karlyn Bark, who's now at Apple, were able to do a really nice study with healthy participants and show that there is some promise, but that we were limited by actuators in parallel. We were working on wrist rotation. We had these little servo based devices that would tap or squeeze or press on your skin. It was with actually an undergrad researcher, Andrew Stanley, who later did a PhD with Allison Okamura at Stanford and is now at META. And as his undergrad summer REU project, he helped design and build these little devices. And we tested how you could use them for motion guidance. And this was much more promising than vibration. And people preferred it. They found it much more pleasant. You could feel the direction. It was very crisp. It felt more like someone reaching over and touching your hand. It was very easy to localize and not as annoying as vibrations. But the devices we could build, these little servos that were used in like model aircraft, model planes and cars, they were so noisy and rigid. And they didn't have that good of bandwidth. You could only send them a command at 50 times a second. So there was a big limitation there in terms of actuation.

And so for years, I was keeping my eyes open for what kinds of actuators could we use that would be able to deliver localized haptic feedback on the skin of a human that would get around some of these disadvantages that electromagnetic actuators have. And my institute, we hired Christoph Keplinger, who used to be a professor at the University of Colorado Boulder. He's now a director in the Max Planck Institute for Intelligent Systems. And he and his team had invented HASELs, which are hydraulically amplified self-healing electrostatic actuators. Basically like a bag of mylar with oil inside with electrodes on the two sides. And if you apply a high voltage, it squeezes the electrodes. The electrodes are attracted to one another, and then oil moves in. So they're able to make artificial muscles that are much closer to the performance of biological muscle and even sometimes exceeding it. Now you have to completely rethink because it's an electric motor. I know how an electric motor works and what I can expect from it. And you get these like bags of oil with thousands of volts. But that was the actuator that we've now been able to use and adapt.

So we redesigned, we fabricated themselves. My brilliant PhD student, Natalia Sanchez-Tamayo, who's co-advised with Christoph, she learned from his team how to make HASEL actuators and started making small ones that we could mount into a wrist, wearable similar to an Apple Watch. I also presented this in my IKRA@40 talk. And we can fold up these

pouches and get an actuator that's very compact, very energy efficient, silent, stays cool, and gets like two and a half millimeters of displacement or up to several newtons of force and a high bandwidth, up to 2000 Hertz or even beyond. And with my deep commitment to high frequencies in both sensing and actuation, this was like my miracle actuator. And so we just had a paper accepted to Advanced Science where we show, for the first time using HASELs for haptics. And we can make and break contact with your skin and press and vibrate up to a wide range of frequencies. And our users could recognize the sensations that we presented to their really, really well almost perfectly. And they said they feel really pleasant because they're made of soft materials. They feel like more familiar, more comfortable. So it just really broadens the expressive range of sensations that we can present. And I'm really excited to start now trying to use that in human-computer interaction. We have a demo at WIST in VR where you're feeling based on what you're touching. In VR, you feel the sensations through this HASEL-based actuator on your wrist or, for motion guidance, like I was talking before. Could you put them in different places on your body and help you learn how to modify your movement in real time?

Q1: That sounds amazing. I'm wondering, you kind of talked about how things have changed in your own words. If you're thinking of robotics generally as a field, what do you think have been some of the main changes? How has it developed over the time you've been involved? And to even make it worse, where do you think it might be going?

Katherine Kuchenbecker: Yeah, this is a very hard question. If I think back to what was taught in a robotics class when I took robotics from Oussama Khatib at Stanford, actually two robotics classes. And it was all kinematics of manipulators. There was a lot of math, forward kinematics, inference kinematics and dynamics. And the kinds of devices that are now considered to be robots and their capabilities, it's vastly expanded. I've already been talking a lot about cutaneous or tactile sensing and actuation. That wasn't really a topic. It seemed, at that time, human-robot interaction, social human-robot interaction has exploded, autonomous cars and navigation by robots, learning, machine learning transformed what we can do in robotics.

But it's very hard to say where it's going. The very first robotics conferences I went to, even then I was overwhelmed with how many parallel sessions there were. I was like, "Wow, what is SLAM? Why are there so many sessions on SLAM?" And I went to a few and was like, "Oh, wow, I had never thought about that as a problem that a robot needs to solve." And now I was at ICRA in Yokohama earlier this year. And I think it's the biggest ICRA ever. It was like 5,000 attendees. So I'm glad to see this level of enthusiasm, that we have so many smart, enthusiastic people working on so many different pieces. I think a challenge in robotics will be that, to keep everyone together and keep learning from each other. And here, I think the format of ICRA@40 is really beneficial because what Tamim and Stefano and others organized is keynote talks by leading researchers in only 10 minutes, ideally. Many people are speaking longer than 10 minutes. But to try to distill their message, the main thing they've learned over the career, their main things they're thinking about, to share them in this very efficient format with the community, the attendees here, and later with others who watch the recorded talks. And I think that kind of thing is going to help facilitate communication and learning from each other so

that the great ideas that are happening in different areas in robotics can cross-pollinate. And so we don't have to keep solving the same problems over and over, or we can learn from each other.

Unfortunately, there are so many papers being published, more papers than you could ever read. And so, of course, you read the ones when you review them, when you write them, the ones that you're citing, the papers really close to your field. But it's, I think, impossible to read all the papers in all the areas of robotics. And that's why these talks are a more efficient way to get a little window and also to look, listen for patterns of like, what are people across the world in Japan, in the US, in Europe, in different countries, in different fields? What are some common themes that are coming up over and over again? And then can we work together on trying to solve this problem?

Q1: That's wonderful. Thank you, Darrel was just saying that we're at about time. But I was just wondering if there's anything that you would have wanted to talk about that you didn't get to, anything you would want to mention?

Katherine Kuchenbecker: Yeah, thank you. I think one other part that's really important to mention is diversity and trying to make sure that robotics is a research community that welcomes people from all backgrounds. I am a woman. There are not that many women in robotics. There are more than there used to be. My lab is very gender balanced. And I think I have more women PhD students than men right now. And we have researchers from literally all over the world and all kinds of backgrounds, all majors. And I find that creates a really rich, cooperative, enthusiastic community. And Christoph Keplinger's lab is the same. And I find this, that bringing in, recruiting a diverse set of students, it leads to more novel ideas, more creative innovations.

And then if my lab, when my lab, when it started, I was the only woman in my lab. I only had male PhD students, male postdocs, and they were great. We had fun. But there was a little bit of a weird attitude. I'd been the only woman in an advanced robotics class at Stanford. And it was sometimes strange. There were some weird comments. I got mistaken for a secretary like repeatedly by a visiting group of robotics professors who were visiting. And they were cackling and laughing about, "Oh, wow. It's so cool that you have a secretary." And I was like, "I'm actually a PhD student. I'd love to show you my research." I mean, I didn't just that they came from, I think it was a group of researchers from Japan, if I remember correctly. And to them, it was just so bizarre to have a woman PhD student, or they were just really surprised. It was obviously kind of uncomfortable to them. And I hope that, over time, more and more robotics labs around the world will reflect the diversity of the people in the world. And especially as we work on technologies, they could directly help people. That's a very motivating goal for many people. And we need people of different backgrounds to input different perspectives and different priorities to help keep us on track.