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Makoto Kaneko

An interview conducted by
Selma Sabanovic
with
Matthew Francisco

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Selma Sabanovic: So if we can start with you just telling your name, and where you were born and when.

Makoto Kaneko: Okay. So my name is Makoto Kaneko, so I was born at... Hagi, is a very small city, is west part of Japan. And... okay, that's it.

Selma Sabanovic: Okay. And when were you born?

Makoto Kaneko: Ummm … 1954, January 18th.

Selma Sabanovic: Mm-hmm. And could you tell us a little bit about your early interests in school?

Makoto Kaneko: High school? Junior high school?

Selma Sabanovic: Mm-hmm.

Makoto Kaneko: So, for kind of...

Selma Sabanovic: Like how did you get interested in – I know you went to Tokyo University...

Matthew Francisco: In engineering, maybe.

Makoto Kaneko: Oh yeah.

<laughter>

Matthew Francisco: Yeah, so where did the interest in engineering come from?

Makoto Kaneko: Yeah, okay. I liked maths and then physics. So when I was a kid, I enjoyed a lot with nature, and such as... that is already 50 years ago. So my city is very small, population is just 50,000, it looks like this city. And there is many nature and many fishes in the river, and many insects. So I enjoyed a lot, so I think if you're working in this... some robotics or something like that, and building up something, and all the equipment is obeyed to some nature rule. So I think when if you are a kid you can enjoy with nature, I think this is very important. This is my experience.

Selma Sabanovic: And so actually looking at the animals and nature made you think about...

Makoto Kaneko: Yes.

Selma Sabanovic: …also constructing some things?

Makoto Kaneko: Yes, I constructed many toys by myself. And I enjoyed a lot, yes. Okay <laughs>.

Matthew Francisco: Oh yeah.

Selma Sabanovic: Yeah, yeah. And so then how did you decide to go to university in Tokyo?

Makoto Kaneko: So actually my undergraduate I spent in the Kyushu Institute of Technology, and then... okay, I decided to go to the graduate school, and then I decided to go to Tokyo University, because the university is the best university in Japan. And perhaps I thought I have a chance to meet with some distinguished professors there; that's my big motivation to decide Tokyo University. But that time I didn't figure out any future work such as robotics, just I wanted to go to graduate school.

Selma Sabanovic: What was your undergraduate degree in?

Makoto Kaneko: Mechanical engineering.

Selma Sabanovic: And were there specific professors that you wanted to see in Tokyo University?

Makoto Kaneko: Oh actually not, because this is a completely different university. I had some informations: how many professors and what each professor is doing, what kind of subject? But I could not figure out which professor it's appropriate to meet. But I just throw some dice ... how to say? Somehow lottery.

Selma Sabanovic: Oh, a dice.

<laughter>

Makoto Kaneko: That's right, yeah dice, right, I throw dice. And then the dice is three, okay, so one, two, three, I decided that...

<laughter>

Makoto Kaneko: …just like that.

Selma Sabanovic: So who did you pick as number three? <laughs>

Makoto Kaneko: That is fluid dynamics, the area is fluid dynamics. He was a – still alive and he was a great professor for me. Okay, he just gave us topics, not precisely, just topics, I mean just like a program, not precisely. After that he didn't say anything, just I can do as I want. I love that kind of style, and the professor just say some comment when I go to the different direction. So as far as I can go straight, he didn't say anything. Yeah, I love that kind of style.

Selma Sabanovic: What was his name?

Makoto Kaneko: Ohashi, Hideo Ohashi, yeah. So yeah, okay. He often said that... the enjoying with nature, that is very important. Because all rules simply follow the nature, such as Newton's Law, or other laws is simply followed with nature. And recently I understand, I love research because the nature never tells a lie, but people says some different words depending upon the situation, but nature never, never say … tell a lie. So I love that kind of rule, very basic rule, so I love to research.

Selma Sabanovic: And so what topic did professor Ohashi...

Makoto Kaneko: Okay, so that is very interesting topics. For example, the topic very related with the current Japan situation, I mean the heavy, very big earthquake, and then at the power plant destroyed. And due to the lack of coolant water, and then it's heaviest, that is heaviest situation. So at that time almost is 30 years ago, and my professor suggest me to do for the research, research is just like pump performance, but this pump is only for the atomic power plant, it's a circulation, water circulations. And then in this circulation system there is a pump, so otherwise we cannot circulate water in the power plant. So that is most important circulation system. But if some earthquake happen, just like this year, then the piping system is break down, and then the one scenario is the no water in the core, because that's the worst scenario. But actually this year's earthquake is very close to that kind of situation. And then I learned... at that time it was piping down, actually internal pressure is kept always very high pressure, as for that we can suppress the <inaudible>. But once piping system is breaking down, and then the pressure is down, internal pressure is down. So then there gradually is some buoy, buoying start, and under such a situation how pumping performance is changed. So that is the background of my work. So at that time I designed a total system including the pump, and instead of buoying, so we insert artificially, add air to the system, and how the pumping performance is changing. And as such waters, air, the two-phase condition, okay? And then just by chance I found a very interesting phenomenon, and under some particular condition the pumping system start a very big oscillation. So oscillation actually is not good for the circulation system, so I did a number of experiments and we found eventually why that kind of oscillation happened. So this is my Ph.D. topics, I enjoy it a lot.

Selma Sabanovic: <sneezes> Sorry.

<laughter>

Matthew Francisco: So you were able to get to design, actually build things, and also do experimentation in the...

Makoto Kaneko: Yes, yes. So actually not everything, because it's too much, but partially. Design and then the building assembly. So the small part we bought, and also we ask some company to build it, yeah.

Selma Sabanovic: And was it ever implemented?

Makoto Kaneko: Hmm?

Selma Sabanovic: Was it ever used in a real system?

Makoto Kaneko: That's a scaled down model, so of course it's a real system, so then it's more than the whole building here, because that is a power plant. Just as scaled down, it's one over ten or something like that.

Selma Sabanovic: And so after... you finished in 1978?

Makoto Kaneko: Mm-hmm.

Selma Sabanovic: With your Ph.D.?

Makoto Kaneko: No, Ph.D. is 1981.

Selma Sabanovic: Oh, you started in '78.

Makoto Kaneko: Oh yes, okay, that's it.

Selma Sabanovic: <laughs> I found from the internet but I wasn't sure if...

Makoto Kaneko: Oh, I see, I'll correct it.

Selma Sabanovic: Okay. And then after that you went to MEL in Tsukuba?

Makoto Kaneko: Yeah, Mechanical Engineer Laboratory is that time, that is a government laboratory, belonging to Ministry of International Trade and Industry.

Selma Sabanovic: So it wasn't AIST or...? Was it part of AIST?

Makoto Kaneko: Yeah, AIST is correct, exactly.

Selma Sabanovic: How did you decide to go to MEL?

Makoto Kaneko: Oh, okay. Because I had two choices... no actually three choices; one is the – I wanted eventually to go to the academia, with like a university, but it just depend on the position availability. And so then okay, and the two choices, one is to go to the private company, and one is to go to such just like a government laboratory. And private company, hmm... okay, a couple of company is a candidate but eventually I gave up entering the private university, and I decided to go to the MEL. But actually it not that easy to enter the government laboratory, because at that time there are two patterns, first pattern is to take exam. That's a really tough exam, its competition rate is over 50, it's very tough. And second chance is if you take the Ph.D. and then if the position is available, appropriate position is available, and then you can go. Yeah. Yeah, for me it's actually... the second chance, that Ph.D.-based entering, then okay, you can continue with your Ph.D. work. So otherwise there is no reason for the government to hire you, because if you have a Ph.D. and then they try to – okay, they have some particular area where they want to advance in the future, and then okay, who is the right person for this area? Oh actually he wrote his Ph.D. in this area, so why not? We can take this guy. So that kind of reason, very reasonable. But in my case I took exam, and then just by chance it passed, so then in that case the government has the right to assign me into anywhere they want. So my background was fluid dynamics but he eventually decided to assign me in the robotics, yeah because this is quite new at that time, it's almost 30 years ago. In Japan is people working in the robotics very few number, in university for example I couldn't see any university working in that kind of area. So at first that is a really big change for me, from the fluid dynamics to the robotics. It's a very big change. So robotics research needs the computers knowledge and mechanical knowledge, and many other, also the controls. So in such sense it's completely different area.

Matthew Francisco: Do you know who assigned you? Who made that decision?

Makoto Kaneko: Okay, that is the top of the institute.

Matthew Francisco: Okay. So is there just one person or a group of people?

Makoto Kaneko: At that time just one person is in that area.

Matthew Francisco: Okay.

Selma Sabanovic: What kind of robotics research were they doing when you got there?

Makoto Kaneko: At that time it's – oh it's a really funny robot, so-called "Guide Dog Robot." Okay, you know for blind person?

Selma Sabanovic: Mm-hmm.

Makoto Kaneko: And sometimes it's the guide dog for him, or he simply follow the way as guide dog is moving. So at that time our institute is developing that kind of robot, and then they assigned me as a part of research in that area. But I couldn't understand anything, okay? That's the starting point. So nearly every day people are discussing how to improve, how to develop the next model, but I couldn't understand any key word.. So that's very, very... yeah, it's very hard for me to follow. That's the starting point.

Matthew Francisco: What changed that?

Makoto Kaneko: Pardon?

Matthew Francisco: What changed it? What got you – or did you ever get understanding of the robot?

Makoto Kaneko: Yeah, so at first I sometimes think about, "Okay, should I come back to the original work?" By changing my job or something like that. But initially, okay there are some common point between my original work and robotics area. In some common, it's very small area but there are some. I was working in that area, and then gradually, gradually assisting to the main area of robotics. So it takes more than five or six years.

Selma Sabanovic: What was that common area?

Makoto Kaneko: Common area, okay, it's a good point. In fluid dynamics is often just scaling effect, scaling is the... okay, for example the big fish and small fish, they can swim by using the fin, but big one and small one is the drag force and the lifting force, of course they are different. But if the scale is similar, then we can discuss is there... some same dimensionally? And then without considering the scale effect, so we can discuss. So the walking robot for example, the very big one and small one, and energy consumption different of course. The big one is large energy consumption, the small one is of course small. There should be some similarity law, then I formulate the equation, and then the equation is transformed into the non-dimensional, then I can guess some new non-dimensional particle; that if we keep this particle, and then we can discuss the energy consumption law without considering the scale. So that kind of common, the non-dimensional and scaling effect. But actually it's not the main part of robotics, but I was very crazy at that time in the formulating and finding some new rule. Even though this is not the pure main part of the robotics, because I didn't have much knowledge on motor control. Because robot control, the essence, the fundamental part is actually the control, and with the sensory feedback. So I didn't have any knowledge of that at that time. So that's the history.

Selma Sabanovic: So how did you start getting more involved in robotic issues?

Makoto Kaneko: Yeah, so the first – after two or three years my boss suggested me to design some walking robot, six-leg robot. And I did, and the basic concept is try... the main body, the design policy is to make the main body as horizontal as possible and as constant height as possible, so that we can reduce energy. Because if the main body is up and down, so it's much, much energy consumption. So that is the first – that's the design policy, so you are obliged to learn the motor control, then I learned, okay? So by necessity I learned, gradually <laughs>, that's the way, yeah. That's my first work, yeah.

Selma Sabanovic: And you probably learned a little bit from … with just talking to the guide dog robot...

Makoto Kaneko: Oh yes.

Selma Sabanovic: …people <laughs>.

Makoto Kaneko: Oh yes, of course, of course. So that is the first robot. And I think that project is five or six years, and then I started to the multi-fingered hand. Again, this topics was given by my boss.

Selma Sabanovic: Mm-hmm. Do you know why they were doing first guide dog and then six legs, and then hands? Was there...

Makoto Kaneko: Oh, I see. Okay, I would say there are a couple of groups. So some group is guide dog, dog robot, and some group is just started the walking robot; I just joined that project. Initially guide dog robot, because I'm just a beginner so they didn't expect me much, just okay, for me just a learning phase.

Selma Sabanovic: And when you got there how many people were part of MEL?

Makoto Kaneko: So roughly 20, 20 researchers. So the group is two or three, yeah... person, yeah.

Selma Sabanovic: Who were some of the people who worked with you on the guide dog?

Makoto Kaneko: Say that again?

Selma Sabanovic: On the guide dog project, who were some of the other researchers? Coworkers?

Makoto Kaneko: Oh coworker, you mean the exact name or just the...?

Selma Sabanovic: If you remember.

Makoto Kaneko: Oh yes, of course.

<laughter>

Makoto Kaneko: So Doctor Tachi and Doctor Komorie and Doctor Tanie. You know him? He passed away.

Selma Sabanovic: Yes, yeah. You've met him too, yes.

Matthew Francisco: I met him, yeah.

Makoto Kaneko: Oh you met him? Yeah. Actually Doctor Tanie was my boss.

Matthew Francisco: Oh, okay.

Makoto Kaneko: For a long – he is a very good advisor, and he's very good, I learned a lot. So these are the core members. And the leg robot also the core members, Doctor Tanie is one of them, yeah. So anyways, Doctor Tanie for long, long years, he was my boss.

Matthew Francisco: So he was also the one who gave you the hand?

Makoto Kaneko: Oh yes, he also – yeah.

Selma Sabanovic: So he was the head of MEL? Or... no.

Makoto Kaneko: Eventually he was almost the head of the MEL, but the MEL disappeared, the institute changed from MEL to AISD to...

Selma Sabanovic: Mm-hmm. Yeah, I met him because I...

Makoto Kaneko: Oh really?

Selma Sabanovic: …was working with Shibata-san.

Makoto Kaneko: Oh, Shibata...

Selma Sabanovic: So he put me <laughs>, so I was an exchange researcher and he put me with the PARO Project. So that's when I met him <laughs>.

Makoto Kaneko: Oh I see, I see. You met Doctor Tanie?

Selma Sabanovic: Yes, yes.

Makoto Kaneko: Oh I see, maybe it's more than... 10 years or maybe...

Selma Sabanovic: In 2005.

Makoto Kaneko: 2005, okay.

Selma Sabanovic: Mm-hmm. So what were some of the things you were interested in in the multi-finger hand? What kinds of problems did you do?

Makoto Kaneko: So every times that I think for the research, is I want to do something which is never done by other people. And okay, there are many, many people working on multi-finger robot, but my idea is... some new sensor, to implement some new sensor. Especially... if we have some object, so human is unconsciously we can manipulate object very dexterously. But for very simple task is robot is really, really hard; I learned that kind of fact through the first model of a hand. And I recognized, I realized the pulse sensors is really important for the hand, artificial hand. And I designed, invented a new type of pulse sensor and... that is really effective, and we got a patent, not only Japan but also in the United States. But see the time is already expired, now everyone can use it. But then okay, that is a very big advancement for me to learn the sensor and also to learn the control architecture, control system of the robot.

Selma Sabanovic: And when was that project?

Makoto Kaneko: That is 1986. And so... I involved the hand research for more than... since that time almost 20 years. That is my main, major work in robotics. So I developed so far five or six robot hand, so initially is just two-finger, and then three-finger. So every design I learned something, so gradually my knowledge increased and then more sophisticated robot hands, so... I could design.

Selma Sabanovic: And were you looking at work that was previously done in other places about robot hands?

Makoto Kaneko: In other places, you mean the different institute? Or another place means...

Selma Sabanovic: Yeah, so I know in the US, like Ken Salisbury has hands and other kind of...

Makoto Kaneko: So Ken Salisbury hand is my textbook.

Selma Sabanovic: <laughs>

Makoto Kaneko: You know that? You know the hand?

Selma Sabanovic: Yeah, yeah, yeah. We talked to him before <laughs>.

Makoto Kaneko: Oh really? So actually it's a tendon-driven system, and there is category. And for example the human hand also is driven by tendon, and in human hand is a tendons are coupled, so one joint maybe it's many tendon. And for the robot, so just like one motor for one joint, so this is the simplest one. And Salisbury's one is... okay, so one finger is for example three joints, and then they approached there are four actuators implemented, so joint number plus one actuator. Then totally see this actuator can control the tension as well. And usually one joint is one actuator; this is a simple, and the controls are easy because this joint - only one actuator - only focus on this one particular actuator for controlling just one joint. This is second pattern, and some pattern is the one joint is driven by two actuators, and so N joint need two N actuators. So there is three categories. And Salisbury's approach is N joint is controlled by N plus one actuator. So my approach is one actuator is one joint; that is simplest one. So N joint is N actuator. Then the disadvantage is this system can't control the tension, the tension is physically – for example the actuator's base it move like this, so that we can keep the appropriate tension. So it may need some mechanical tension controller. But anyway, the Salisbury's approach I gained a lot, that is an excellent model.

Matthew Francisco: So did you do any traveling and visit him or visit other...?

Makoto Kaneko: Yes, yes. So I visited MIT, at that time he was at MIT. And I visit many places, another one is the DLR hand, this is another very famous hand, in Germany. And in Italy also maybe you know Dario, Paolo Dario, and he is also one of the pioneer in such hand. So anyway, I visited many places.

Selma Sabanovic: And what were some of the differences between the different hands that you built? How did you develop the hand further?

Makoto Kaneko: A good point. It's – my interesting point is the force control for compliance control, I mean, the human. And we can control the fingertip compliance. So for example, if you keep tension in that part, because the muscle is here. And if you keep tension, and then the fingertip becomes stiff, but if you lose tension, fingertip, it move very compliantly. So this function is very important to manipulate objects dexterously. So the – my concern is always how to generate such a compliance. But this is not easy, but it's my point is that compliance, fingertip compliance. So my sensor is the so-called torque sensor or force sensor. And force sensor is very important. But actually, for our human hand, there is no force sensor. But just force control is done by keeping tension, so by will. So then, the muscle contracts. Then, fingertip doesn't move, even though some external force is given. As for the robot system, if you tied some wire ends outer two just like a braking system in the bicycle, so that has a very big friction in it, then it's very hard to achieve the very fine force control at the fingertip level. So in order to achieve the fine force control, we need some force sensors at the final joint. And then, this force sensor if force sensing feedback, we can compensate for friction. So this is – therefore, the force sensor is very important for the hand as far as you utilize <inaudible> system. Another important point is the backlash. You know what backlash? There is a gear, the gear is often utilized to reduce the velocity, because motor is usually move very quickly. So if you drive the motor directly to the individual joint, then too fast. But on the other hand, it's not powerful. So we reduce the speed and for gaining the power, enough power for gains of force. Force and speed when multiplied is almost a constant. If you increase the force, you have to reduce the velocity. If you increase the velocity so that you can't obtain the applied force. Anyway, so the gear is – in the ideal case there is no gap between the teeths and teeths. But actually, there is a small, small gap. Moving in this direction are these two make contact with these two. But to change the direction, there are some gap, therefore, it takes some time, delay time. So the delay is some nonlinear element. Nonlinear means okay, this is some gap where such a delay is interlinear component. That's a nonlinear component. And the control system includes such nonlinear elements, then control itself is not that easy. So the ideal situation is no gap, just in this direction always makes contact at this point makes contact with this part. And then opposite rotation – okay, the other part is contact with this, resulting in time lag. So then, we can keep some linear transmission system. That is ideal situation. So the question is how to realize such an ideal situation. Then, okay, if you utilize cable, cable have some elastic element and then, the external, outer two there is a contact between outer two and internal wire, some friction. Ok. Actually, it is a very big friction. So the system is some elastic element, and then the friction element, and elastic friction. This is distributed system. So this is very complicated system. And then that kind of transmission system always includes the backlash. Backlash means that if the actuator moves, start to move, but actually doesn't move fast, because there is some time lag. And then, this actuator moves the opposite direction, but against another time lag. So that kind of control system is very terrible. I ran that kind of fact through the – a couple of development hardware. And okay, so the – I recognized the important key point of such a tendon control system is how to remove the backlash. Then, my design is eventually, don't use outer tube, because this combination terrible. Just don't use a wire, which I think is okay. Because wire is elastic. Elastic element is a linear component. So then, the basic rule for designing the hand is that. Anyway, don't use outer chip, and don't please remove such backlash. That's a key point. So my final version was a robot system, and hand system is I don't use any outer tube, only the wire. And the wire is as short as possible, so that we can remove such unexpected friction and we can keep as linear system as possible. So that's a key point.

Selma Sabanovic: When did you finish your final hand?

Makoto Kaneko: Final hand is 1996. That is – no actually, in 2003. That is my final design.

Selma Sabanovic: And what were some of the studies or experiments that you did with the hand while you were designing it to see how it works?

Makoto Kaneko: Say it again please …. Key points or … ?

Selma Sabanovic: So what kind of studies did you do with the hand?

Makoto Kaneko: Okay, so good point. So I love the simple system, not complicated system. But multi-finger hand already complicated now. The idea is I don't want to put many sensor such as humans. We have four kind of sensors, type of sensors. And then distributed, especially at the fingertip area. The huge number of sensing element such an element can detect a force. Some element can detect the slippage, and some element can detect the pressure, and so forth. But I didn't implement that kind of sensor. I simply implemented the joint position sensor. This is definitely necessary. Otherwise, we can't control such kind of shape. And we implement force sensor. I mentioned before, force sensor is also important to execute, to achieve the fine function fingertip element of force control. But of course, we need the fingertip tactile sensor. But I didn't implement it. Then, my idea is okay, the fingers, five fingers makes contact with some object. How to determine such a contact point without using any tactile sensor. This is very interesting problem. Then, my idea is to for example, okay, this is one finger. And for example, this shorter path we keep very confined like this. And then, this terrible part joins this actuator here. And this is very rigid. And we move – short wire is very compliant. And this part is very rigid. And then hit, for example here. Then okay, additional motion is given to the <inaudible>. But this is very compliant. And then, this kind of motion happen. This is the contact point. Contact point doesn't change, but the arm may change. Posture may change, like this. Then, this is a position sensor, this is also a position sensor. Then, we can just – robot know how the posture looks like. But this point doesn't move. Then, if you have a – such kind of posture in the computer display, and then, the posture is changed with respect to time. But there is one point which doesn't change, because the contact point as far as object doesn't move. So this contact point doesn't change. So we can easily – then one point that doesn't change. Oh, this is the contact point. So I think this idea is very clear, because without using any tactile sensor, we can detect a contact point. So you can save some money, but you can obtain somehow the effect of tactile sensor. So I did this work during my stay in Germany that is my post doc program. So I really enjoyed when – I was really feeling happy when I found that kind of rule. And okay, this is also what I published as a IEEE paper Transaction. I really enjoyed that work. So my policy is not so many sensors. Try to reduce the sensors as much as possible, but we keep the function. Okay, so that is my consistent policy … consistent design policy.

Selma Sabanovic: Did you use that policy in other ways?

Makoto Kaneko: Oh, yes. Always all work. All my work as simple as possible.

Selma Sabanovic: Do you want to give us some more examples of robots that you really enjoyed making?

Makoto Kaneko: I in 1990 I – sensor … tactile sensor. Okay, this one is also the kind of tactile sensor. And at that time is just beam. Beam means elastic beam such as a piano wire. If you look at the inside of a piano, there are many wires. And these wires is this length of the wire, maybe this length, and no tactile sensing. No element. But for example, the cockroach there is antennae. And then, they can detect a contact point very quickly, and they're always moving their antennae like this. So I think the act of motion just by giving the act of motion, even though there is no tactile sensing element, only – actually, the cockroach, the antennae sensing element distributed all over the antennae. But I asked my student is cut the antennae of the cockroach, and then after that, we connect the cut antennae by glue. Then, the nerve system already done. Already cut. So the nerve system doesn't work anymore. But the base point, there are many – as a sensor, maybe some sensor can feel the sensation of force. Then, okay, artificial antennae, if some object makes contact with the thick part, but the force is transmitted through the connecting point to the base, then the cockroach behavior is not like the original one but it can detect some object. In this case, it's just pulses passing through. Then, okay, my idea is just like that, is the such that piano wire is somehow flexible, and then the base is one actuator and one pulse sensor or torque sensor. And then it makes contact. Contact can be detected by the torque sensor. And then with additional, small displacement given through the piano wire, then the torque sensor increase, sound would increase. So this principle is really simple. For example, this is rigid. In this case, it makes contact, if the object is rigid, you cannot give any further motion. But if this one is for example, fish rod. Suppose fish rod. Fish rod is very elastic. Then that part, if the rod makes contact with the environment. So you can give the farther displacement at the base. This point doesn't move, but you can give the farther displacement. Then, the idea is very simple. For example, this is fishing rod. If the tip part makes contact with the object, just for example, 10 degrees additional displacement to the base, you feel near nothing. But this point, if you give 10 degrees additional displacement, you feel a big force. This is the idea. So if the contact point is close to tip, then you feel very compliant. If very close to your hand, you feel it's very stiff. That means the compliance you can feel at your hand is a function of the contact distance. So the idea is really simple. So the – I really enjoyed to find this rule. And of course, I wrote this idea in the IEEE paper. And I'm very happy when the paper was referred in *Science* – I think it's not *Science*, *Nature*. I think since that time many people referred my paper. Actually, this is a very happy moment to find the paper is referred in *Nature*.

Matthew Francisco: And it came out of – especially that observation of the animals and insects. That's very nice.

Makoto Kaneko: Yes. Then, at that time I landed. This sensor system is actually – initially I observed the cockroach. I have it here. If you want, I can show you. But nowadays it's biologically inspired robot. This keyword is very popular. But in my opinion, so you have to be careful. Because the robot and some animal, including human, is okay, because I'm not a human that has a long, long history. So only the strongest one can – alive continuously. So therefore, they should include some very sophisticated function. So therefore, the robot should learn a lot, should imitate some animal, some human behavior. Okay, idea is beautiful. Idea looks like very very fine. But we have to be very careful, because the – if you peel the – for example, the human robot and the shape looks like very same, but once we open the inside, the components is completely different, because the actuator is just only one for each joint. But for humans, many muscle are coupled. And the sensor is holding but with just a few knuckles. So the mechanical component, electrical component completely different. So therefore, the simply run, simple imitations often fail. So this is my experience. Okay, I will give you a very good example: airplane. So designer is – many people from Roman period, they wanted to design just like a bird. That kind of swinging motion. But then, they failed. This is a long, long history, and then the Wright brothers, United States eventually succeeded. But one clever guy found that without swinging motion, the artificial system, they can get a lifting force. So the swinging motion produced not only the propelling force, but also the lifting force. So the swinging motion can produce two kinds of force. Then, the point is not the swinging motion, the point is how to generate a lifting force, and propelling force. So it's not necessary to start the swinging motion, just a fixed wing can do that. Additionally, it's propelling is the highest peak of rotation that system can move forward. Then, the system move forward, the system includes such a fixed wing. The fixed wing automatically gets a lifting force. This lifting force is the – is proportional to the moving speed. Actually, the quadratic proportion. So the clever guy is the – such kind of analysis. I mean, the swinging is not necessary, did not imitate the swinging motion, just swinging motion is producing both the lifting force and propelling force. Then, the question is how to realize these two forces. Okay. Then, by combining propelling force – propeller is producing only the propelling force. And airplane can go forward on land. Then, with the fixed wing, it automatically gets a lifting force. So this guy is very clever. So then, I always thinking about okay, why wouldn't it inspire robot. So biologically inspired robot, this keyword is very interesting, but we have to be very careful. The pure imitation of biological motion often fail, because this example of development of the airplane is one very good example.

Matthew Francisco: We only have a few minutes left – or, we only have a minute so –

Selma Sabanovic: Do you – since you have to meet your friends, right? <laughter>

Makoto Kaneko: Okay.

Matthew Francisco: But you're starting to get warmed up.

Makoto Kaneko: Actually, it's just the beginning. I didn't come to the key point. Okay, then that is the history of my grasping. And then, also some sensing. Then, in 2002 or '03 I met an associate, one associate professor. He's high-speed vision, and joined my lab. This is a great jump for me. And his idea is – his vision is almost 60 times faster than human eye. So this kind of rate is 1,000 frames per second. Human can handle roughly 10 frames per second. One thousand frames per second is 100 times more than human. Then, I think about if we combined both high-speed vision and high-speed actuator, then we can easily develop the robot system that can exceed the human capability. So this is the idea. Then, I developed the 100g capturing robot. Okay, the 100g means the action. This quick action is acceleration is100g. So the 100g is very, very big acceleration, where g is a gravitational acceleration. So 100 times more. So if your weight is for example, 50 kilograms, then it's 100 times more. So there under such a situation, you can survive not at all. Okay, then we designed and such kind a 100g captured robot and combined with the high speed vision system, and we dropped object from the one meter height. And at that point, it's almost 4 m/sec, the speed. Speed is so quick, and human cannot capture. But this robot can capture. So in such sense, this robot is overcoming the human capability in some particular task. So then, my interest is – okay, so far at that time, before that time, my goal is to design the robot hand just like a human hand. But I gradually learned this is nearly, in terms of the dexterity – it is actually the human is very good at dexterity. We can manipulate that kind of object is very dexterous. But the robot hand can't do that. Even the most sophisticated robot is a DLR hand, it cannot do that. But on the other hand, if you change the viewpoint. So, very easy, we can develop the robot system that exceeds the human capability. Okay, we should go in this direction. So since that time, my computer – my lab catchphrase is hyper human. Hyper human is we designed the artificial system that can exceed the human capability. So this is more impact. So this is just eight or nine years ago. So therefore now, I'm really happy, because I found my real direction. Then, after that, I developed three robots, including the 100g capturing robot. The catchphrase is, "Too Fast to See."

Selma Sabanovic: Except video.

Makoto Kaneko: Yeah, you did?

Selma Sabanovic: No, except for the video. Yeah.

Makoto Kaneko: And then, the second robot is the – on the air hockey table, we – one guy, he moves the objects just like this. But other guy tried to capture this robot on the air hockey table. But as I was always fair, because it was a lack of the regulation speed of a human eye. Because of moving like this, then the subject can't get which point is appropriate for capturing always fair. Then, this is very good example for me. Now, they designed a robot system to capture this object. Then, this is the second robot. And somewhere when I enjoyed pizza in the Italian restaurant, and I just by chance, the pizza master is manipulating the pizza in the oven. They are using just very simple plate, and then, with a <inaudible> and then, he is moving this part and then just this kind of motion. Then, the pizza is not only translating motion, but also repeating it. Okay, this is another good example. And I designed this kind of robot, and by combining high speed vision system and we can manipulate the object and more than human and more faster than human. This is start example. Then, I realized many people ask me, what's the application. So actually, there is no exact practical application. Okay, maybe the robot can capture fry, can capture mostly, but I did.

Selma Sabanovic: That's good.

Makoto Kaneko: Then, I think about can now, I would like to design and develop something which is very benefit, provides some benefit to the human. Then, okay, it's a good application field is the medical field. Because the stiffness is very important for medical area. If you didn't see a medical doctor, then with some disease, then medical doctor often touch your body by their hands. This is palpation, so-called palpation. Then, medical doctor tried to find somewhere is there any stiff point or not, especially this part and the stomach and so forth. And so therefore, stiffness measurement is very important in the medical diagnosis. Then, I have the technology for the high speed vision. I have the technology of the high-speed actuator. If you want to get stiffness, you need some actuation. You have to give some force. And then, you observe, how the deformation looks like. Then, you can obtain the stiffness. So I then realized, I have the two technologies. Why not I apply these technologies to medical area. So that is 2005. So the – during the last six years, I involved heavily in the area, and so I'm shifting my area from robotics to medical area. Okay, this is my whole story. I'm really so happy right now.

Matthew Francisco: It's really, really interesting. I mean, it's a very nice story of how it all kind of goes.

Makoto Kaneko: So that is if you combine the – I really want to show this bipedal. Also, you can see in my home page, but it not have all. So I show you – I'll give you some –

Selma Sabanovic: That would be great, 'cause we can add that.