Leuven, Belgium
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Hendrik Van Brussel

An interview conducted by
Peter Asaro

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Q: So we're just gonna start by having you introduce yourself. Tell us where you were born and where you grew up and went to school.

Hendrik Van Brussel: Where?

Q: Yeah.

Hendrik Van Brussel: From university?

Q: Yeah, yeah.

Hendrik Van Brussel: Well, I'm Hendrik Van Brussel and I am Belgian. Born in Ieper well known from the First World War. It was the battlefield in the First World War. You see all kinds of graveyards still, of the time. And then I – my first engineering degree was in Ostend in the Belgium coast, which was in mechanical engineering. And then I went on to Leuven for what we call civil engineering. It's a Master in engineering but there I took electronic engineering. That means that I have both disciplines and that's why I took robotics and mechatronics as my research topics for the rest of my life, actually. That – the borderline between mechanical and electrical and computer science actually. Yes, that's mine.

Q: What was your graduate thesis?

Hendrik Van Brussel: My graduate thesis, my doctorate thesis was – had nothing to do with anything with robotics. It was in mechanic – in manufacturing. It was a dynamic analysis of the metal cutting process. So there, I used principles of system theory to identify the cutting pr – dynamics of the cutting process. So nothing to do with robotics. And then later, for after my Ph.D., I went to Indonesia actually to do development work where I established a metal industries development center in Indonesia. So again, nothing to do with robotics. And then I came back and then – and I was an assistant professor. I started to teach a course in measurement systems, dynamic measurement systems. And then, as a research topic – then I chose robotics. And I chose force-controlled robotics, which was, at that time, a topic which nobody did, except Dan Whitney and Draper Lab in the United States and a few Japanese at the University of Tokyo. And everybody laughed at me and say, "What the hell are you going to start robotics in Belgium and then on force-feedback?" But I think we were quite successful and Dan Whitney had developed his famous RCC, a removed center compliance, which was a kind of interface between the robot and the work piece where the – so that the position of the work piece, for instance, for begin to whole assembly was automatically adapted through springs so that you could fit tightly fitting parts. And I decided to do that in an active way so we developed what we called the AACW, the active adaptive compliant wrist. There was a wrist, which was active, where you had springs in many degrees of freedom but which could be programmed. And by programming these springs and measuring the forces, we could design an algorithm to automatically adapt – fit work pieces, closely fitting work pieces. Like, for instance ball bearing in a whole with the clearance of .01 millimeter, which is in fact very difficult by hand. But there we could do it in automatic way. And it was, I think, a world first actually, at that time in the – to do that in an active way.

Q: What year was that?

Hendrik Van Brussel: That was 1978 where I represented it. I presented that '79 in Washington in the ISIR Conference. I was talking about – and I was sitting next to Dan Whitney and I saw him reading my paper and so he was quite interested in the way how we did it. Yes, that was quite successful. And then later, we – because it was still a tool you had to mount between the end-effector of the robot and the work piece. So then what I did is to incorporate this behavior, this spring – adaptive spring behavior into the axis of the robot itself and we called an active adaptive compliant robot, AACR. And in fact, that's what it is now. It's compli – it's an impedance control. Everybody uses it now but at that time it was quite, quite innovative.

Q: What made you decide to go into robotics after your earlier work in Indonesia and elsewhere?

Hendrik Van Brussel: Well, I was looking for an interesting job in automation and that was the time when robotics, well, became – let's say there was publications about robotics and everybody says, "Robotics is the future," and so on. So then that's why I decided that. And then I had to look for an interesting subject. Then I decided force control. Huh? Because in assembly, you need to limit – to minimize the forces in order to be able to mount closely fitting parts and that's what I wanted to do automatically. It was a challenging job, challenging subject actually.

Q: Was there anyone else in Belgium or...?

Hendrik Van Brussel: No, Belgium – we are still the only ones, except Luc Steels, perhaps, but we are still the only ones with the robotics activity so wide as you have seen or you can see and I will talk about more later.

Q: What about elsewhere in Europe at that time?

Hendrik Van Brussel: At that time, nobody. In that area, nobody. As I said, Dan Whitney and the Draper Lab and a few people in University of Tokyo, like, professor Inoue. And we have applied that in many cases, in assembly, in deburring of castings, in shoe carving actually. So many practical – also in mounting television picture tubes for Philips in <inaudible>, where you have to fit – and to feel how they fit exactly. So we had – the mounting compressors for <inaudible> for instance. We have – where you have the rotors. You have to fit the rotors into tightly fitting holes and that could only be done by active force feedback. So we have quite a few interesting applications but, when it comes to using it in industry, then you hit the barrier of the closeness of the robot controls. So you cannot get rid of your algorithms into the robot control because they are hermetically closed actually and that's why we – well, we were very happy that we could do it and the people in industry for whom we did the jobs were very happy two. But then when it came to really apply it in industry, then everything stalled. And, in fact, I was talking about this mounting of these rotors into housings of compressors. This was 20 years after our first development. So it took 20 years before we really could supply it in industry.

Q: What were some of the really big challenges from taking the first prototype to actually getting something that would do this very –?

Hendrik Van Brussel: Well, first of all, you have to convince the industry people that they need that and, secondly, you have to implement it into the existing hardware on the market. And, as I said, this hardware is specially developed for certain tasks but is not open at all and that's where everything stops. Actually, still today. Like in – companies like Siemens, for instance, where they're N.C. controls for robots and machine tools. They talk about open systems but we have another idea of open systems than they have. Huh? It's like in computer software on operating systems. UNIX some, huh? Not everybody is convinced that UNIX is the best way to go, although eh.., it's an open system. So that's, in fact, the main hurdle to take. But still today actually. Yes. So...

Q: <laughs>

Hendrik Van Brussel: That was concerning force feedback and so on. And this goes on still today because now we have developed very nice applications of impedance control. For instance, for lifting aids in industry or you can – or for physical interaction between robots and humans, where you can take the robot by the hand to do some work for instance. Huh? Also, The iron nurse to lift patients in the hospital. So to get rid of this back pain, which many nurses have actually. Also rehabilitation robotics, where you can impose gently a motion to a human limb in order to rehabilitate it. So that's- today, we still apply it. So that's a whole history. And Professor Joris De Schutter who is my successor I would say, who is now leading the robotics lab. He has developed a very impressive, let's say, formalism for what we call constraint based robot control, where you define constraints. A little bit like Matt Mason did in the '70s actually.

This is an extension of that formalism, actually, where you can do very interesting and very nice applications based on these constraints, just by specifying constraints actually when you have contact or whatever. So this is a constant development in our activity. The second one was developing systems for multi-robot control or multi-machine control. We call it holonic control of manufacturing systems or robotic fleets of – yes and this is based on the concept of holon and holon is a concept borrowed from Arthur Koestler who was a Hungarian philosopher actually and who wrote a book, "The Ghost in the Machine." And he wrote that book in the 1960s and then everybody forgot about it until the Japanese were looking for the ultimate structure of the factory of the 21st Century. And then they rediscovered that book and they took that as a basis for, let's say, the structure of the 21st Century and they developed a world-wide program they called IMS, Intelligence Manufacturing Systems in 1990, well, to realize that. And we were among the first to have a project in that large program and that was called Holonic Manufacturing Systems. So we were applying this concept of holonics to factories, to manufacturing systems.

And so, what is a holon? A holon is an autonomous entity but which has to collaborate with colleagues, holons, in order to achieve a global goal. Huh? It's an agent. Huh? Now we call it a multi-agent system. Hm? But based on that concept, we developed a architecture which is now quite well accepted as well, the PROSA Architecture. PROSA stands for – P is Product, R stands for Resource, O stands for Order and S stands for Staff agent, or holon, and A is for Architecture. And with that, you can, let's say, program such systems consisting of many, many holons who are all autonomous in their own right. But they collaborate – when something happens in the system, they collaborate in order to achieve a higher goal. And we applied – first we applied that to an assembly system and – an assembly system consisting of five robots around a conveyor system with pallets. Huh? And with the pallets, the product were assembled. Huh? So then you launch process. You launch an assembly process. You'll say, and this is the sequence – possible sequence – but you have many possible sequences. So you keep all – everything open and you start with the hierarchical structure. You say, "The best way to do that – to assemble that system is in this way, this sequence," and it starts like that. But when something happens in the system like, for instance, a bull-feeder gets empty, then this holon, this robot, asks the neighbor, can you do that for me, hm? And does it comply with the allowable sequence of operations? And if it is so – so he sends – without intervention from outside, he sends that job to the next holon robot, does the job and then it comes back. So the system behaves completely autonomously and it solves the problems up to a certain level, let's say, completely autonomously. That was a quite successful – I have a very nice movie about that. But we applied it also to harvester fleets, fleets of harvesters. We applied that to traffic systems.

So everywhere already have a large amount of holons, of agents, who have to work together and who have to solve the problems autonomously without, let's say, external intervention. In the factory, traditionally, when a rush order comes in, then nobody knows what to do because you have to stop everything. Here, a rush order is just an order like any other order – and see what are the possibilities, who can do what. We applied that also to a painting plant of Mercedes in Germany, where you have 20 kilometer of conveyors, where they have the wide bodies going through, one has to be painted in red, the other one in black and all one through the other – and how to control such a system. And if you're at a painting booth, you should not change anything to the rest. You just have to add it and – add a few rules and the thing is going. So it's a very powerful procedure which is now – which we're now using also for multi robot system. For instance, in warehouses they have many robots, many AGVs going through, one through the other. That was the second line. The third line is then mobile robotics. Mobile robotics where we, let's say already in '95 I think, we developed the first freely navigating robot in the world I would say, without artificial landmarks. Normally you put strips on the wall to see to – and the lasers cannot looking where it is. No. We use the natural environment or the factory environment as the landmarks actually. And then, also, there was collision avoidance systems. So it was quite a powerful system. And then we extended that, not only to navigation, but also to mobile manipulation, so a robot with an arm on it or a wheelchair with an arm on it. And that's an order of magnitudes more difficult than, let's say, complete pure navigation and two dimensions. And there we applied a new concept – well, new concept, a concept which is not well-known, which is the – what we call the behavior-based control. Hm? So, in fact, a task is executed as a concatenation of elementary behaviors. For instance, when, well, in that corner, the telephone rings then I start – I wri – I stand up and then I'm attracted to the telephone. That's the first behavior and then I start moving. But then, see, I see this obstacle and then I forget about that – they – that goal and then I start to solve that problem. That means avoiding the obstacle. When that problem is solved, then again the attraction to the goal starts again. It's a concatenation of elementary behaviors, which you have to define on beforehand, and one behavior is then started based on sensor information from the sensors com – measuring the environment. This is a very nice concept and we developed that to – for instance, for opening doors, for grasping a cup, for cleaning windows where you don't have to define the trajectories but you'll just have to define the behaviors. Huh?

That's another way and it still goes on now within – we have, three weeks ago – two weeks ago we had a Ph.D. which was developed – which was defended on that subject and again. That's two. That's three? The fourth line of research is medical robotics. Medical robotics, where we deal with problems with robotized laparoscopic – the minimally invasive surgery, where normally the surgeon is manipulating, by hand, the tools which is going through a small incision through the body. And then you have a third laparoscope which returns a picture from the inside on a screen and the surgeon looks to the screen and he manipulates the tools by hand. Now, if you replace these hands by a robot, then how can the surgeon then control the robot or the position of the tools? A joystick is very poor. And so what we did, we developed a, what they call, natural interface. So we write the trajectory with a pen on a digitizing tablet. We write the trajectory the robot has to follow and it is executed by the – in this case, it was a laser laparoscope where you remove a material tissue by ablation actually. Huh? So you have to program the trajectory the laser has to follow. And this is just done by writing. Huh? This is our Vesalius robot which is – now we are trying to turn into a spinoff company actually, which is, in that market, not so easy because you have one, let's say, monopolist in the world which is –

of course, you know it – Intuitive Surgical. And which owns all the patents or they buy all the patents which are available.

Yes, but that's still enough. That's – for laser laparoscopy that's okay because, there, you have no forces. But for normal, I would say, laparoscopy then the surgeon have to feel what is the – how hard he is pushing, how hard he is pinching, how for stitching, for instance, surgery. So the force are very small but he have to have a feeling in his fingers and that's why we have another research line which is on the haptic feedback. So we have four sensors inside the body and which reflect the force information to the surgeons and by tele-operation, haptic teleoperation. And it – a second aspect is there – what we call tactile feedback. If you have a surgeon in manual operation, he palpates the tissue with his finger and then he see where are the hard spots, for instance tumors, or where are the veins or the arteries, by his fingers. So we developed a tactile finger, which is an array of tactile textiles actually. And then – which reflect back that tactile information to a ring with pins which push on the finger of the surgeon so that he has a tactile image in his finger, as if he would palpate the tissue during open surgery. So these are two lines we can – which are quite, let's say, speculative things still. Although, tactile is – haptic feedback is already – I think, intuitive surgery already is entering that field but for tactile imaging, that is still a long way to go, I think. But we have made a proof of concept and it is quite impressive actually, if you see it. Well, this is more or less the range of activities I have.

Q: How did you become involved with Cincinnati Milacron?

Hendrik Van Brussel: Oh, that's a long story. Well, not a long story. We – I am a member – I was a member –I'm still a member of the International Institution for Production Engineering – International Academy of Production Engineering. In short, it is CIRP, which is a fringe operation and this is an international, let's say, academy now where you have all the best people in production engineering. It's in the broad field of production engineering, in every country. For instance, every country can maximum have – the large countries can, maximum, have 15 members. In the small countries, like Belgium, three or four. So altogether there are over the world 175 members but we are really the top of the class. Huh? And one of these members was the famous professor Eugene Merchant, who was an employee of Cincinnati Milacron or Cincinnati Milling Machines at that time. That's how we came in touch.

Q: What was the project that you worked on?

Hendrik Van Brussel: No, we didn't have a project for them particularly at that time. We just bought it, for a reduced price perhaps, eh? But afterwards, we went there to show our results. Yes? And Mr. Messinger, Dick Messinger, was the guy there and I remember he was very upset because we had a film with us, super-8 at that time still and – where we showed how we got – have impedance control. So we had this huge robot and we took it by the hand and we could shake hands with it and they were really shocked by that, let's say. "You should never show that to anybody. I don't want our name to be associated with an eventual dead body based on this – on these experiments." Now, they were quite interested but then very soon Cincinnati lost interest in robotics and they sold it to ABB and then ABB just got rid of it later. So, yeah. But that was my first robot and we have done really beautiful things with that because we redesigned the whole controller. So we had a button say, "Original control and arm control," and without having one electronic scheme of the computer and so-and-so, we all had to find it out by reverse engineering it so that was quite nice and they were quite, quite impressed by what we did <laughs>.

Q: <laughs>

Hendrik Van Brussel: Yeah?

Q: So, what year was that that you got that robot installed?

Hendrik Van Brussel: Installed here in 1980. Yeah, and I used it until 1998. It's a little black there but it's in Dutch so you can read it there.

Q: Yeah, yeah, but for our audience. What was the next robot that you got after that arm?

Hendrik Van Brussel: Then we got an ABB robot and then we got many Kuka robots but we just threw five of them away last year when we remolded the laboratory, so that was full of Kuka robots actually and – yes. And there again the problem was when you want to do force feedback with these Kuka robots to enter the controller – and there, at the beginning, you have time delays of 12 milliseconds which is impossible of course. And then it start with improving itself. And that's why we – another colleague of mine Herman Bruyninckx who was also my successor but in more the embedded software field – he developed a very famous now Orocos Software. Let me see. Open robot software, control software, which is used by many, many research labs but also by many industries – by several industries now. And that was, in fact, a consequence of our problems we had with the available robots that we couldn't do anything with them. Anything interesting, I would say. Huh? Yeah.

Q: So who were some of your early students and are they still working in robotics?

Hendrik Van Brussel: Well, yes, De Schutter. Joris De Schutter got his Ph.D. in '86 and now he's a professor here, in robotics, and he is – I would say my successor. Huh? And Herman Bruyninckx is also my student but he's younger and he is also now professor in robotics, yeah, but more the software and – embedded software side. So these are the two but I think they are doing quite impressive work. Like, Herman Bruyninckx is now the president of EURON. EURON is the European network on robotics and so he's quite influential in that sense also.

Q: Have there been other big collaborations that you've done with other professors of this university or other universities?

Hendrik Van Brussel: Yes, we have professors – at this university we have Licth Van Hole, who is now in – half time here and half time in Zurich on vision. So, all vision problems were solved not by us but by these guys. Huh? Of course, with people like Hetzinger in Germany we had – with Bruno Siciliano, with Paolo Dario, all mainly in the framework of European project. Huh? We have had many, many, many European projects with all these guys. The rebel gang of Europe, it was – they were involved. Huh? Yes. Yes, and – yes, Dario and Dillmann. Are you going to see Dillman in Carlos Road.

Q: I've emailed him but he hasn't responded.

Hendrik Van Brussel: Yeah, it's...

Q: Talking to Dickmanns, then, you know.

Hendrik Van Brussel: Yes. And then – yes, and recently with Martin Buss in Munich and with Wolfram Burgard (27:20) in Freiburg. Also with the French guys, like – at the time, Girault in LAAS and, and Raja Chatilla (27:35), who is now the director of LAAS. Well, I belong to the, I would say, the European gang.

But then my interest was broadening to other fields, to more, like I said, the holonic system sensor. So that then I lost a little bit track and I was not belonging again to – but these guys, now, like Herman Bruyninckx and <inaudible> they are taking my place much better than I could do. But somebody must be first and I was the pioneer I will say. Yep.

Q: And how did the collaboration with the Japanese evolve?

Hendrik Van Brussel: Oh, yes, very good. In the framework of this IMS we had collaboration with University of Tokyo. Now I am still collaborating with University of Tokyo in the field of medical robotics, but also with Kobe University. I have one Ph.D. student, now postdoc, who have this Ph.D. in Kyoto with Professor Yokokoji. So, yes, yes, we have had many, many good contacts, Professor Arai from Tokyo University. Yeah, many. Oh, Sugano from Waseda University.

Q: And in terms of implementing the impedance controls that allow this compliant behavior, what was the real sort of technical hurdles that you had to have solved in order to make that work effectively and not be really dangerous to people?

Hendrik Van Brussel: Well, not really dangerous. I don't know. I think there is no solution for that and that's one of the big problems now. Like, KUKA is now working very hard towards standardizing or making norms to allow people to work physically – to interact physically with robots, but I think it's a long way to go still, yeah. I think. 'Course that is not solved. Software can never be made intrinsically safe. So that's still a problem. And you have to do it in another way. You have to make it soft – hm? So that when you hit something some lump of whatever, that it doesn't harm because of skin, soft skin, or such things. But intrinsically safe doesn't exist. So this is one main hurdle when you want to really want to really implement it, but industry is working at it. Another hurdle is also for, let's say, impedance control or force control, with very small forces is the compensation of the friction. And here we have very good team. I think we have the most advanced friction models available for control, here and – called the Leuven model. You know the LuGre model, you have the guy in United States – I forgot his name, but we have the Leuven model, which is the best <laughs> out of all of them.

Q: How does it work?

Hendrik Van Brussel: Well, it's a generalized Maxwell-slip model so it consists of several parallel connections of Maxwell elements, Maxwell-slip elements, which is a mouse which slips over a surface with a spring. And you have several of these elements in parallel and then you have to identify the mouse and the spring and the friction of these elements. And with that you can model hysteresis very accurately and all the phenomena which are taking place in friction. And with that we have been succeeding very well in order to really very accurately to apply this impedance control for very, very small forces. I was talking about this eye robot. Well, this eye robot, the forces there are millinewtons. So there also you have friction in these robots. So you have to compensate very carefully otherwise you don't feel the real force. And so that's quite an important part of our research also. Yes. Not only for robotics but also for machine tools, for instance, yeah? Same. Yeah.

Q: And when did you start working on that?

Hendrik Van Brussel: Oh! That's a long time. Twenty years, 1990. Yeah.

Q: Do you remember the project?

Hendrik Van Brussel: Oh, several projects. For instance, we had a project with harmonic drives. You know harmonic drives are these gear boxes in robot joints and the company Harmonic Drive is situated somewhere in Germany and there we developed very accurate algorithms for, let's say, improving the accuracy of the harmonic drives. We had also a project for the VolkswagenStiftung, which is a kind of funding agency in Germany, has nothing to do with Volkswagen. But it was after the war, then there were Volkswagen shares and nobody knew to whom they belonged and then they made a kind of research fund out of it. And that was one important fund we got from them in order to model friction. And on several other, let's say, European projects which we have done where it was part – not one project on friction modeling; it's just part of it.

Q: Yeah, yeah. And when did the work on the mobile robotics without landmarks begin?

Hendrik Van Brussel: That was 1990. 1990, yeah.

Q: What was the project? You said it was a warehouse or –?

Hendrik Van Brussel: No, that was a company in Antwerp who make warehouses but also AGVs for warehouses. And they have a whole line of AGVs and they wanted to improve the intelligence. And that was a project sponsored not only by them, but also a Belgian funding agency funding projects in collaboration with industry. And we have had quite a few of them. That was one of those. So these are typically, let's say, three-year projects with a budget of, I would say, a couple of hundred thousand Euros. You know, typical. While the European projects are a couple of million Euros.

Q: <laughs>

Hendrik Van Brussel: But more partners, of course. Yes.

Q: So what was the first one of those that you got, the big European grants?

Hendrik Van Brussel: '86. '86 was the Esprit, the famous Esprit program and there the project was, well, yes, control of robots, force control of robots. Yes. SACODY it was called with the French company that was then KUKA was involved. AEG, but AEG was at that time one of the big German companies, but now they more or less disappeared or reduced their activity. They made a controller; and that was funny, of course, because the KUKA robot on the market had a Siemens controller, but the part and the project was AEG, another manufacturer of controllers. So that's one of the contradictions you get in European project, of course. But that was quite nice. Also, we could improve, for instance, the bandwidth of the robots. It was on spot-welding robots and when you have a spot-welding robot and you position the robot, then it starts moving like that and then you have to wait until the vibration has damped, until you can position – you can close the tongs of the spot-welding gun, actually. So let's say this takes one second times one hundred spots per body times one hundred robots in a line, so there's a lot of half seconds if you can gain half a second per spot. So what we did there – and the problem there was they were very heavy robots, you have vertical axis where you have a mass of one ton and then you have a gearbox and then you have a belt transmission and then you have the motor. That means you have a spring, a very soft spring. That means the natural frequency was five hertz. That's asking for problems, of course. Eh? So what we did is, we measured at both sides of the joint and then we made a model, dynamic model, and took that model into account into the controller by which without changing any hardware we could increase the bandwidth by a factor of two or three and we could reduce that positioning – we could damp that vibration in an active way so we can reduce from one second to 0.3 seconds, if I remember well, times hundred – times one hundred. That means a lot of half a seconds you gain. And that was a very convincing result of what I call mechatronics, which is the marriage of control engineering with mechanical engineering. And if the mechanics are not good enough anymore, then you have to go to control in order to improve that. This is my topic, my pet topic, of my life. So how to marry these disciplines in an optimal way? Yes, but again, KUKA never applied it, I mean, for the same reasons, because there you needed a controller which was able to receive and to incorporate these algorithms. Yeah. That was –

Q: Has that changed now? I mean, there's more intelligent controllers involved?

Hendrik Van Brussel: Yes, yes. I think ABB is now working on a very intelligent controller. Also, KUKA has now – yeah, yeah. All I can say. The small KUKAs you have seen in the lab have very nice control.

Q: Why do you think it took so long for them to take up that technology?

Hendrik Van Brussel: That's the inertia of industry. Ending inertia – industry is very conservative. Really, they are. Really. Even still today they are conservative. And it takes a long time before you can convince them. I have had contact with Siemens. At the time Siemens had also a robot factory and they made robots. And so we went there with all our results and also our eight movies and so on. Everybody was very happy. And at the end of the meeting they said, "Can we copy your movie?" we said, "<snapping fingers>" and then nothing happened. I mean, these are big companies and they look where they can find the best help and, of course, a little country like Belgium – and then you have university – in Berlin you have University in Stuttgart and very near Siemens there. So I mean, it's not – it's easy to understand. But also same at Philips. We have a beautiful project with Philips, but I think it never came to the real implementation unless we don't know, but I don't think so.

Q: Did Philips ever get interested in developing robotic stuff to sell?

Hendrik Van Brussel: Yes, they have done it. You mean here in –? Well, yeah, but what we do now is medical robots is developed here and that we want to commercialize. This eye robot is developed here and we want it to commercialize it. But these are special niches, not general robots. We have these very nice – I didn't talk about that actually. This was in mobile robotics; we have this very nice project on shared control of wheelchairs, intelligent wheelchairs. Where, in fact, what you do is you have a wheelchair and the driver is controlling the wheelchair with a joystick but he has some tremors or some limitations in the motion of the joystick. So that means his intention is not so clear. So what we do is we try to infer the intention of the driver by measuring the signals of the joystick. And then with Bayesian methods we try to look for the most probable intention he has. Does he want to go there? Does he want to go to that table? Does he want to go to that switch there? So – and then we have an algorithm, which plans the best track to that table or the best track to the – but this is updated all the time. So if he says, "No, I don't want to go there," and he tries to deviate, then the system, let's say, notes that and makes another plan. So it's kind of shared autonomy. The driver still always has the impression that he keeps control over the wheelchair although it's not true. I have a very nice video before, for instance, sitting in the wheelchair and he wants to dock to that table. And he just can push forward. He pushes forward and then he comes at an angle at that table. So then there is a laser scanner measuring the position of the legs of the table, measuring the position of the top of the table and then automatically adapts the position and he just stops just in front of the table exactly the position he needs to have. But he has the impression that he does it actually. But it's corrected by – we call it "shared autonomy". Control that's shared autonomy. We share the autonomy between the computer and the driver.

Also, we have had control with brain – computer interfaces. So you have these electrodes on the top, kind of swimming hat with electrodes and just by thinking we have defined three talk processes, which one is going forward, one is going to the right, one is going to the left. And then, yes, without touching anything you can control the robot, although it's not that easy. So let's say you have a probability of sixty- seventy percent to be right, so on top of that we have collision avoidance algorithms which keep away from obstacles if it goes wrong. But I think the results are quite impressive or quite promising I would say, but it's not for the next two years to implement it. Yeah, this was – I forget to mention that this was a very important topic of research in our – and still is – in our mobile robotics research. And you have seen quite a few wheelchairs in the lab. And we have now a new robot – a new European project in that area which we call single-button wheelchair. So you go to the shop, you buy a wheelchair and you can start, in a safe way, you can start moving around. Not optimal, but gradually the system learns to behave better and to learn about the handicap of the person and to adapt its behavior to the handicap person. And even if the handicap is changing, for instance, in a person with MS, they have a kind of progressing of the disease, so there the system itself has to adapt itself, its behavior itself, to the progression on the disease. And, well, I think this is quite powerful and promising area, which we want to continue – not me.

Q: What motivated you to shift from industrial robots to healthcare and assistance robots?

Hendrik Van Brussel: Oh, I think because of – with – our industry robotics it's okay, is well developed, is well established now, and so we were looking for another and, of course, there is an improving – and increasing pressure by the society to go into projects which are, let's say, more relevant to society and that's why I think. And also to countries like Belgium, we have not a robotics industry, we have hardly a machine tool industry. We only have users of robots and that's for research people not good enough. But on the other side, we see a lot of potential in rehabilitation robotics and – yes, this wheelchair business. That's the main reason is in societal awareness, yeah.

Q: But you started with surgical robots – or?

Hendrik Van Brussel: Well, yes, that's another story. We have done quite nice things and now we want to implement it into a spin-off company, but it's very hard to find venture capital, because they say you have these guys there in California and they have all the patents. So what can you do against these guys? We have one patent, which is not governed by them and which we think is strong, but if the patent agency then finally decides it's not awarded, then we have a problem. And, that, the venture capitalists are aware of that. They don't want to venture too much. They want to be sure about their ventures, really. That's why I count on the Flemish, in this case, government because they also have budgets and I think their role is to just to support these projects with very high risks, which the venture capitalists don't want to support. And that's what I'm now trying to do, to convince our local government, because we have no government, yet – central government – but we have local governments, which work very well. And, yes, I have a few guys now, postdocs, who are really are pushing very hard to start the company, but without money you cannot do anything. And we are now in the position, let's say, that we with two or three months we can, I think, really start. Yeah.

Q: And do you see it as trying to build the whole, like, robotic system or –?

Hendrik Van Brussel: Yeah, the whole robotic – no, but we will start very, very downsized with a tool holder – with the camera holder. First, a passive one, then an active, and then start with the laser robot and then start with the many – several robots like that da Vinci system, next to each other of which we claim, of course, we have a lot of advantages, of course. Yes, but we are sure about that. But, yes. We even have had contacts with da Vinci. They have been here intuitive. But these guys are so powerful that they just look and say, "Oh, that's interesting." But to make a contract together, it's difficult.

Q: Have you had any other attempts to start up a venture company or robotics –?

Hendrik Van Brussel: Yeah, not in robotics. We have had quite a few successful ones in this lab here, but not in robotics. One was in rapid prototyping. One was in engineering – dynamics engineering. One is in metrology – robotic metrology, also, yeah, but not pure robotics. No. I think we are living in the wrong country for that. <laughs>

Q: <laughs> Come to California.

Hendrik Van Brussel: Yeah, why not?

Q: Have you continued the research on the mobile robotics? And you said you just were building a helicopter?

Hendrik Van Brussel: Yeah, that's not me, that's De Schutter That's De Schutter who is doing that. Mobile robotics is mainly the wheelchair. Yeah, and also the mobile manipulation, behavior-based mobile manipulation. But the guy now, he was my last Ph.D. student and I don't know whether my colleges are going to continue that.

Q: So what were some other projects or things you want to talk about? I'm feeling we skipped over lots of things.

Hendrik Van Brussel: I don't know if I have written down something here but think I more or less covered everything. Well, I personally still going on with this holonic stuff as a personal hobby I would say and still have one Ph.D. student who is now – and it's something very funny happening there, because this has proved its value in manufacturing very much and now we are doing it for fleets of robots. And we don't get the paper published. People don't understand what we are talking about. And that's what we try now to find out. Now we have IROS conferences in, what is it, San Francisco in October, we had a paper it was just turned down and you see the reviewers, they just – next to the question. But you have no possibility for rebuttal. So now we are going to say – we said we are going to publish a journal paper so that you have really a means to defend yourself, yeah.

Q: Do they get confused with multi-agent system or are they just kinda swarm robots. So these others –

Hendrik Van Brussel: Yeah, but it's more than multi-agent systems. That's the problem. You can do much more with our architecture, but I don't know. It's like they don't understand. And now we are trying to compare our system with available systems on the market, which are not there, actually. And you go, for instance, to University of Southern California, Maja Matarić, they have this – I saw theirs in your list also. Well, what they do is just the same thing, but navigation only, and we want also to extend it to manipulation, mobile manipulation, and so on, and prove that if you go really to complex tasks then that's the only way to go. Yes, that's one of my hobbies still today and I want to write about that. Intelligent wheelchairs, no. But I think that's about it. Of course, we do quite a lot of more theoretical things, which support that, like the Bayesian methods. There's a whole Bayesian library which has been developed here over the years. Also, a control library, yes. But, as I said, I'm interested in robotics, but also in mechatronics, which is much more broader. So I apply all these concepts also to machine tools and to machines. That was also part of my research. So I had many projects with machine tool manufacturers in Italy or Germany, yeah. But they also need friction compensation. They also need that. So they also need, for instance, this parallel kinematic robots, which is – machine tools, they are robots actually. So all the software you develop for robots you can apply there.

Q: What do you see as the difference between robotics and mechatronics?

Hendrik Van Brussel: Well, I would say robotics is a separate set of mechatronics. So I call mechatronics the science of motion control. It's the science of machines and machines that have motion, and how to coordinate motions, how to generate motion, how to suppress motion. That's what I call mechatronics. Some people say, "No, this is too narrow." It's not. If you look at it, it's all about motion and how to control the motion, how to synchronize motion, how to get rid of disturbances. For instance, instead of throwing out a gearbox and replacing it by an electrical motor, this kind of stuff, and robotics is nothing else. Of course, robotics is much more when you talk about multi-robot systems and so on. But you'll have the same in a – a factory is multi-machine system. It's controlled in exactly the same way as a multi-robot system. Yes. So I have a very broad view about that and not only confined to robotics.

Q: What do you see as the big challenges facing robotics over the next ten to twenty years?

Hendrik Van Brussel: I think it's going towards service robots and so, let's say, interacting in a human way with people, with humans. Yeah. And when you look at mobile manipulation, for instance, which is one order of magnitude more difficult that navigation, there you see there's quite a lot of – that the programming is still the problem. So you can teach by doing, by demonstration. You can show it. You can take the robot by the hand and demonstrate it. You can do it with a joystick. So how to talk to machines, to robots, in a human way so that they are accepted by – people speak about using robots in the household. Well, they will not be able to use them if they cannot speak to them in a natural way and if they behave in a natural way also. And there is still a lot to do there with that in the control, but also in, like you said, like I said, and the safety. If you use robots in the neighborhood of humans, then it must be intrinsically safe. But that doesn't mean intrinsically safe, because I can also give you a blow with my fist. I mean, it's not – I'm not intrinsically safe, but a robot will never be intrinsically safe. <laughs> Yes. And all this things in literature about – or in the popular literature about robots with emotions and so on, I think forget it for a while. <laughs>

Q: And for young people who would be interested in a career in robotics what's your advice to them?

Hendrik Van Brussel: Well, I think it's a very interesting subject in the sense that it's very broad subject. And you have necessarily to limit yourself. But there is still a lot to do there. So I think I would advise them to go into the use of robots for the benefit of mankind I would say. Because industrial robots, I think, that's okay. That's past thing. Not past thing, but I mean there's not so many interesting problems to be solved there. But for their use with humans, I think that's where the challenge will be. And there are problems at every level. Pure technical level, but also the computer science level, the control level, even psychological or interaction – communication level. So, yes. Yes, I think there's a lot to do still.

Q: Is there anything else you'd like to add?

Hendrik Van Brussel: Well, no. Not really. Anything you want to ask more now? <laughs>

Q: Well, that's all the questions I have, but we can take a little tour of the whole lab, with the camera.

Hendrik Van Brussel: Yes, yes.