Oral History of Daniel P. “Dan” Siewiorek

Interviewed by:
Marc Weber

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Marc Weber: I'm Marc Weber of the Computer History Museum and I'm here with Dan Siewiorek who's a major pioneer of wearable computer. Thank you for doing this.

Dan Siewiorek: Pleasure.

Weber: I should say it's the 23rd of May, 2016. I want to start off at the beginning, so what is your full name and when and where were you born?

Siewiorek: Daniel Paul Siewiorek, born in Cleveland, Ohio on actually the first day of the Baby Boom, nine months after the declaration of peace was signed for Japan.

Weber: To the day.

Siewiorek: To the day.

Weber: And talk a little bit about your childhood, what was your neighborhood like, what did your parents do, what did you like to do?

Siewiorek: Okay. Well my father was a turret lathe operator, my mom was a homemaker. We lived about three miles from downtown Cleveland right on the lake[1]. My father was sort of a hunter and fisherman who was trapped in the city so he would go out and fish in the lake a couple of times a week and whatever he caught, we ate.

Weber: What were your hobbies or interests as a kid?

Siewiorek: Well I was consumed a lot by Boy Scouts, we had a very active Boy Scout troop, I was an Eagle Scout. One of the highlights was the same Scout official [Willard Friend] who gave my father his Eagle badge gave me my Eagle badge 30 years later. So that was kind of cool. And we got to Philmont in New Mexico and did a lot of hiking and camping even though we were a city bound troop.

Weber: Talk about what were your favorite subjects in school or what did you like or not like?

Siewiorek: Well I very much enjoyed science and mathematics and the technology that was available at the time. But the toughest thing for me was French.

Weber: Can I ask you about what values you were raised with, did politics, religion or ethics play an important part in your family?

Siewiorek: Well you talk about the greatest generation, basically all of my relatives just sort of led by example, they helped the Boy Scouts, they helped the American Legion, they helped individual people in the neighborhood, people wore hand-me-down clothes, everybody sort of worked and pulled together and it was before we were distracted by media and ads so you had people gathering, going to softball games, going to bowling alleys and so forth, more social activities, which were kind of fun. It takes a village they say to raise people.

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[1] [Interviewee’s note] The lake is Lake Erie

Weber: And were you interested in electronics and technical things early on or that came later?

Siewiorek: Well back in the those days, I was sort of what was called an October Sky kid, October, '57, you go out in the backyard and you could see Sputnik and that really got me interested so I kept following NASA, to work for NASA was a dream of mine which I eventually did a little bit later. But in the meantime I was playing with building models, building model rockets, doing electrical motors and just anything I could get my hands on.

Weber: And any particular teachers that had a big influence on you?

Siewiorek: There were several that I could recall, my eighth grade math teacher when he started doing volumes and solids, that really turned me on. I was really very fortunate in my high school because I had a very good college algebra teacher[2], I had a very good geometry teacher, a very good solid geometry, trigonometry, so I had a very solid background in mathematics which really helped by the time I got to college.

Weber: What did you think you would be when you grew up?

Siewiorek: My children hate my answer to this story [because it did not provide them insights on planning their careers] but they wanted to know why electrical engineering-- I had no role model, I didn't know who an electrical engineer was or what they did, but in the sixth grade before promotion they ask us, "Well, in 20 years what do you want to be?" and somebody would write an essay about it. So I was playing with motors and batteries so I said, "Electrical engineer," so they wrote that essay. And when I got to college, "Well, what are you going to major in?" Well, that's the only one I had thought about so that's what I ended up doing and turns out it was very good because you could go all the way from analog circuits to computer software and find a niche for yourself even though you had the same basic undergraduate education.

Weber: So I'm assuming you were exposed to computing in college?

Siewiorek: Well it didn't exist in those days. I mean the first computer science departments were coming in 1965, I started school in '64 but I went to University of Michigan which was deep in the evolution of computing at the time and me not knowing it, compilers and eventually time sharing systems and so forth. So as an undergraduate you sort of took advantage of what the environment, the faculty were creating even though we didn't know the faculty were making history at the time.

Weber: So talk a little bit about university and <inaudible>.???

Siewiorek: Well let's see, so I'm a first generation college student in the family, only four students from my high school class went to college, so we were a real inner city school, 80 percent African Americans. So it was somewhat a struggle in the sense that, which school do you go to, what type of advice you get, any financial aid and so forth. And so I was very, very lucky in the sense that-- just a side story here but

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[2] [Interviewee’s note] The algebra teacher who suggested me to attend University of Michigan as good school as undergrads was Mr. Jefferson

when I went to the University of Michigan, so the first thing is, why did I go to the University of Michigan, well SAT scores allow you to pick three universities, so I picked a local university in Cleveland but they wanted to wait until April for early admissions which seemed to be not very well for me to adapt if I didn't get in. Then a major national university that everybody knows about, I went for an interview and the alumni said I wouldn't make it there so don't even try. So that left me third choice, my college algebra teacher in high school said Michigan had a good math department. So I picked Michigan. And being from Ohio, my father was hoping I was going to Ohio State but five year degree at Ohio State was more expensive in state than out of state for four years. Not that that was a major point but-- so Michigan was really good because it was very strong across the board and I could find my niche. And when I finished I had a undergraduate one credit unit computing course that went all the way from higher level languages down to assembly languages and with punch cards you turn in your [card] deck, maybe you turn around in eight hours but more likely three days, it sort of discouraged me from computing. In my senior year I took an analog and digital computing course and they're docking the Gemini spacecraft at the time and so you could actually write the differential equations for the docking, plug in the analog computer and get it to solve the equations and that was kind of really neat and they had a classic PDP-8, the one with the smoked glass and so forth, get your hands on the computer and that turned me back on so that saved my senior year and saved me when I went to graduate school.

Weber: But when you started as an electrical engineering major, obviously you were not yet thinking of computers, what did you think you wanted to do as an engineer?

Siewiorek: Well, see I had a number of summer jobs and so I worked with consulting engineers which were laying out hospitals and office buildings for electrical motors and electrical outlets and so forth, one summer that was boring and so I didn't think I would do that. And the next thing I tried was with the power company but the power company was looking at 20 year horizons just to plan a power line and this was the time of the Northeast Blackout so people were doing a lot of load flow studies, computer studies which were kind of interesting. Then the next year, my senior year in college, after that I worked for NASA and they were working on the hypersonic airplane where they took a delta wing fighter plane attached two jet engines under [the wings] it and they put sensor ports so you could actually get a profile of the air pressure on the wings. And that was really cool and I liked doing it but then halfway through the summer I got laid off and that was already the start of [down sizing] -- even though we hadn't landed on the moon yet, they had already started cutting back. So I decided that maybe aerospace wasn't as stable as I wanted. And then I went onto grad school and in grad school I thought I wanted to do circuits, analog and at the time Hewlett Packard had just come out with their first 2114 mini computer and the designer of that taught the class. And so we got to design a mini computer on paper and that seemed to be really neat, so then halfway through my master's program I switched to digital and been there ever since.

Weber: And where did you go to graduate school?

Siewiorek: Stanford.

Weber: And by that time, when you applied there, you knew you wanted to…

Siewiorek: Well I knew I wanted it and I actually got a minor in computer science. And if you think of the people that I got my courses from, I had Bob Floyd teach me Algol, I had John Forsythe teach me numerical analysis, John McCarthy teach me LISP and AI, Zohar Manna taught me theory and then there was this young upstart person who always had an airline ticket in his pocket to go to Utah, Alan Kay taught me compilers. So in those days, I still didn't realize how stellar a constellation of instructors I had but I couldn't have had a better set of instructors.

Weber: And back at Michigan, were there any mentors or professors that kind of were very important for…

Siewiorek: Not as much, it was a big state school, much more Stanford as a graduate student you got to know more people. They pretty much prescribed things for you. Actually, probably the one I remember most [at Michigan] was my engineering English teacher. And believe it or not, in those days, they actually had an engineering English department and I had to take six English courses, liberal arts students took two. So I had two composition courses like they did. So of all things, he was so good, he actually got me to take Greek drama and I would never have taken Greek drama but he was such a good instructor.

Weber: And at Stanford, obviously you had some amazing pioneers.

Siewiorek: Right.

Weber: How did the professors at Stanford shape the direction of your career?

Siewiorek: Well, like I was saying, we had a memorial symposium for my thesis advisor yesterday, Ed McCluskey, Quine- McCluskey, logic minimization, he was doing testing and I got interested in reliability so he created what he called Reliability and Testing Seminar called RATS. And he also had PIGS which was Parallel Information Group Seminar and so he was doing parallel processing and reliability at the same time. And we had Harold Stone was on the faculty, Ed Davidson who later went back to Illinois, Vint Cerf just came as I was leaving, so again it was just a very formative area for computer engineering. Of course, Ed McCluskey was the first president of the IEEE Computer Society. And I remember one thing that while we were there, he was running a contest for a logo for the Computer Society and IEEE had [the] right hand rule where they had the arrow and the circle representing current and the magnetic field. So he [McCluskey] selected a logo where he had a one circled by a zero, so it had a very strong symbolism with the IEEE but was unique in [and] of its own in terms of basic symbols.

Weber: So you're talking about Stanford and some of the important people there and so what were the decision points you made there about which direction to go?

Siewiorek: You mean go to Stanford or…

Weber: No, at Stanford.

Siewiorek: Well after, again, I feel fortunate that a number of decision points in my life I had one choice, so about a year before I graduated, Gordon Bell had come out to Stanford to talk about his register transfer modules and at the time I was TAing the digital logic course and we had these DEC logic stations which were something like four foot tall by three feet wide or something and we took two of them together and did a lot of plugging of NAND gates to try to make an adder and he [Gordon Bell] had the register transfer modules, he [John Grason, a professor at CMU] had students in junior level classes as one of four labs in a 16 week semester to actually build a mini computer. And it was one of these wow things. And then of course Bell and Newell book had just come out which we were using at the graduate level for computer architecture, so I didn't realize that was the beginning of bridging me to go onto Carnegie Mellon. So June of that year, they [Carnegie Mellon] actually invited me out for an interview. It turns out that my advisor-- I wanted to teach, I wasn't sure if I would go to the industry and then teach later after I had more experience, which was my original plan and so they had a "Do You Want to Teach?" course and it turns out Angel Jordan who was head of the Electrical Engineering at CMU at the time had come out and perused that list, figuring I'm from Ohio and more likely to go back to Pennsylvania than try to convince a West Coaster to go to Pennsylvania, he invited me to come out and interview in June and he offered me a job literally on the spot. And I hadn't even started looking yet, I thought I was a year away from graduating, I had only ten percent of my thesis research done at the time, not written but just ten percent of the results. But that following January of '72 I was there teaching my first class and we were using Bell and Newell's book at the junior level and using the register transfer modules where we were having the students build computers and they were building so many systems at Carnegie Mellon I thought, well I could get systems building experience there, I didn't have to go to industry to do it. And in those days we had very close relationships with Digital Equipment Corporation and so we did consulting for them, we did work on their products before they're announced and it was just the best of all worlds.

Weber: And tell me about your thesis.

Siewiorek: Well my thesis was in reliability and the biggest part of it, we were looking at switching replicas into systems to keep them running. And so I came up with something called iterative cell switch which is basically a spatial sequential circuit instead of wrapping around in time, you just replicated the logic in space. Surprisingly it made simpler switches that you could actually mathematically prove that they were minimal. And so did a lot of reliability modeling also which continued, after I left Stanford, I continued for at least two decades doing reliability research.

Weber: So you were at CMU then…

Siewiorek: Yeah.

Weber: …but you permanently went there when?

Siewiorek: January of '72, after watching Stanford beat my alma mater in the Rose Bowl, that was a real struggle when you had your undergraduate school and your graduate school playing in the Rose Bowl.

Weber: Fighting each other. And so which group or area did you first go into at CMU?

Siewiorek: So this is where the bridge with Gordon Bell started picking up. Gordon was CMU at the time and he had a group that were looking at what was the future beyond register transfer modules and he had gone back to DEC [Digital Equipment Corporation] and he let me inherit his students as well as a five year NSF grant to explore what became multiprocessors. Because after we looked around at the next logical thing above the register transfer level and ALUs was computers. So we had a project called computer modules which Sam Fuller who was actually [a close colleague], we were undergraduates together at Michigan, we had Ed McCluskey for our advisor. Sam worked on parallel processing, I worked on reliability but it turns out at the time Carnegie Mellon was looking for two people and they were going to be joint appointments between EE and computer science which was in those days in the College of Science. And so I was one and Sam was the other and the joint appointments really worked right from the beginning, it was really great even though we had two different department heads and two different deans. So we formed a team and eventually it became Cm* which we made a 50 processor system out of a then new DEC single board computers called LSI 11s which we actually roamed the DEC mill[3] at night working with the design engineers there to see how we could adapt them to a multiprocessor, in the meantime debugging some of their logic for them. And that was a very interesting project because we had three faculty and five students and out of those eight people, five ended up in the National Academy of Engineering [Andy Bechtolsheim, Sam Fuller, Anita Jones, John Ousterhout, and myself], so it was a really powerful group and we just didn't ask permission to do anything, we just went off and did it and had fun while we worked.

Weber: Can you speak up a little bit? The mic is fine but there's so much air conditioning, I'm having trouble hearing some of it.

Siewiorek: Okay, I'll try.

Weber: But DEC was in Massachusetts but you were…

Siewiorek: Well for over a decade we spent summers at DEC and I was basically working for field service and for a decade I did basically the reliability and maintenance plans for the DEC VAX product line. And from that I got to write a book on reliability and Gordon had invited me to write the second volume of the Computer Structures book which we did. So I ended up with about ten textbooks. So typically what I do is I come up with a research topic and we go off and build some prototypes systems to get some data to demonstrate to people that these things were of interest and help get the funding going through the government agencies and we'd work on building the systems, measuring them. When we had finished a number of theses, we'd actually write a textbook and usually found a company or transition technology to a company and we've done that four times in four very different areas.

Weber: Okay. So I guess tell me about the first time you did that which was back in this period, right, or the research lab too?

Siewiorek: Well it was a small company [Windward Technologies] when we were doing what we called trend analysis where we take a look at the errors reported by systems and you could actually look at time series and we were able to predict things like disk failures like six weeks in advance, so you could actually pull things before they failed catastrophically. So there's a small company that went off and commercialized those algorithms and were bought out. Then later on, multiprocessors, we transitioned

[3] [Interviewee’s note] At the time DEC was housed in an old linen mill

some of the technology to DEC, we also had another company called Encore which was Fisher and Gordon Bell and Henry Burkhardt and that was very interesting and we were building a high end multiprocessor, 100 processor system by tying together 20 processor clusters and that eventually went public. So some of the other ones with wearable computers, we actually, we did a lot of work with maintenance and there's things called interactive electronic technical manuals which we'll talk more about later, we founded a company there [called Inmedius]. That eventually was acquired by Boeing so they could convert what was done for the military into commercial aviation and we did things with computer-aided design which was sort of after the multiprocessors, we worked on computer-aided design, started some companies there and we still got a couple of companies in flight.

Weber: But the beginning of all this, because let's go sort of chronologically, so in the early years at CMU, you started going every summer back to DEC.

Siewiorek: Right.

Weber: And that was you and who else?

Siewiorek: No, just me. The parallel processor was more of a joint research project [with Sam Fuller and Anita Jones], the reliability was more consulting although it led to very interesting questions and PhD theses on how systems failed and how you recover from them and like I said, led to one of our textbooks.

Weber: And so what years was that roughly?

Siewiorek: Well probably from about 1974 to about 1986.

Weber: Okay. And the projects within that were, what are the main milestones?

Siewiorek: Okay, so Cm* started in about 1974 and I think we turned it off in about 1980 or so. But in the meantime what we realized is it was taking us longer to design these multiprocessors that with Moore's Law and faster microprocessors that if it took us two or three years to design a multiprocessor, your microprocessors would be so much more powerful at the time, people would wonder why you're doing it. And so that's what got us into computer-aided design. And in particular we were looking at design from what I call specifications. So if you take the back end of a product brochure you'd see what processor, what clock speed, how much memory, what IO ports you had and maybe they would tell you the cost and maybe how much power it consumed, maybe even the reliability. So if you literally answered about 20 questions in five minutes we'd have a parts list and net list for you and we would go through an optimization phase where we'd get a factor four improvement after another ten minutes. And so we started a company called Omniview for commercializing that. Unfortunately it's one of those cases where it was a little earlier than the world was ready for because the world was only doing-- less than half the people were doing board level simulation let alone synthesis. So now you'd call it silicone compilers or compile systems on a chip and the same way with the multiprocessors, people call them multicores now, so people are starting to revisit some of the same issues that we had when things [e.g. electronics, power supplies, housings] were a lot larger.

Weber: And that was a company that you started as a spinoff from CMU?

Siewiorek: Which one?

Weber: This first one you're saying, I mean that was the first company you were involved in.

Siewiorek: Well let's see, the CAD company spun off of CMU, the Encore was a part of a set of DEC people and other people starting a rather large vision where they were doing work stations, small cluster parallel processors, large cluster parallel processors all as a continuous product line.

Weber: But chronologically is this back-- I mean just take-- let's keep going sequentially.

Siewiorek: Okay. Well initially in the '70s with Cm*, the technology was initially transitioned to DEC and DEC had some multiprocessor products and then a little bit later Encore came out with the idea of share memory with caches keeping the data coherent which matter of fact Cm* was often called the first NUMA machine, non-uniform memory access because it took us about a factor of three longer to get to memory in another computer and then another cluster was another factor of three and how do you handle that was part of the pioneer [research] and the textbook that came out of that was a guideline to a lot of people, application programmers after that. So in the early '80s we started the computer-aided design to try to synthesize these parallel processors quicker and so that transitioned into a company in the late '80s and early '90s [4]. And in the process of doing that, the next phase came along which was wearable computers.

Weber: But all these companies were coming out of CMU through local, where were they, who were you working with?

Siewiorek: Well, let's see, so Encore was mostly in the Boston area except we had a branch called Ultra Computer doing the high level large clusters in Pittsburgh. Let's see, so there's another company in there called Ardent or Stardent which did high speed work stations and did basically super computer technology for individuals. That was located out here on the West Coast. And then the, let's see the reliability company was also out of Boston and let's see, I forgot one in there somewhere. Okay, the CAD, Omniview was out of Pittsburgh. So pretty much teaming with wherever the principals were.

Weber: And what was your role generally in this?

Siewiorek: Well generally either chief technical officer or in Encore I headed up the Ultra Max division for the high end things, I wrote the DARPA proposal that got them ten million dollars to build that high speed multiprocessor. So I'd be either chief technical officer or-- a lot of times you didn't have titles.

Weber: But that sort of role basically.

Siewiorek: Yeah.

Weber: And CMU was a good platform from which to do this then.

[4] [Interviewee's note] The company was Omniview which was mentioned earlier.

Siewiorek: Well yeah, the students among other things, some of these companies we started with students, sometimes students became principals in companies when they're started by people with more experience.

Weber: Okay, so talk about what did get you into wearable computing?

Siewiorek: Okay, so one of the things that we did was we needed some vehicles to demonstrate that the systems that we synthesize could actually be built and be useful. So one of our first single board computers is the basis for our first wearable computer which was the vehicle demonstrating that the CAD software worked and in particular, something called Private Eye had come out so that we could have a low cost head-mounted display and so we decided to combine that with the single board computer and put it in a package. And at the time, we actually went to our design department which is the College of Fine Arts and asked for an undergraduate student to design the packages. Because before that, everything was rectilinear and looked like this-- the other thing that came along was stereolithography, this is the 3-D printing and it just started in about 1979 or so. So we could actually start-- I'm sorry, 1989, I got that wrong, stereolithography was available in 1989 so the idea of making a housing to fit the computer to fit on an individual and integrating those different disciplines came about and we were actually teaching a summer course to a number of automotive engineers about interdisciplinary design as part of our NSF funded Engineering Design Research Center and so we were looking for something that the students in that ten week course could actually participate in designing and then we build it so everyone in that course walked home with one. And that became our first wearable computer, we made the boards, we made the housings, matter of fact if you open up the housing you'll see the signatures of all the students that were in the class at the time. But when we started showing the device around to people, our first application was just carrying blueprints, if somebody was building a house or something, they could check the blueprints. And it turns out that when we showed this application to other people, all kinds of new ideas came up and every time we showed it, another idea came up, "Can you do this? Can you do that?" And we actually evolved like on the order of one or two different designs a year for about a decade. And part of the reason was we were looking at what were the basically killer apps that would make a wearable computer go. So for a desktop it was Word, it was PowerPoint slides, it was a spreadsheet, what were the equivalent for mobile workers. So we kept building the systems and injecting them into real applications with real applications with real end users until we started seeing repeated patterns. And so we actually got ourselves, three major patterns that we think are still very valid today.

Weber: And what are those patterns?

Siewiorek: So the first one is, you could think of it as a checklist. There's a lot of places like we got into maintenance, and one of the reasons we got very heavy into maintenance is in the early days after the private eye, the next head-mounted displays were like 5,000 dollars each and you're not going to have individuals buy a 5,000 dollars thing. But we were working with US Air at the time and had a maintenance base in Pittsburgh and they said when they had an airplane fully loaded to dispatch, they lost 1,000 dollars a minute. And so it didn't take long to pay for a portable information device. So there's a lot of places where-- and later on when we take a look at some of the devices, I'll show you the applications that they actually use. So that led to maintenance and then the next thing that happened was what we called work orders. It turns out for example, we work with Freightliner, Freightliner made

72,000 trucks a year, 27,000 different models. You can have different engines, you can have different transmissions, you can have your stereo different, the speakers could be in a different place, literally every truck is custom built and now how do I know-- this actually happens with military airplanes too, you have block numbers and each one is slightly revised and so forth. So if you take a look at their maintenance manuals, they have a library which is probably ten feet long and they all have-- well if you're block D, use this subset of instructions, if you're block E, use these set of instructions. So that created the idea of interactive electronic technical manual where I could now literally pull together a virtual manual from all the different pieces that were unique to what the individual is doing. And so as they're doing these work orders, they may change from day-to-day so I'm not working on the same thing each day, I'm working on a different airplane and so forth. So from the inspectors, to find what's wrong and then the work orders go to people who have the skills and materials to affect that repair. So that was the second one. And the third one was because what we called, help desk or collaborative work and this again was motivated by real applications working with the Air National Guard at the Pittsburgh Airport where you have literally weekend warriors that come and have to maintain an airplane and they see what's going on maybe once a year and so now you've got a 40 million dollar airplane and you've got to make the repair and you don't remember what you saw. So you have the experts who literally have to run from plane to plane to try to answer people's questions. Well, it's very simple to take a head up display with a camera, take a picture or something, a guy back in the hangar could draw on the picture and say, "Take a voltage reading here," or certify what the person had done. So that way, sometimes we called it a helpdesk and then we generalized it to a group of field service engineers again with Digital Equipment Corporation. Half the equipment they serviced was not even DEC equipment, they didn't have the manuals for it. And if you are a field service person who was being charged at 300 dollars an hour, you walk in, you don't know how to get the front cover off a piece of equipment, it doesn't make your customers feel very comfortable that you know what you're doing.

Weber: And so those are the three killer apps or ones you hope are killer. But you said, you got into wearable as a way to find a use for custom circuit boards.

Siewiorek: Right.

Weber: But did you have any preexisting-- it sounds like a whole bunch of things that came in, I mean both wearable but also user interface. Were these things that you had a preexisting interest in? What made wearable appealing to you?

Siewiorek: Well I mean, you could sort of follow your nose. I mean the thing that was exciting to us was we started working with the design students.

Weber: And sorry, who is us, who is we?

Siewiorek: Well okay so my partners in crime were Asim Smailagic [Also Dick Martin, John Stivoric, Chris Kasabach, Drew Anderson, Randy Casciola, – more about them later]. So Asim joined us in 1992 from Yugoslavia just after the war had started and so we've been collaborating ever since. And actually a lot of these projects I'm talking about actually came out of student projects in courses. So that was the neat thing about the wearable computers, after we got the parallel computing, it turns out it was not possible to have students design these systems anymore, we got to high speed logic and it was taking them too long, you couldn't come up the learning curve but now with the wearables now we're something that students could design and it wasn't something that industry was jumping all over because it hadn't been proven yet so it allowed us to iterate and try new things very rapidly because these were small and they were now projects of the size that you could expect a student to do in a couple of months.

Weber: And Private Eye was out by '89, so you were starting before your colleague came from…

Siewiorek: Actually, if I look at the enablers, our computer-aided design, our work with the design students in the Private Eye, it sort of coincided in 1990 for us to build our first ones.

Weber: And so it was really around the course that you started this, and what course was this?

Siewiorek: Oh well, we had something called rapid prototyping of computer systems and the idea is to take students from multiple disciplines, mechanical design, electrical design, software, user interaction, design form an aesthetics point of view, put them together into a team and we started out with basically, we called it independent research, the first couple of units were built that way where we had students interested in working with us and we put them together in a team. But after a couple of years we saw we could do this yearly as a capstone design course in electrical computer engineering type of things that ABET required to have a capstone. So ABET is the Accreditation Board for Engineering and Technology, they accredit engineering programs and they require the seniors to have what they call a capstone design course where they take the things they've learned through all their undergraduate years and put them together into practice building a system. So that became readymade for it and it's sort of just word of mouth and we've built about 30 of these systems, some of them went commercial, some of them have gone on to be platforms for research, other ones have been applied to things like National Institute of Health grants to put out into the field these wearable sensors for seniors to be able to take their own vital signs and share them with their doctors and caregivers.

Weber: So you had taught this course had been going on but it was a decision to switch what the project would be in essence.

Siewiorek: Well it sort of grew out of the fact that we were getting larger and larger research groups and to put it together in a more systematic way and since the timescales for doing these things were like one semester, 15 weeks, it became a good vehicle for students to practice. And the neat thing about students, we always got a commercial customer, but the neat things about students is they didn't know what couldn't be done and so they always came up with new ideas that sort of blew the socks off the clients because the clients were so used to doing things the same way. But just one example, one year we worked on offshore oil platform crane operators, so we actually got half a dozen students, flew them down to New Orleans, got them to a training facility for crane operators so they could operate a crane, got a helicopter out to the oil platform, got to ride a crane cargo net down to the boat. And the guy sitting on the deck and the boat's 200 feet away on eight foot waves and he can't see the boat, so they've got somebody on the edge of the platform giving signals by hand to the crane operator trying to time this thing so he doesn't put this 20 ton object on the boat and sink it because he got out of rhythm with the waves. But students just get real problems out in a real situation like that, they just become super motivated.

Weber: And so what was the very first wearable system?

Siewiorek: Well our very first wearable was VuMan 1 which like I said, we did that for a summer course and we made 30 copies and everybody in the course took one home with them and we just had a simple demo there with respect to the blueprints. And then the next one we decided…

Weber: What year was that?

Siewiorek: That was 1990, 1991. And then the next one we did was, okay, so that was basically a box about this size, it was about a two pound PC-AT, second generation personal computer equivalent. And so we decided to see what was the least we could do. So we went in and cut that board literally in half, cut the-- so we went from a two pound to a half pound.

Weber: And the first board you had, where did that board come from, you made it in-house?

Siewiorek: That was synthesized by the MICON system, the board level synthesis program I had mentioned earlier. So it was exactly that design. And then they reduced the-- without changing the previous circuit board, they cut it in half literally physically and were able to put it into instead of a two pound four watt, it turned out to be half pound 2 watt system.

Weber: Why did cutting it in half reduce the wattage?

Siewiorek: Well at that time I didn't have as much money so we told them that we couldn't turn the new board but we wanted to take the existing board and find out what the minimal system could be. And back in those days they had things called PCMCIA cards and it was like 300 dollars for a megabyte of memory and this is the way we transferred programs to the device before we had wireless.

Weber: But why did cutting it in half reduce the power[5]?

Siewiorek: Well what we were doing is saying, okay we built the system but once we knew exactly what we needed it for…

Weber: Okay.

Siewiorek: …talk about it, it's like application specific if you please, how could we actually reduce it. So we got it down to show people you could do a half pound two watt system, that was not trivial, you could actually do useful work with it.

Weber: And you're using just standard DOS at the time probably, right?

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[5] [Interviewee's note] Several techniques were used to reduced power including reducing voltage until the Private Eye stop working (which in turn reduced the number of batteries saving weight) and removing unused or slightly used electronic components and providing their functionality in software.

Siewiorek: No, we weren't using operating systems at the time.

Weber: Oh, okay.

Siewiorek: Because you could consider them embedded computers, they were dedicated computers.

Weber: Okay. So you were doing all your own interface.

Siewiorek: Yeah, because otherwise if you had to run DOS, we would have been four times larger.

Weber: Yeah, yeah, a lot more memory, yeah. Yeah, you would have needed more memory and…

Siewiorek: We needed more memory, needed more power, needed more weight because more batteries and what we were looking was the dedicated application and what we could do with it without compromising the functionality to the user but minimal resources.

Weber: So you're then, you and your students creating these applications.

Siewiorek: Yeah.

Weber: And what did they look like, what was the user interface like?

Siewiorek: Well we did things like-- well the next phase actually is we got a DARPA contract and DARPA had been investing in head up displays and they were looking for applications to apply them to. So we got a five year contract from DARPA and from that literally every six months we created a new generation for a new application and the applications came from the military and DARPA got us access to. So the next one, so that was VuMan 1 and VuMan 2 were the first two we talked about. Then we got the VuMan 3 which really sort of launched us because what you'll see is it had a very unique sort of dial and software [ph?] relationship and we actually took it out to Camp Pendleton Marine Base and actually had them doing vehicle inspections with them, we actually improved the inspection time down to one-third of what it was without the wearable computer and it had a lot less errors and so forth.

Weber: And that's the one that you have a movie about, right?

Siewiorek: Well we have movies about several of them, but yeah we do have…

<overlapping conversation>

Weber: Okay, but the one that I think that I saw.

Siewiorek: One of the movies we have is the Marines first using the VuMan 2 to get the specification for VuMan 3, but it had a very unique dial relationship and from that we actually had one down to Epcot Center where they wanted us to do an Epcot map so visitors could have information about the pavilions and it was really made for that because there was a circular array around a lagoon and we had a dial and so it really matched up very well. But it also, at that time, we entered it into an international design competition and these are aesthetic competitions basically and it won an award. And it turns out at the jury missed the point because they said it looks almost good enough to work and it was actually out working with the Marines.

Weber: And which competition?

Siewiorek: I would have to look that up. {Industrial Design Excellence Awards (IDEA) co-sponsors Business Week magazine and Industrial Designers Society of America (IDSA)]

Weber: And what year approximately?

Siewiorek: That was probably about '94, '95. And at the same time, we had another one, 1998 we had a system with DEC called MoCCA to coordinate field service teams as we were talking about and that won a design award. So we actually won three design awards in about a five year span which put us up with IDEO and some of the other major design houses. And the interesting thing is it's done by students.

Weber: I was going to ask, who did the-- but these were students from you said, was interdisciplinary so some were from which part of the CMU?

Siewiorek: Well from the School of Design which is in our Fine Arts College. But just tell you a couple of little stories. So the student that did the first housing was basically one of the founders [Chris Kasabach] with the second student that worked with us BodyMedia which is probably one of the first wearables but now BodyMedia has been bought out by Jawbone so his name is John Stivoric or Ivo, he's now a senior vice president for Jawbone. And the students that were doing the electronics for VuMan and for DARPA started their own company[6] and they've done most of the electronics for Fitbit[7]. And then the other little footnote is that one of the founders of Fitbit [Eric Friedman] was my older daughter's prom date. So nice little world together.

Weber: But not the same as-- he was your student then or…

Siewiorek: No, he just happened to be in Pittsburgh.

Weber: Okay.

Siewiorek: Yeah, his father's a very famous inventor, [Mark] Friedman.

Weber: So for instance the dial on the VuMan.

Siewiorek: Right.

Weber: So what was the collaboration like to produce that?

Siewiorek: Well it's mutual, we actually, if you take a look at systems there is power which is electronics and the mechanical people worry about mechanical to get the power heat out, electronics to try to reduce

[6] [Interviewee’s note] Drew Anderson, Randy Casciola; Morewood Labs.
[7] [Interviewee’s note] All the electronics for first five products until Fitbit built up internal capability.

the power then you have the designers who work with the mechanical engineers to do the different type of tactile interactions and they work with human computer interaction students to work on the user interaction. And then the software people have the electronics that they have to write their software for but the user interaction's been defined by the designers and human computer interaction students. So there's a team, they're iterating, they're bringing in their different ideas and if somebody comes with a constraint, the other groups take it as a challenge to solve the constraint. And so it's all sort of really wound together, it's a lot of fun because it's creativity and everybody's contributing.

Weber: And this is all in the course of an academic year for a project.

Siewiorek: Well most of them are one semester.

Weber: So you'll have all-- how many people are taking the course then basically?

Siewiorek: Well this last semester we had 18 but the year before, we had 47. So they're all working on a single product for a single customer and we normally run it for 25 to 30 students which is about five to 7,000 engineering hours so you can get some rather substantial systems built with that type of intensity.

Weber: And what's the allocation, what percentage of the students would be doing say hardware or software, UI or it just varies?

Siewiorek: Well we don't really have that much control over the input [i.e. student’s background] so what we do is we keep morphing the project to fit the skill sets of the students and so sometimes we'll have very heavy front end on HCI students, so it's a much more richer user interaction. Maybe we have more embedded students and so we get more sensors involved but we sort of-- and sometimes students have to learn a new area to fill in the gap because we don't have all the skills. So that's part of the skill in running the course is to take all the people you have and merge them into a single group.

Weber: So at the beginning of the semester you'll sort of look at who you have and try to figure out what a logical…

Siewiorek: We’ll give you an example, so we did a system for Pennsylvania bridge inspectors.

Weber: And by the way, you'll have the client first?

Siewiorek: Oh yeah, we have to have the clients.

Weber: So you have a client where they've expressed some need, right?

Siewiorek: Yeah, right. So for example, the Pennsylvania bridge inspectors. So in the fall, we went out and we talked to bridge inspectors, we went out with them on a bridge inspection, we videotaped things, we got examples of bridge inspection reports. And so the first week of class, the bridge inspectors come in, they talk about what they look for in a bridge inspection, they show the equipment they wear, they show what an inspection report looks like, [we] arranged with a local company that trains bridge inspectors to give a special three hour super tutorial on bridge inspection for the students. We went out to a local bridge to let them see what pigeons and other things do to the bottom side of bridges and what the bridge inspectors have to do. So after the first week, they've got the context and then they start taking off from there. And sometimes if we need people to do the visionary scenario, if we don't have any human computer interaction students, we'll take ECE students and train them on the skills necessary to do that. And so the students do all the work, they may have more or less in depth experience with the techniques, whether they're just being exposed to the techniques or whether they've had it in their undergraduate training.

Weber: And how many professors or TAs are involved?

Siewiorek: Well, Asim and I, it's just the two of us.

Weber: So then you'll sort of break them into groups or they do that themselves?

Siewiorek: Well, we have three phases, first phase is conceptual design and we'll break into groups by discipline. So the HCI students will talk with the end users, they will get the requirements, they will create a baseline scenario which is how things are currently done, create a visionary scenario on how technology might inject to help them, but without specifying exactly how. The different technology groups - wireless groups, sensor groups we will have infrastructure groups that do operating systems and databases, they will be searching the web for all the different technologies that would be available and by the third week we will bring all that information together and in the fourth week, we do hardware architecture, software architecture, user interaction architecture and then from that we create functional subgroups which will exist for the second and third phase. So I might have, like I say, an infrastructure group, I might have a wireless group, I might have a physiological mobile sensors, I might have stationary sensors. So I'll have groups working on that, maybe two, three, four students but they also have to all come together to create a complete product by the end of the semester. So the third phase is integrating these functional subsystems.

Weber: And then the actual building of the product?

Siewiorek: Well no, they do that in the second and third phase. So the final demo for the class is a walkthrough of the visionary scenario demonstrating it's functional.

Weber: Wow. And how mature are they fully working by that point?

Siewiorek: Well one thing we did was a health kiosk and this came to us from the nursing school at the University of Pittsburgh where people who are in high rise apartment buildings have to get their blood pressure and other vital signs taken and they have to go to a doctor. Well they have to have public transportation, public transportation's late, they get to the doctor's late, miss their appointment, have to start all over again. Why couldn't you have a piece of furniture where there was a computer that the doctor can say, "Miss Jones, I'd like you to take your blood pressure in the morning when you wake up and your blood oxygen before you go to bed at night," and there'll be a pulse ox there and a blood pressure cuff and they'll be instructions on how to use it, once a day just collect it, it goes directly to the doctor and the caregivers. And so first it became a functional prototype out of our class then we took students in software engineering and they made the software more robust as the capstone for their class and we improved the user interaction through an HCI capstone undergraduate course. And from that, we now had something stable enough that we could bring in clinicians and therapists to critique it for us then we took that and improved that and now we've got an NIH five year grant to put ten of these out in the field to see if longitudinally whether it improves people's health. So some projects get their own life if you please, one of them we did, back in 2004, we did a smart watch and we used that to do gesture recognition and activity recognition and it was a platform for ten years for us in terms of doing experimental research on context-aware computing. So after wearable computing, we went to context ware computing as we add sensors to the wearable computers and machine learning to learn about context.

Weber: And the basic architecture of these changes each time or do you kind of recycle?

Siewiorek: No, they change, they have to evolve. If you just take a look over a decade, in the early days we had to build our own single board computers, now you get a Raspberry Pi. And so I think our wireless data rates have gone up over fourth orders of magnitude during the course -- so in the beginning, we took still pictures and people draw on the still pictures, now you can take videos.

Weber: On the early ones were they connected wirelessly at all?

Siewiorek: Well there's a range of wireless, we start off with basically CDPD over cell phones.

Weber: But even in the early '90s you were doing that.

Siewiorek: Yeah, even in the early '90s, yeah, we had wireless.

Weber: Sure, yeah.

Siewiorek: But not the capability, not the bandwidth, not the application software you have nowadays.

Weber: So you're doing in the early days all custom software so this would be just turn it on and it's ready to do whatever it's…

Siewiorek: Yeah. Now not so much. Like for example, the class we just finished wanted to have both stationary sensors in the house to know if you're getting up and moving around. We also have the wearable sensors for blood pressure and so forth. And we also have things called ecological momentary assessment, these are short surveys that when people answer questions they get at things like their mood and eating habits that we can't directly sense. And we want to merge all those things into our own database. Well we get a Fitbit, data goes to their cloud, we scrape the data from their cloud and put it into our database so we can look at the data from multiple dimensions. So it's a little bit circuitous that way but it saves us a lot of time, so student time is the most precious thing. In the very early days when we were dealing with GPS on a car for General Motors, it turns out that some of the sensors worked on Linux and some sensors worked on Windows and rather than try to write drivers for the different sensors and convert them to one standard operating system, we had two computers and let them network together and pass the data that they needed. So that's why I call it a functional prototype, it was demonstrating the function and once we understand what we need, then like when we went from VuMan 1 to VuMan 2, we could cut that by a-- the next time we did it, we did it with a laptop in the trunk of the car.

Weber: And how much did-- each year sometimes it's related to what happened the year before, sometimes not I take it.

Siewiorek: Yeah, it depends on who our end users are, end users have to dedicate some time and sometimes [answer questions] like this last time we had [delete answer] doctors, rehabilitation nurses and care coordinators as customers and they all had different views of data, the same data is organized by different views depending on what they were most interested in.

Weber: And how do you determine who's going to be the end user?

Siewiorek: It's a little serendipitous, people know what we've done in the past. We don't advertise, we start looking at this time of year for some candidates and then we vet them a little bit. So it's more word of mouth type thing, it's not something we can scale very much so we don't want to let it out too much.

Weber: But do you sometimes have more than one that would…

Siewiorek: Sometimes we have more than one, yeah.

Weber: And sometimes you have to hunt for someone?

Siewiorek: Well, so we'll run the same class and same procedure except on two topics or in some cases, we'll try to merge the topics if they're relatively close together, they have maybe a common sensor and database but different user interactions. So it's part of what we do as the faculty to put together something that we can envision that we could actually get a usable system out of without having to invent cold fusion or something.

Weber: And at the end, I mean these are a functional prototype but it's not a product they can use. So a few times you've gone on to spin it off into a company but usually it just ends there.

Siewiorek: Oh yeah, and the public domain people can use it, I mean each phase of the system has a presentation and a written report and the demos are videotapes. So the history is there if somebody wants to pick it up.

Weber: And what does the end user get out of it then?

Siewiorek: Well the end users first of all get their horizons broadened with new concepts Sometimes the end users are in a position to have enough clout with vendors to say, "I want that." Because if you ask end users what they want, they'll just tell you more of the same because they don't know what's possible. But when the students get in there and they show how bringing things from different areas together give you a capability you didn't think was possible, now you can go out and start asking for it.

Weber: Because it's a fair time commitment on their-- I mean flying people out to oil platforms and letting them go around inspecting bridges, I mean this takes time and resources.

Siewiorek: Yeah, and that's part of their cost, if you please, because if they don't give us that type of domain expertise, then the course is going to fall flat.

Weber: But they feel it's worth it because they get…

Siewiorek: Yeah. Well, and students, again, it's energizing work of the students, the students are just full of ideas and that makes them think deeper and helps them decide their directions, where they want to go in the future.

Weber: Any funny stories or things that went particular well or poorly in all these years?

Siewiorek: Well there's a couple of things, one thing is always do your demo before you let anybody else touch the system. Because we were down in Fort Gordon in I think it was Georgia, so we had our VuMan 2 which has this PCMCIA card and it turns out that the general down there grabbed the card and says, "Does this bend?" And he said he's so used to things in the field breaking. I mean it was my only card and I would have had no demos without it, but luckily he didn't bend it that much, he just curved it but it still worked. So that's one thing. Another thing is what I call muffled pops. So we had the VuMan 1 and we didn't know it at the time but we were actually overdrawing from the batteries. And so we're at the National Academy of Engineering and John Hennessy was being inducted and other people were being inducted and we were showing off the wearable computers and we hear these <makes popping sounds> couldn't figure out what it was. And then a little bit later my student's pants were getting all wet and it turns out that they had created steam bubbles, they're drawing so much out of the battery that the battery heated up and burst and then it was the electrolyte that was oozing out. Luckily we didn't get anybody in the National Academy wet but it could have been a disaster. We had another one, we were out, I call-- warning signs are no substitute for good design. So we were using lithium ion batteries for the first time and they need a special type of recharger and we were doing a field test out at McClellan Air Force Base in Sacramento and it was one of these things where we didn't have the charger finished so we just had a sign, "Don't recharge overnight." First night, they recharged overnight, blew up the batteries, we had acid all over the inside of the system. Luckily it was only a three day test because the [printed circuit board] etches [ph?] held up through the acid, if it was a longer test, we would have probably got some malfunctions. So that's another one. So another, we had our Navigator 2 which had speech recognition and it was doing sheet metal inspection out at McClellan Air Force Base and it was August in Sacramento which is kind of warm. And even though the device only generated two watts, we were getting a lot of complaints about how uncomfortable it was. And it was about this size so we actually had it in the small of the back. And what it was, was basically creating a vapor barrier, in other words, the person couldn't sweat over that region and that was enough to make it uncomfortable. So these are things that you don't find out in the lab. So a little bit later when we went onto the context-aware computing in this health kiosk I talked about, we went out with senior citizens and they had no concept of a touch screen. So you had to say, "Touch here," so they touched, "Nothing happens, it's broken, I don't trust it. I'll never use it again. I'll tell my friends to never use it." Well every software engineer in the world is looking for that, the release, "But you told me to touch." But if you change touch to tap, the problem goes away. So something as simple as that, take something that is considered broken and unusable. So we had another when we were demonstrating for Boeing. So we were using speech recognition and we were looking at different parts of the airplane and they had two digit designations zero, nine or whatever. And so speech recognition in those days was very erratic and so I was trying to move along in the demo and somehow the software got looking for a number but I thought it was in a different point and so I was telling it, quit, logoff and so forth and it was never matching what it was expecting and we thought it was a hardware problem, software, but it turns out it was basically a logical problem. And so I had to do a song and dance for the Boeing personnel while the students were rebooting the system and trying to get us back to where we were. So you learn a little bit about subtle bugs. So one story I really like is we were going to Pawtuxet River in Virginia which was the East Coast fighter squadron test base. And so we get on base and one of the persons that's helped us a lot through all of these military things was Dick Martin. So Dick Martin [a Navy fighter pilot] served two tours in Vietnam, 600 carrier landings, 100 at night, commissioned the first F-14 fighter squadron for the Navy, was at Top Gun, was nuclear trained by Rickover and he was the commissioning captain for the Carl Vinson nuclear aircraft carrier. So we get onto the base and we go to the engine shop and Dick just introduces me very briefly and says, "Dan tell them what you're going to do for them." So this chief there, he'd obviously been in the Navy for quite a while, folded his arms, leaning back and you can tell he's being polite, so I'm trying to tell him what we're going to do but it wasn't getting any traction. And then after I finished he walks up to Dick and says, "Were you on the Vinson?" And Dick said, "Yeah," he {Dick] was the captain, the chief says, "I was on your first round the world tour." Anything we wanted from then on, we had, instant bonding. So the key is if you can find a champion inside, even if you don't get the technology exactly right, they're going to talk it up and sell it whereas if you just do it top down [it is not accepted], like when we did the bridge inspection thing, luckily somebody had just given them a system before that for example, handwriting recognition they had a window about the size of my pinky that you had to put a 12 digit number in. Nobody remembers bridges by a 12 digit number, it's Jackson Run [ph?] Bridge, it's the Golden Gate Bridge or something like that. And so we had a great example of how not to do it. The fact that we were listening to them and they could see us make changes according to what they're saying, instantly got us credibility and again, we didn't have to get it exactly right because they became our champions.

Weber: So how many companies came out of this course then?

Siewiorek: Just the wearable? Well I think we had the company called Inmedius which did the interactive electronic technical manuals and the other ones it was more the students that we produced, a couple of our software students[8] went on to Navdy where they have the gesture control of the cell phones in your car for example. So I think a lot more were gotten out by the students we trained then directly as product companies.

Weber: But that one that came out, that was based on which, on the VuMan…

Siewiorek: Well it was more based on the maintenance and what learned about doing maintenance and maintenance software. We weren't doing any hardware. And hardware changes really quickly and so forth. Now we did get VuMan 3 to the point where it was on a procurement list for the military but they

[8] [Interviewee’s note] Harvey (Hrvoje) Vrsalovic, Matt Hornyak.

never picked it up, so it's a little chicken and egg type of thing whereas the software and how the software is used and given that there are languages for writing technical manuals, there's much more traction, much less risk, much more effectiveness. So whether it runs on Toughbook or something like that, rather than try to do a dedicated hardware, software allowed you a lot more options.

Weber: And so that was a system for compiling for instance a manual for a particular…

Siewiorek: Well it basically, there's S1000D, it's a language for creating manuals and so getting the authoring tools and the templates and different software development kits if you please, so that people-- because right now, I think the military is requiring all the systems to have S1000D manuals. So it's more than just displaying the manual, it's being able to author. There's other things like, what do the experts do? The last time the Air National Guard did, something, you'd like to know what the expert did and which manual pages he went to rather than try to figure out his own path. So you could add extra functionality.

Weber: And the military in the '80s put a lot of money into SGML for manuals.

Siewiorek: Well I mean I think it's a subset of S1000D.

Weber: Right. So you've mostly worked with vertical applications. What's your opinion about a wearables in the consumer space?

Siewiorek: About what? Oh, in the consumer space. Well I think there's a niche with the physical activity recognizers and so forth. The cell phone, nowadays-- we're doing now what we call virtual coaches so to context-aware computing we add feedback and so we're working on people recovering from stroke and receiving therapy. So I see a lot of applications in let me call it the virtual coach space because we're having fewer and fewer medical people that clinicians for example that can watch whether you're doing your exercises, can encourage you to do the exercises, correct you if you're not doing them correctly. So there's giving one-on-one attention to people and using the wearables as either a sensor platform or a delivery system. I see a lot particular with the older generation where people being able to live independently longer, I see lots of potential in that area. One of the things that we did learn was when we did the wearable computers we did not make it like virtual reality, in other words, when they used the Private Eye, it was down in the lower part of your vision like a dashboard of an automobile so you maybe spent ten percent of your time looking at the material, the rest of the time in the physical world. But there's been studies that show that the more high fidelity you have in the virtual world, the less people interact with the real world and as a result, I see people in school all the time almost running into people texting with their smartphones, so if you give them a higher fidelity and so forth. So there's a real issue of if you're doing something like maintenance in the real world, you can't be distracted, that whatever hazards there are in the real world like walking in front of a jet engine. It's the same with driving and distracting while you're driving and so forth. So there's this human attention and how do you split that up and make it so that some people in the early days of wearable computing, you could tell that they're looking at their head-up display and unless that becomes socially acceptable, it becomes a little bit disarming, who's more important, you who are physically here or what's going on in cyberspace.

Weber: So all your systems or most have been more of a head-up display that's just a part of your vision, nothing immersive.

Siewiorek: It's a part of the procedure, it's not the dominant part, but it's there to help you, like our virtual coaches, they're observing but we can tell you by the pitch of your voice, your emotion, we can adjust the way we interact. So I think you need, so Siri plus plus in terms of interaction. So there's a very vibrant area of research right now, human robotic interaction, you can just think of these wearables as a form of information robotics that how do you engage the people to the point where they're not distracted from what they're doing but that you're generally helpful and people want to come back and use you.

Weber: I'm sure you're going to show us some, but for the input device, you generally have a pointing device, what about text when it needs to be inputted, voice recognition or…

Siewiorek: Well, we've got several things, we've actually in one of our papers we have these concentric circles that look at the input/output and the data structures. And typically we start with text and in a case of inspections for example, their vocabulary is already fixed. It was kind of interesting when we went to McClellan Air Force Base, an offshoot that we didn't anticipate of the benefits of the wearables, we actually standardized their vocabulary. They did not have a standard vocabulary, by putting up on the screen is this gouged, is this scratched or whatever, they had a standard vocabulary. Because before that, somebody would say it's gouged, somebody would say the same thing was scratched, what type of personnel, what type of skill, what type of material do you dispatch to fix that problem. So sometimes just regularizing the vocabulary may be the major advantage and the wearable is just a vehicle to accomplish that.

Weber: But how would they be entering let's say their report?

Siewiorek: Well most of the time, what we have is particularly routine maintenance and things like that, you don't really discover new things that often. So if you've got it all sort of codified, so we do have a free form field to put in and we also have speech recognition or it could be just an other field and they could fill that out later when they actually finish, submit their report. So we haven't found-- once we understood the procedure and if I've got 5,000 amphibious tractors, as they age there may be a new defect appear but you could easily add that to the software. So we never really had the field that we had to have too much free text.

Weber: And intelligent agents like Siri type things then are…

Siewiorek: Well we had some work back in 2004 on something called radar where we were looking at intelligent assistants and actually out of that same DARPA program, Siri came out from SRI. So we were actually looking at people handling your email and then when you had a process like planning a conference and watching what experts do, we could actually tell people, it's about time to think about this or time to think about that and what we did was not so much improve the performance of top people, but we really squashed down the range in performance and take the underperforming people and make them as competent as the average was without such assistants. So I see these assistants could really help cut the tail of distribution and drive the quality up to a higher norm.

Weber: And before we go to the physical objects, anything else we should cover?

Siewiorek: Well, I like the process where we go and we try something, we get some data, we get some research done, we publish some papers, we transfer the technology, write a textbook, that's been a very effective way to bookend, if you please, a set of topics. It's also interesting that with the multicore things and so forth, we're starting to revisit some of these same issues that we had in 1970s, except that the hardware is bigger and so forth. So one of the things, when we did a computer structures book, came out of Ivan Sutherland talking about graphics, the wheel of reincarnation and if you start reiterating it-- so I think we're starting to go around the wheel a second time on my career.

Okay[9], so let me take you through about 15 years of our wearable technology from 1990 to 2005 [**Start on screen subtitle “VuMan 1”]** So our first system that we built was called VuMan and later VuMan 1 and it was part of a course that we had during the summer on how to do design and we wanted to have people design an artifact as well as listen to the theory so that they were doing something with their hands. So we actually had 30 students in a class and we actually made 30 of these and it was really a vehicle to demonstrate how we could use our single board computer design automation software to create a usable board. So we had a system called MICON and it built a single board computer which became the internal guts for the wearable computer and the wearable computer was just a demonstration vehicle for the computer-aided design software. So we had a Private Eye which made it possible to have output for people on the move and the idea here was that you would put it on and you'd use it like a dashboard of an automobile, it was down below your [eye]-- unlike Google Glass which is above, it's below and I could glance at it and still have a complete view of what's going on in front of me. And we would spend less than ten percent of our time in the virtual world by basically verifying the steps I would have to do. Now this is an example of what happens when you have fine arts and designers get involved with the people who are mechanical and electronic engineers. So we gave them as typical in those days, a restriction, "So here's the board, package it." And so they came up with this style and it's sort of over your shoulder like a European purse and this little bump up here was like a hand rest or your mouse and they had two different types of buttons, scroll up, scroll down, select and they purposely were different styles so that you could touch and by feel, know which one you're on. The other thing is that this is raised and we actually made this a chimney with the hot components arranged underneath the chimney so that we got more air circulation, so we got the mechanical design from a thermal perspective involved with the electrical design and so forth. Now one little thing that happened here, which was kind of interesting, as we were merging the disciplines, what happened was there's this thing called a reset button and all the engineers wanted to be able to get things back to a known state. When the board came out with the reset button, the person who designed the housing said, "What's that?" He had never seen the reset button. And unfortunately they hadn't made accommodations for it, so we had to go around drilling extra holes for it. But the other problem that happened was since this was mounted on the housing, they hadn't left enough space for the board so that the pins from the button were actually shorting out a couple of memory pins. So then we had to go back and do some rework on it. So this got what we called a design escape between the different disciplines, so we put mechanisms, in place so that we wouldn't duplicate that problem by one group not knowing exactly how their piece fits in with the other groups.

[9] Interviewee moves near a table with wearable objects: VuMan 1, VuMan 1 printed circuit board, Private Eye head up display, VuMan 3, Spot printed circuit board, Navigator 2, TIA-P, Itsy/Cue, eWatch.

So this is the first one that we came up with and later on we did a cost and size reduction. So this was about two pound second generation IBM PC, it's equivalent to a PC-AT then we actually made another one which was VuMan 2 which was about half the size, we literally cut the board in half and got it down to a half pound and two watts.

So the next one that came along was called VuMan 3 and this was actually used by U.S. Marines at Camp Pendleton for vehicle inspection. **[Start on screen Subtitle "VuMan 3"]**And now you can see our printed circuit board has taken on a different shape and one of the things that happened-- this outer shell which adds to the bulk is there just for shock absorbing and the fact that the Marines work in a much more hostile mechanical environment than most of us. So you can see that the system actually is contoured so it fits the shape of your hip. The idea here is that there is a very strong model between mechanical manipulation and the software, so everything on the screen was in a circular list, and as I rotated the dial around then the circular list, you'd progress around the circular list. And so it was designed if I'm right-handed or left-handed, I've got a thumb button for basically selecting, I could also select with the fingers across the bottom. And the metal band is not only for rigidity but it's also the heat sink, so we were able to get the heat out of the system. Now what happened with the board is that in the process of doing studies of where on the body you could mount wearable computers, they found out that if you get more than about a two inch profile, then people will actually change the way they move. And so you'd start bumping into things, you become conscious of your body being expanded. So your body has an aura, your mind knows how to control that space but if you make your body bigger than that space, it becomes clumsy**. [Start on-screen subtitle "VuMan 3 board"]** So what they did was they put this shaft so the dial would go through the board so we'd keep the profile down and then the cutouts here would be where the batteries are so they could mount the board mid level between the stack of batteries. So again, this is how the electronic designers and the mechanical and industrial designers work together. And it's kind of interesting, we took this out to Twentynine Palms and we liked the tactile feel but the Marines didn't like the noise. Sound carries in desert and they didn't want to be shot at doing vehicle maintenance by giving people targets. So again, those are the type of things that you don't get necessarily in the lab. And so this was also entered into an international design competition and won an award and the jury thought that, as we mentioned earlier before, thought that this looked good enough, it would actually work but they totally missed the fact that it was operational in the field. And so that is VuMan 3.

Then the last system we built was called Spot, which came out in 2000, 2001,**[Start on-screen subtitle "Spot Board"**] and again, you see the printed circuit board looks very different and because they wanted to create a system that was contoured to the body and that the taller components were at the center and thinner components at the edges. But the other thing is that they wanted to have a wireless radio card but if they used connectors to connect the two boards, it would have been more than two inches. So they went back to the people doing the printed circuit board and asked, "This is an eight layer board, could we take an internal layer and make it effectively a ribbon cable so that we could fold it over like a taco and put the PCMCIA card in there?" And they were able to do that. And again, that's the type of thing that you get when you take the disciplines and have them work together. Now [holding VuMan 3] it turns out later on, we actually just did the dial and so you might think this is big and the reason it's big is because of that [speaker showing his hand], this has not changed over thousands and a hundred thousand years, and so you have to have something big enough for people to be able to grasp. And so later on we would just make the dial as an input when the electronics got really smaller and we use it down at China Lake, down in Southern California. **[Start on-screen subtitle "VuMan 3"]** And it turns out that this was good because it's effectively a linear mouse and everything on the screen would be in a circular list is a very simple mental model but the thing is that I'm not disoriented. When we were working on our earlier systems and we would have basically a mouse, people were wondering, "Well what was the left button, was it when the mouse was up, when it was down, pointed towards you, pointed away from you?" People got confused, whereas on the desktop you have a relationship between a mouse, you know where it's at. Nice thing about the dial, it operates no matter what orientation. So Boeing doesn't want it on the hip because they're crawling through aircraft with small access spaces. So they would rather have things like a shoulder holster. When we went to sailors on aircraft carries, they carry chains on their shoulders, so they didn't want something up here. So it was important to get an input, output mechanism that was somewhat independent of the location on the body but it was very intuitive to use no matter what location it was. So those were some of the things that went into-- pretty deep thinking, came out with a very simple approach.

So we had another series called Navigator, now **[Start on-screen subtitle "Navigator 2"]** Navigator explored speech recognition and global position sensing and so forth. And again, what you'll see here is a metal frame which is both for rigidity and also is for heat sink. And it looks good and again, when it looks good, people very likely want to use it. You can see it's contoured so it's designed to go in the small of the back and we have sort of the cummerbund to hold it. And it turns out that we did use it with speech recognition so people could annotate the inspections they were doing. It was used in McClellan Air Force Base in Sacramento for sheet metal inspection of KC-135s and as you know, Sacramento can get very hot in August and even this thing only generated two watts, people complained about being uncomfortable from a heat point of view because when they had it in the small of their back, it blocked a part of the back which perspires and helps cool the body. So it was a vapor barrier and even though it wasn't creating much heat itself it was preventing the body from dissipating heat. And again, these are things that maybe we should have known but we didn't know until we got out and actually tried it.

So we took the speech recognition step one step further and this is called TIA-P {Tactile Information Assistant – Prototype], **[Start on-screen subtitle "TIA-P]** and it was developed for DARPA for English to Serbo-Croatian translation for NATO troops in Bosnia. And we couldn't go in country so we had to train people on how to do it and they took in country. And if you actually feel it, it's fairly hefty and it's actually an industrial based housing from a company called Telxon [ph?], you could drop this onto concrete from eight foot and it would bounce and nothing would happen, you could smash your fist into it and the screen would still work. We sent six units over and we got part of one back and so even though we thought we had a very resilient system, it really wasn't up to all the rigors that the troops could put them through.

Then about 1999, we combined with Compaq, **[Start on-screen subtitle "Itsy/Cue"] Compaq** made this top art called the Itsy [ph?] and it's probably one of the first things that actually used accelerometers for control and it had something called rock and scroll, you could actually rock it and it would scroll that way. And we added extra battery to it and wireless and it became Itsy/Cue and you could almost argue that this was sort of the forerunner of the smartphone because it added the wireless and it had a full blown operating system.

Then in about 2004, we were looking at adding sensors to devices so that we could do what was called context-aware computing now **[Start on-screen subtitle “eWatch”]** and so we have something called eWatch and again, the shape was designed by students from the School of Design and it had accelerometers, it had a light sensor, it had a sound sensor. And surprising enough to us, we did machine learning and we could tell a light and sound footprint for different rooms. So we could tell if you were in your bedroom, you could tell if you're in your kitchen, whether you're in your office, whether you're at a restaurant, whether you're on a bus or whether you were at a grocery store. So we could literally tell your location from light and sound signatures. And it as only 30 megahertz processor so it was very efficient, we could run it for a whole week without having to recharge. And so we actually made about 50 of those and used them as research platforms for almost a decade.

So anyway that's a rather quick tour through probably about 100 person years worth of research and literally a couple dozen different applications.

Weber: So the VuMan 2, what changed between the 1 and the 2 and then the 3?

Siewiorek: Well VuMan 2 was just to see how small we could make it and still be a useful system?

Weber: But same functionality.

Siewiorek: Same functionality as we had in VuMan 1. Well we actually programmed other functionality into it on top of it, but basically used a one megabit PCMCIA card for transferring programs and it was literally like half a pound, so it was almost the size of a package of cigarettes.

Weber: And the pointing device was still just the two buttons as in the 1?

Siewiorek: Yeah, as a matter of fact, if I show you the VuMan 3 video, you'll see VuMan 2 as the predecessor in terms of working with the troops. So it had itself the size of a hockey puck with basically instead of this [hand rest], it had a disk with a tail. So now we had three wires, we had one for the battery compartment, one for the Private Eye and one for the disk, and one thing we found out is that very quickly you could tie three wires into a knot. So what happens with VuMan 3 is there's only one wire to the display, so even though three wires doesn't sound excessive, it did prove somewhat of a tangle. So the batteries are built internal to here so we don't need that wire and then of course the interface is built in.

Weber: And you're using the Private Eye up through the 3…

Siewiorek: Yeah.

Weber: …and then the next one…

Siewiorek: Then we started using a more sophisticated, I don't remember exactly, let's see, it was one of the companies that DARPA had funded that did the display chip and I forget, I'll probably remember it as soon as you turn the camera off. [Virtual Vision]

Weber: But another head-up display <inaudible> specification.

<overlapping conversation>

Siewiorek: Yeah, it was not a standard display, this was CGA-like, so it wasn't even a standard display format, so this is four times the resolution or pixels as this. So here we could do text, here we could start doing diagrams. Until we had VGA we couldn't really do the graphics.

Weber: And so what's the pointing device or equivalent for this one?

Siewiorek: Well we had a micro mouse.

Weber: Okay. So that's just completely in the small of your back and you're not touching it as you're going.

Siewiorek: You had this cummerbund and you had a little commercial joy stick mouse.

Weber: Joy stick, not a track pad.

Siewiorek: Not a track.

Weber: Okay. But then you're getting into a stylus and a touch screen here, right, in the next one [referring to TIA-P]?

Siewiorek: Yes, this is stylus and touch screen, again, try to get it all integrated and the idea here is that if I'm-- we're trying to be more native friendly, if I'm wearing a Private Eye or something like that and I'm already in a war zone <inaudible>, whereas here it's perfectly acceptable to have-- so it was more of an issue of putting the civilian population at ease when you're asking them questions that may get them killed.

Weber: So the one in the small of the back though, also you're saying voice recognition.

Siewiorek: Yeah, we had voice recognition with this.

Weber: But the primary application was?

Siewiorek: Well in this one [referring to Navigator 2], we built it for the sheet metal inspection, so it's a 36 hour task, they strip down to bare metal, these aerial refueling tankers once every five years and people literally get in there with a magnifying glass looking for corrosion and cracks and popped rivets like that and then people who are doing the inspection then have to put a tag on the airplane and log it whereas here you could just put a tag on the image of the airplane and it would be automatically in the computer. So we saved them data reentry. A lot of these systems would save data reentry. On the inspection here, people would have a clip board and a paper and they'd write things down and then hand it to somebody to type it into the computer. And people are doing these inspections with gloves on, it's cold out, it's wet out, their handwriting isn't that good, so there's a lot of errors made from transcribing, whereas once you've got it in the image, it's in the database just download it into the work order generating computer.

Weber: And the previous ones were only text based so you couldn't do…

Siewiorek: Yeah, these were text. We did have a couple of experiments, when we did Epcot Center [referring to VuMan 3 with the Private Eye head up display], we were able to create a little bit of a caricature of the different pavilions around a lake in one screen but even the pictures of the pavilions were black and white and just more hinting of what it looked like because the resolution wasn't very good.

Weber: And when you switch from making your own complete embedded system, you said later on you went to more off the shelf hardware and software, so which generation were after all these?

Siewiorek: Well let's see, in some sense, this is a hybrid [holding Itsy/Cue] because we had the Itsy from Compaq and then we created the housing and so forth. But I would say once the smartphones got to the point where they had sensors in them, because they already had the wireless and they already had the screen, so we started probably by 2005 we were pretty much totally on phones.

Weber: And talk about when did wireless come in, or all of these had some wireless capability.

Siewiorek: Yeah, well we had wireless, we had CDPD in Navigator 1. These were just basically plug into the computer and offload the data. But pretty much from here on, we used different styles of wireless. We actually have an article coming out this month[10] from the course that we talked about, looked at the different systems we built in the course including things like down at Warner Robins Air Force Base we used wireless to couple the inspectors with the people who were doing the work order generation.

Weber: And what year was this one?

Siewiorek: This one was probably about 1994, '95.

Weber: Actually if you could go, I know you've talked about it in context but just give a year for each.

Siewiorek: Okay. I'll do it from memory but better off, I think I've left you our poster that has the years. But this is 1990, 1991 [pointing to VuMan 1], about 1993, '94 [holding VuMan 3], this was about 2000 [pointing to Spot printed cuircuit board], this about 1995 [pointing to Navigator 2], this was about 1997 [pointing to TIA-P], this was 1999 [pointing to Itsy/Cue], these are 2004 [eWatches].

Weber: Anything else you want to add?

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[10] “A Quarter Century of User-Centered Design Engineering Project Classes with Multi-Disciplinary Teams,” Dan Siewiorek, Asim Smalagic, GetMobile, January 2016, Volume 20, Issue 1

Siewiorek: Well it's been a lot of fun. And there's actually a research monograph on it from Morgan Claypool [Application Design for Wearable Computing, Synthesis Lectures on Mobile and Pervasive Computing, Dan Siewiorek, Asim Smailagic, Thad Starner, 2008] I believe, you can actually see our experience written up there and there's lots of little anecdotes about what happened with some of our students met and married each other from the project and so forth, so some more personal stories there too.

Weber: Great. Well, thank you, I really appreciate you do this.

Siewiorek: Thank you so much for the opportunity, I appreciate it.

END OF INTERVIEW

