

FEATURE

Walking as Jazz: Virginia Tech takes on the biggest challenge in robotics

By Paul Miller (<http://www.theverge.com/users/futurepaul>) on November 8, 2011 10:31 am ✉ Email (<mailto:paul@theverge.com>)



Dennis Hong is incredibly, almost intimidatingly, energetic. When I met him at his Virginia Tech lab in September, he had just pulled an all-nighter writing proposals in his office and planning his latest round-the-world trip. He strolled into his modest Robotics and Mechanisms Laboratory (RoMeLa) around noon looking remarkably fresh, and proceeded to promote his lab on camera with an affable gusto. Hong's demeanor is of a preschooler gleefully Crayola-ing the walls while his parents aren't looking — though perhaps that manic quality was induced by the thirty odd hours of wakefulness I found him under. "Don't print this, but I would do this same thing even if they didn't pay me!" Not that Virginia Tech has any reason to complain: RoMeLa is an astounding success.

The conventional wisdom is that America does the boring military robots and vacuums (the stuff that pays well), while Japan and South Korea get all the fun humanoids that [look like Albert Einstein](http://www.youtube.com/watch?v=tF-ZnvxStrQ) and [fall down stairs](http://www.youtube.com/watch?v=ASoCJTYgYB0). From a funding perspective that's certainly true: Honda has spent over \$300 million and 100+ man years on its ASIMO humanoid, widely considered the most advanced in its field, and Korea funds robotics at a rate of \$80 million a year, compared to a measly \$10 million for the National Science Foundation (NSF).



In fact, there are only a handful of groups in the world who have managed to make full-size humanoids. The challenge is much greater than just jumbo-sizing one of the relatively agile toddler-size bots. It's a physics problem, as Hong explains: "If you make a robot twice as tall, its mass becomes eight times as great, not double." Still, Dennis Hong and company dominated at this year's RoboCup competition, winning at both the KidSize and AdultSize soccer leagues with two brand new humanoids, DARwin-OP and CHARLI-2. A mere two years after RoMeLa started building full-size humanoids, the AdultSize CHARLI-2 also won the Louis Vuitton Humanoid Cup for Best Humanoid. Not bad for 18 grad students, 30 undergrads, and an insomniac.

DECADES OF STIFF, ARTIFICIAL, AND SLOW HUMANOID ROBOTS ARE BUMPING UP AGAINST A STEEL CEILING

But all of this sounds like a mere warm-up act in comparison to RoMeLa's next project: a firefighting humanoid that can navigate the difficult terrain of a Navy ship. The challenge encompasses all the biggest problems in robotics, with entirely new mechanisms to design, algorithms to code, servos to build – and of course, there's that whole "fire retardation" problem. Decades of stiff, artificial, and slow humanoid robots are bumping up against a steel ceiling. RoMeLa will have to charge past the established thinking to build something more graceful, something a little more like the humans that inspire them. If anyone can do it, it seems like Hong and his team can. But first they'll have to play a little bit of soccer.

Playing games



The goal of RoboCup is to field a team of humanoid robots by the year 2050 that can beat the men's World Cup champs in a game of soccer. In reality, RoboCup is an annual competition where some of the smartest men and women in the world slide around in socks on fake little soccer fields, trying to keep their mechanical creations from falling over. Competition includes wheeled robots of many sizes, and pure, AI-focused computer simulations of the game, along with challenges related to rescue and "@home" domestic applications, like cleaning your house, but humanoids are the real prize.

Dr. Oskar von Stryk heads up the robotics lab at Technische Universitaet Darmstadt in Germany. Between his name, and the dominance of his Darmstadt Dribblers humanoids at RoboCup, we've got the makings of a great Mighty Ducks sequel. The team has been mostly unstoppable in competition since it joined up in 2004, back when the Sony AIBO was the standard platform. Dr. von Stryk first got to know Dennis Hong in 2006 when visiting Virginia Tech, since they had mutual students collaborating on a PhD project.

Hong was already dabbling in humanoids when Oskar introduced him to the RoboCup competition. RoMeLa's first humanoid was dubbed Mini-HUBO (an ode to Korea's full-size HUBO, a close competitor with ASIMO for the world's most advanced robot), and its original purpose was to study human locomotion, with platform software borrowed from Virginia Tech's third-place effort in the DARPA Urban Challenge (a project co-led by Dennis Hong). Still, qualifying for RoboCup is a feat in and of itself, and Mini-HUBO didn't have what it takes, so RoMeLa got to work on the next generation. The result, DARwIn (Dynamic Anthropomorphic Robot with Intelligence) was the first American-built robot to qualify for humanoid competition when it went to RoboCup in 2007. The robot didn't make it far, but a seed had been planted.

The missing element was AI, which is where Dr. Hong's longtime collaborator Dr. Daniel Lee comes in. Daniel first met Dennis about a decade ago when the latter was a graduate student at Purdue, working on analyzing the "friction cones of grasping." Lee brought Hong to his lab at U. Penn (appropriately dubbed GRASP) to give a talk to his students, and the two have been collaborating ever since.

Both Dr. Hong and Dr. Lee are Korean Americans, which Lee cites as one of the reasons they hit it off initially. Dennis was born in the US but lived in Korea when he was young, and is actually a bit of a celebrity in the country. He's been the subject of an hour long Korean television documentary, and people recognize him on the street. Perhaps even more than Japan, South Korea views robotics as a very important

"ROBOTICS IS SUCH A BIG, WILD FIELD YOU CANNOT BE AN

industry for its future — during Hong's most recent tour of Korea, Lee Myung-bak, president of South Korea, was scheduled to meet CHARLI-2 and shake the robot's hand, but sadly Myun-bak had to cancel at the last moment. Next year RoMeLa is even getting its own full-size HUBO to play around with, thanks again to Hong's strong ties there. "Many in Korea want to work with me, which leads to opportunities," he says.

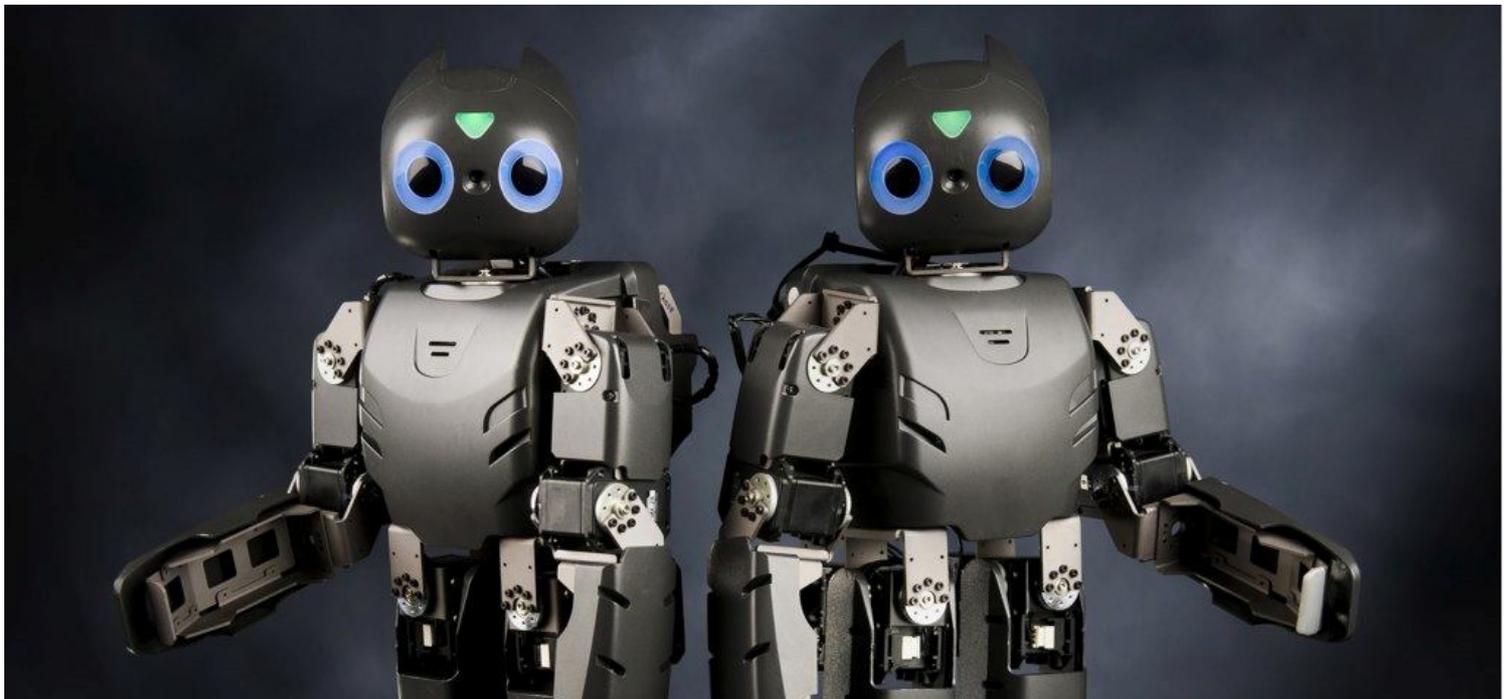
Much of RoMeLa's success has been built on collaboration. "Robotics is such a big, wild field you cannot be an expert on everything... I'm more like an end user of artificial intelligence," says Hong. Lee's team builds the "apps" that run on Hong's team's hardware. Lee, who originally studied neuroscience, has his work cut out for him: "Conventional programming," says Lee, "is to think about all the potential situations, enumerate all the situations, and then write down, essentially, what the machine should do in all the situations."

EXPERT ON EVERYTHING."

Robots, on the other hand, don't know exactly what they'll encounter, so they have to learn as they go. When on the field, DARwIn's responsibilities include: finding the orange ball, walking to the ball, kicking the ball toward the opponent's goal, getting up when he falls over, and repeating. All of this is accomplished with a single camera, a single onboard accelerometer, and a WiFi connection for collaborating with teammates. Outside of signaling to the robots that play has begun, and dragging a malfunctioning bot off the field, the sock-clad humans have to remain entirely hands-off during play. The robots attempt to tell each other where the ball is, and who's in the best position to play goalie, but mostly they just fall over repeatedly.

"As humans we make decisions on uncertain evidence all the time. This is something that's hard for robots to do," says Dan. The true challenge comes from making the transition from digital to the physical, and back again. Dan calls IBM's Jeopardy-slaying Watson supercomputer "a nice example of machine intelligence, but I think what's lacking is having that intelligence actually be embodied." Watson doesn't have to hear a question read out loud, or physically slap a buzzer, and Watson certainly doesn't have to chase a little orange ball around like an animal.

Dr. Lee's UPennalizers team had been a strong contender in the AIBO and Nao-based standard platform league ever since 2003, but never managed to bring home a championship. After taking 2008 and 2009 off, the UPennalizers teamed up with RoMeLa, forming the Megazord Team DARwIn, and reached the semi-finals at RoboCup 2010, hosted in Singapore.



A bigger vision

When Hong got into the game in 2007 there were no custom, ready-to-program humanoid robots available, but in 2008 the Aldebaran Robotics Nao humanoid became the new standard platform at RoboCup, replacing Sony's discontinued four-legged AIBO. Teams can purchase the robot and build their own software on top of it, but can't modify the hardware, meaning there's a level playing field. The toddler-sized bot costs around \$16,000, and you need three of them to play. Of course, for a mechanical engineer like Hong, building the hardware is the best part.

Still, not everybody can build a humanoid from scratch. Hong was getting letters from people who wanted to buy copies of DARwIn, but he didn't have a way to sell it. Luckily, the NSF stepped in and offered \$1.2 million for RoMeLa to open source the robot and have 35 units built for various institutions in the U.S. RoMeLa had actually attempted a bit of open sourcing with Mini-HUBO, posting fabrication and assembly instructions for students at Drexel to build without RoMeLa's help. The early practice run helped them formulate their approach to open sourcing DARwIn.

To do things at scale, the lab teamed with Robotis, a Korean robotics components company, who helped RoMeLa design the final version of the robot — including its adorable new shell. Much of DARwIn's agility on the soccer field can be attributed to Robotis's Dynamixel servos that reside in each of its joints. Even if an institution chooses to follow the open source instructions to build the robot instead of buying it pre-built from Robotis, they'll still need to buy the proprietary Dynamixel — keeping Robotis in business either way. Robotis sells a productized version of the newly dubbed DARwIn-OP (OP = Open Platform) for \$12,000 a pop, and schools can buy it for closer to \$9,000. Hundreds of units are now being used worldwide.

Better yet, I've heard from multiple sources that there's talk of making the DARwIn-OP the new standard platform, in place of Aldebaran's Nao. "This is currently being discussed internally, and I think before the end of this year there will be an official announcement," says Oskar.

Jesse Hurdus, a former student of Hong's, who did some of the earlier work on DARwIn and now works at TORC, an R&D spinoff from Virginia Tech, put the promise of DARwIn-OP this way: "Once we can standardize these platforms, and not reinvent the wheel every time, it enables people to do much more advanced, much cooler things, and that's where you'll see technology and robotics go to that next level." Dr. Lee's UPennalizers quickly capitalized upon this promise, optimizing a walking algorithm for DARwIn-OP that made the robot 30 percent faster than its predecessor.

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PASSING IT ON

Dennis Hong's approach to robotics builds on decades of research in mechanical engineering. Interestingly, however, Hong has a nice little hereditary link to one of the primary methods for describing the motion of robotic limbs in 3D space.

Denavit–Hartenberg parameters

In the 1950s Jaques Denavit and Richard S. Hartenberg put down some foundational research in the realm of kinematics (the study of how objects and groups of objects moves). Their namesake, the Denavit-Hartenberg parameters, was the first "minimal" representation of a line, and is commonly used today by engineers in calculations — especially in robotics, where the cascading links make position calculations spiral out of control quickly.

John Uicker

At Northwestern, John Uicker studied under Denavit and Hartenberg, and his own PhD work went further in understanding the motion of linked objects with mass and momentum. He's considered one of the "pioneers" of the dynamics of mechanisms.

Ray Cipra and Dennis Hong

Both Dennis Hong and Raymond Cipra studied under Uicker, a couple decades apart. Ray did his undergrad, graduate, and PhD under Uicker at University of Wisconsin–Madison, but after doing his undergrad at Wisconsin, Hong went to study under Cipra at Purdue, where he went on to get his PhD. Both men have published jointly and separately on the topics kinematics and robots, working as mechanical engineers in a field better known for its electrical engineers and computer science types, and building on the work of nerds that came before them.

What's so great about Dennis Hong?



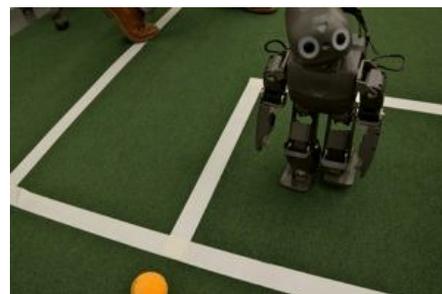
"I don't know how to turn CHARLI on," confesses Hong, with a hint of pride. The CHARLI humanoid project is headed by Jeakweon Han (known as JK around the lab, pictured), who is about to wrap up his PhD and then head back to Robotis, where he was an engineer before he caught Hong's eye with a humanoid robot that can transform into a car and back again. While Hong sets the vision, gives guidance, and helps score funding, the students are truly the ones designing and building the robots.

"I'd like to say that not only his robots but also himself is 'opened,'" says Byoungsoo Kim, president of Robotis. "It means that he has an open mind. I think that is what propels him." Dennis Hong's undergrad mentor, John Uicker, who is currently working on a new book on mechanical engineering, also praises Virginia Tech for giving Hong freedom, in contrast to the rigidity of many other academic research labs. Hong passes that freedom along: "You study other publications, read papers, study theoretical work and try to improve upon it. At RoMeLa we're pretty open ended, I actually give a lot of freedom to the students."

In a TED Talk about his creative process, Hong mentions all-important brainstorming sessions with the students. "Really, anything goes, people talk about the weirdest concepts. If I see some potential then I support that and let the students investigate more, and that sometimes leads to great projects." RoMeLa is also strengthened by its multi-disciplinary approach: "If you look at other robotics research labs, they're experts in one field. In our lab I keep it open." Even the students agree: "If we have a vision for a robot he will steer that vision where he thinks it's most likely to succeed, but within that direction we have a lot of freedom to do what we like," says Mark Umansky, who teamed with fellow graduate student Coleman Knabe to make a prize-winning gripper for DARwIn-OP, which wasn't a part of the bot's original design.

"Creativity is the ability to connect things that are not at all related," says Hong. Oskar calls Hong's ideas "off the beaten track." For example, part of the inspiration for the non-humanoid STRIDER, a three-legged bot that flips its entire body to swing a leg forward to take a step, was watching a mother braid her daughter's hair. The question Hong asked himself was "how could you perform this same motion without getting the three strands tangled?" Basically, how can you braid without braiding. The resulting machine is delightfully creepy.

"IF YOU LOOK AT OTHER ROBOTICS RESEARCH LABS, THEY'RE EXPERTS IN ONE FIELD... IN OUR LAB I KEEP IT OPEN."

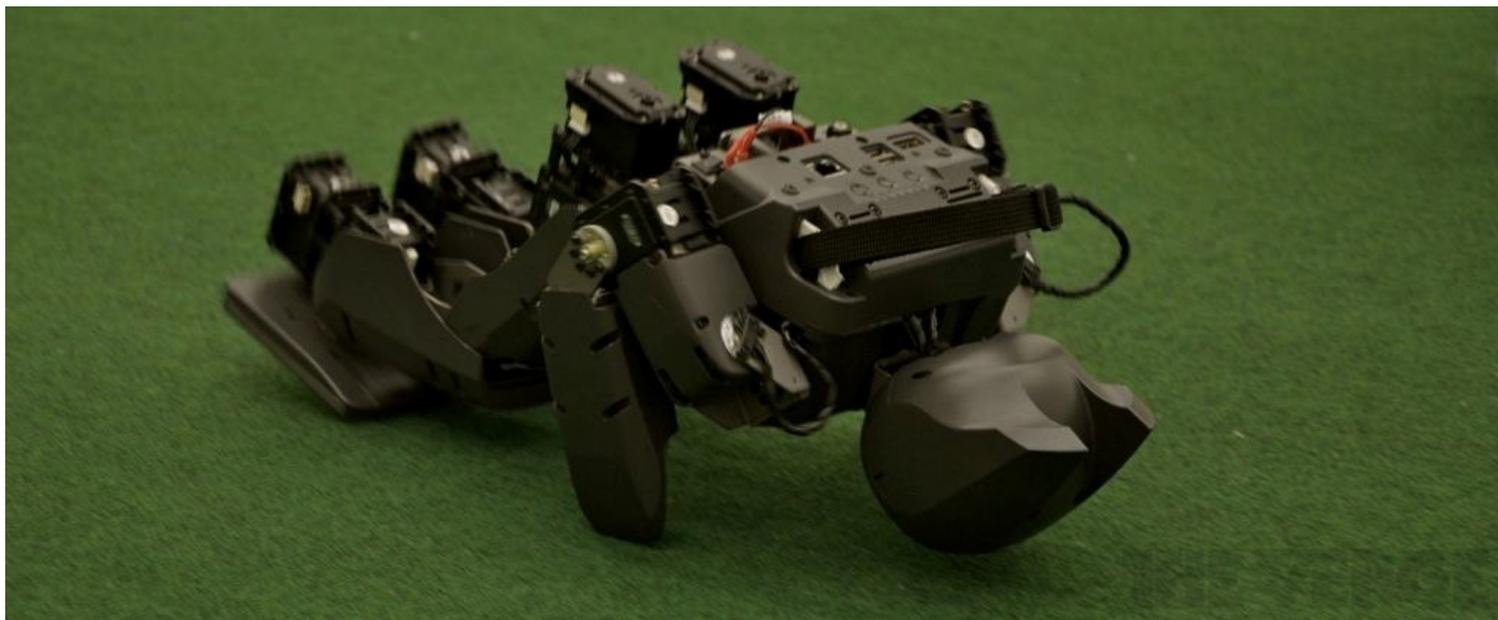


Hong can't be accused of fitting the absent-minded professor stereotype, either. Jesse calls him "a great professor," in contrast to some: "Whether or not they're so brilliant for research that they don't take classes seriously or they don't have time or they think they're better than it." Hong is always careful to emphasize the importance of education in what he does. "There's a reason why they teach you things in grad school. A lot of times you see people with passion, interest, they're hard working, but they lack the education to go to the next step." The flies-to-honey approach seems to be working. Hong gets the best and brightest students, and gets them to work their asses off. In fact, RoMeLa is so popular at the school that there's an intense vetting process for bringing on any new undergrads. The few and the proud wear RoMeLa shirts daily around the campus. They're the rock stars of Virginia Tech.

Robotics poses its own set of problems to the traditionally educated engineer, because it's just so multifaceted. Jesse says, "You can't really boil it down to one

simple problem that you can just attack and throw lots of people or money or research at." You might get lucky in the lab or in simulation, "but as soon as you bring that robot somewhere else it fails."

In the end, it was that "somewhere else" that finally caught up with Oskar von Stryk's Darmstadt Dribblers. That and a speedy little robot called DARwIn-OP.



Falling over, for the win

"EACH MUSICIAN MUST PLAY A JOINT ARRANGEMENT, OTHERWISE THE OVERALL PERFORMANCE IS SPOILED."

For a machine that looks and sounds more like a mechanized holiday iteration of Elmo than the results of cutting edge research, there's truly an amazing amount of complexity that goes into RoboCup's KidSize robots. "In one leg a humanoid robot needs at least six rotary joints, and we have two legs," explains Oskar, whose own Bruno humanoid has (relatively) amazing ball-handling skills, including a side-foot and heel kick. Include a hip joint, arms, and an articulated neck, and the servos quickly add up: "In our humanoid there are 21 rotary joints, whereas a regular industrial robot only has six joints." Plus, a humanoid has to carry its own power source and computing power. Oskar likens the manifold joints in a humanoid to musicians in a band. "Each musician must play a joint arrangement, otherwise the overall performance is spoiled."



The 2011 Robocup semifinals in Istanbul came down to Oskar's Darmstadt Dribblers and Team DARwIn, the two favorites to win it all. DARwIn-OP was faster, Darmstadt had strong defense and terrifying kicks. On its very first possession, a Darmstadt bot rattled the ball into Team DARwIn's goal from the complete opposite end of the field. Meanwhile, DARwIn's kicks could barely go half that distance. DARwIn relied on its superior movement speed to dribble the ball towards the Dribblers and tied the game up 1-1, but Darmstadt dominated the rest of the half. With goals being scored from anywhere and everywhere, the score was 4-1 in favor of the German team moments before halftime. Then things started to fall apart for the Dribblers. A communication failure caused the goalie to believe he was the only player on the field. DARwIn walked the ball into the goal while a Bruno stood as still as a statue, inches away. It was 4-2 at half-time, and the fresh, speedy legs of the DARwIn bots started to wear on the older Bruno models in the second half.

"The overheating of the motors is a consequence of the non-optimal walking we had employed," explains Oskar. "Our robots when they walk are pushing more strongly on the ground, which isn't good for the motors." Hong explains this simply as robots getting "tired and sluggish." With machines whose motions are



planned in advance mathematically, a little bit of sloppiness can severely impact performance.

The Dribblers attempted to troubleshoot their communication and mechanical problems, but DARwIn caught up in the meantime, and before long pushed ahead, 5-4. With a couple minutes to go in the second half, Team DARwIn had a strong offensive push rebuffed by Darmstadt's stalwart goalie.

The DARwIn striker marched up to the larger goalie bot and knocked itself over, picked itself up, and then fell over again. Yells from the Darmstadt side of "goalie touching!" got the infringing DARwIn player ejected, with seconds left in the half. Darmstadt drove down the field, and managed to tie the game 5-5, sending the match into overtime. From there, Darmstadt scored only once more, and the DARwIn bots ran the score up to a final 12-6.

Team DARwIn moved on to the RoboCup final, up against the larger, blade-armed bots of Japan's CIT Brains team. Right from the start, DARwIn sped down the field with the ball and kicked the ball at a goalpost. The ball bounced off, DARwIn recovered it, and then kicked it at the goalpost again. Meanwhile, the CIT Brains were powerless to stop the misguided offensive onslaught: Goalpost. Bounce. Recover. The large CIT Brains bots were just as good at falling down as DARwIn, including a couple planned falls for goal-protecting purposes, but they were slow to get up, and often knocked a DARwIn-OP over in the process, getting themselves temporarily pulled from the field — which is what finally let DARwIn get his first goal in. The game ended in a landslide, with Team DARwIn winning the match 8-1.

"Bottom line, I believe that on another day we would've won," says Oskar, referring to his own match. In fact, Darmstadt beat DARwIn in earlier practice matches. The communication problems had actually been encountered, and solved, in a previous year, but because Bruno had been trouble-free last year, they forgot to bring along the code to 2011's competition. Oskar feels his team might've simply gotten lazy. "They are now eager again, ambitious again, and they want to try to show that they still can do it." Oskar thinks another Darmstadt win would've been "terrible for the league," and that DARwIn's triumph can be an inspiration to other competitors — especially since the robot is available for sale. "I'm very glad that his team won, actually." Despite his grace in defeat, Oskar wasn't entirely short on taunts: before the match he threatened Hong that if DARwIn won he'd come after CHARLI next year in adult sizes. "But it'll probably take us two or three years," he admits.

Moving on



AT ALL TIMES THE ROBOT IS COMPLETELY IN BALANCE. "THAT'S WHY THEY LOOK LIKE ROBOTS WALKING, NOT HUMANS WALKING."

While DARwIn and CHARLI's success at Robocup is impressive, it's a far cry from the competition's stated goal of beating humans at soccer. To do that, robots (and the humans who build them) will have to take a huge theoretical leap — literally. The limitation to existing algorithms for robotic motion is that they rely on the robot having precise knowledge of all its limbs at every moment. When it comes to walking, something called ZMP (Zero Moment Point, a robotics concept related to the dynamics and control of legged locomotion) rules the day. It needs the robot to have a stiff ankle joint, using a complicated stride that keeps the flat underside of the foot parallel with the ground. At all times the robot is completely in balance, and "that's why they look like robots walking, not humans walking," explains Hong.

Even the greats, like ASIMO and HUBO, have to walk on smooth, hard surfaces — a minor variation in the floor could send them toppling. CHARLI-2 is much less picky, even walking on grass in one daring demo, but that's because it's so light it can use the same sort of walking algorithms that power DARwIn (CHARLI-2 stands almost five feet tall, but weighs only 35 pounds). So while it deserves credit for getting us this far, ZMP isn't the future: ZMP robots can never jump or run like humans.

The problem? With ZMP requiring precise knowledge of all its limbs at all times, the robot can only go as fast as its sensors. The difference, explains Oskar, is between feedback control and feed-forward motion. "For example, if we humans are learning something, like the piano, with our elastic arms, we have visual guidance and audio guidance. We learn very slowly, and this is fully feedback control, because we can modify this at any moment." Once a human has learned something, however, they can translate that motion into feed-forward motion and increase the speed substantially. "Like an arrow from a bow. It's an elastic, forward explosion. This forward explosion is not controllable, if you try to control this motion while you're doing it it's spoiled completely. You must train it until you can do it with high quality and high speed."

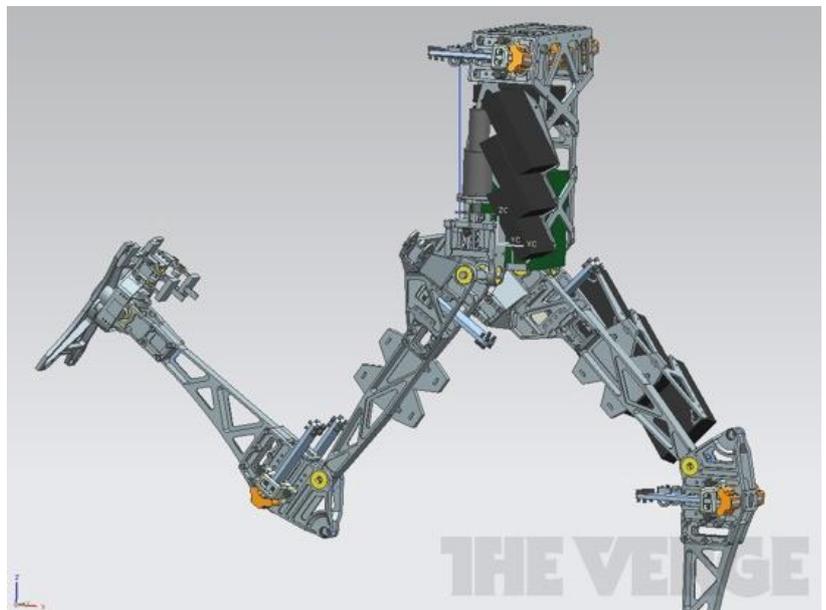
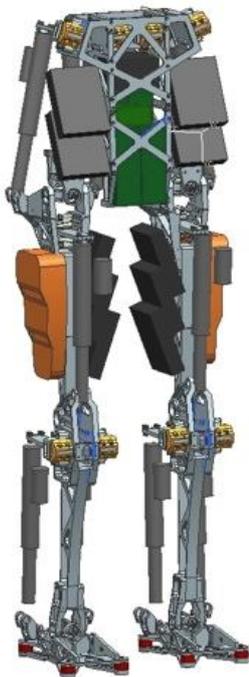
Musicians know this concept well. When practicing a piece, initially you go slow, and you repeat a section until you get it perfectly before attempting to speed up. Suddenly my mom's repeated exhortations about how "perfect practice makes perfect" make a lot more sense. Oh, if only I'd known about feed-forward motion then! Another way to think about feed-forward motion is in terms of jogging or running. Each step is in itself unstable, but the entire motion is stable. "You can't stabilize during the contact, our neurosystem is too slow," explains Oskar. "You have to stabilize for the next step."





Learning to walk again

EACH STEP IS IN ITSELF UNSTABLE, BUT THE ENTIRE MOTION IS STABLE



RoMeLa's next step is called SAFFiR.

When the Navy approached RoMeLa this year in search of a fire-fighting robot, the lab presented two options. The safe option was a robotic hose. The wild and crazy option? A never-before-done humanoid. A human-shaped robot can navigate anywhere in a ship a sailor can, including up stairs and through hatches, and a two-legged bot can wear a fire-retardant suit, without wheels or other appendages left exposed.

Still, a humanoid isn't a slam dunk. "You have a lot of environmental variables like the fire, the smoke... being able to walk around the ship is a huge challenge," explains Dr. Lee, whose team helping is helping out on the software for SAFFiR, with monumental challenges of their own. "If the ship is pitching and rolling you have balance issues, you don't know if a door has been jammed shut or if certain things are blocked and the robot has to figure out alternative ways to get to where it needs to get to."

Luckily for RoMeLa, the Navy was looking for a "high risk, high reward" project, which is pretty much the opposite goal of most research funding, especially when you have the military and robotics involved. The Navy is fully funding SAFFiR for three years, with a generous \$2.6 million, and if they like what they see they'll re-up and the project will enter phase two, in which it becomes "huge," according to Hong. Derek Lahr, a 10 year veteran of Virginia Tech, who became involved with RoMeLa during his senior design project, heads up the robot's development.

At the risk of being overly reductive (also: at the risk of justifying the sensational headline of this piece), if the precise orchestration of a ZMP algorithm can be likened to an orchestra of musicians following a piece of sheet music, the SAFFiR approach to motion is more like jazz, with the same instruments improvising and swinging to a basic song structure.

SAFFiR's basic approach is called "force control," which means that the AI tells the motor to output a certain amount of force in a certain direction. "The other way most roboticists control a robot is with 'position control,'" explains Lahr. "These roboticists command a specific position of each actuator. The actuator will try to maintain this position no matter what force is applied to it." While a ZMP script can be sped up or swapped out to react to the environment, force control is more reactionary and flexible.

For instance, Hong likes to demonstrate CHARLI-2's stability by giving the robot a little shove, and he once shoved the bot hard enough that he shattered a gear inside the hip assembly. The students had to stay up all night fixing the robot for a demonstration the next day. CHARLI-2 broke because the shove over-torqued a rigidly-positioned motor. With force control, a robot can roll with the punches.

"Most robots use a very stiff ankle," explains Derek. "So if your ground isn't flat, it's difficult to adapt the foot to uneven terrain." With force control they can just tell the ankle to go limp, and once the foot detects that it's fully made contact with the ground, the motors can power back on and start pushing for the next step. This compliance will be incredibly important on SAFFiR's first major testing ground, the USS Shadwell, which the Navy uses to train sailors how to fight fires. "The deck is warped considerably, to several degrees within one stride, and within half an inch over each stride, so it's a very uneven surface to make the robot walk on."

IF THE TEAM BEHIND SAFFIR CAN PULL IT OFF, THEY WON'T JUST BE JUST EARNING THEIR GRANT MONEY, THEY'LL BE SOLVING THE FUNDAMENTAL QUESTIONS OF ROBOTICS.

SAFFiR's newfound flexibility isn't just in the motors, the design also includes springs. "That's normally a no-no in robotics," says Hong. As Oskar points out, we've actually been trying to eliminate elasticity in industrial robotics for the past 50 years. "Elasticity has always been considered harmful. The concept for robots has been that you have a rigid link, which is connected to a rotary joint which is also rigid, and then the next link and then the next rotary joint and then the next link."

We're not talking sloppy trampoline springs here, however. In fact, when handling some of the "springs" at RoMeLa, I found them anything but springy — they're more like slabs of metal bolted to a joint, with tens of pounds of pull that only results in the most minute flex. A better analog is a human tendon, which is actually what Derek and his team is attempting to emulate. It's our tendons that allow us to unleash enormous amounts of power, lifting things heavier than ourselves. "[Humans] can kick a ball much, **much further** (<http://www.wired.com/gadgetlab/2010/04/human-beats-340-pound-robot-in-football-kick-off/>) than the strongest available industrial robot can do," says Oskar.

If force control and those "no-no" springs don't present enough of a challenge to getting a robot that can walk, the ultimate application of SAFFiR, a Navy ship during a fire, would give any roboticist pause. Still, if the team behind SAFFiR can pull it off, they won't just be just earning their grant money, they'll be solving the fundamental questions of robotics. It's a hugely challenging project, confesses Derek. "But in addition there's a very high payoff because if," at this point Derek catches himself, "when it works out, the Navy will have a robotic sailor, basically, and there's no end to what you could do with a humanoid robot aboard a Navy ship."

Stepping into the future



NEXT UP? A THREE STORY ROBOT

While there is plenty of mechanical and computational innovation to work on, one of the biggest roadblocks to robotics (and, really, the entire tech industry) is chemical: we need better batteries. "Right now we have robot runtimes on the order of 15-30 minutes," says Derek. There are vastly stronger and faster piston-like electric linear actuators that would zap SAFFiR's batteries in one or two thrusts, and similar, non-ZMP robots like Boston Dynamic's PETMAN use external power supplies. Really, any advance in materials, electric, and computer science will help robotics. "We need everything," says Hong.

Dennis Hong isn't sitting still while he waits, of course. His agenda includes a business spinoff that he's not quite ready to get specific about, and a three story robot of some sort that he's also not at liberty to explain. As for robots being the next big PC-style boom? Hong has some doubts: "At some point I agree with that, but as an actual person developing these robots, I know the limitations of the robots. I know what we're trying to do is very, very difficult. I know all the problems we're encountering." CHARLI-2, for instance, isn't ready to walk around the unstructured environment of a home, and the next five years aren't likely to change that. "Ten years? Hopefully. Twenty years? Then yeah, I'd say it's probably likely."



IN AMERICA WE TYPICALLY WAIT FOR YOU TO MAKE YOUR FIRST BILLION BEFORE WE NOTICE YOU'RE TRANSFORMING AN INDUSTRY

There's also an inherent challenge in being at a university and maintaining your momentum, which is part of what prompted Jesse Hurdus to move to the private sector: "You always have a flow of people graduating and new people coming in. Which is great, because you have this constant inflow and influx of new ideas, but it also makes it difficult at times to maintain continuity and really develop an idea or develop a system beyond the prototype stages." Projects like DARwIn and CHARLI are always at risk of abandonment, and Navy's heavy funding of SAFFiR is an extreme exception, not the rule.

So Dennis Hong will keep pulling all-nighters, writing proposals, while his students coax their creations into taking their first steps. His work has as much to do with people as it does with robots — forging relationships that help his lab thrive, while inspiring a new generation to join in the fun. In Korea he's mobbed for autographs, but in America we typically wait for someone to make their first billion before noticing you've transformed an industry.

Next year you'll find Hong on the sidelines of another miniature soccer field, screaming louder than anybody as his robots exhibit marginal improvements, up against other robots that will be marginally improved as well. None of them will be able to get you a beer from a fridge, or make your bed, or be your best friend. None of them will even stay upright for more than a couple minutes straight. Still, thanks to Hong and his kind, they're getting better. Hong says it succinctly, as always: "It's just hard, I'll put it that way."

THERE ARE 74 COMMENTS.

[zeagus](#) says:

I haven't even finished the article yet, but I had to say it's fantastic so far. Seriously, well done, can't wait to finish it. Very much a magazine feature style piece. Bravo!

Posted on Nov 08, 2011 | 10:39 AM EST (#82351250)

[SunnyDee's](#) reply:

Oh wow, for an article this length I would totally prefer a tablet! Gonna stick with my MBP for now, but as soon as the iPad comes out with higher resolution this will be even more awesome! :)

Posted on Nov 08, 2011 | 12:50 PM EST (#82361585)

[Marconus Macbeth](#) says:

This article (and others before it) made me create a profile on here. Paul, you and the others are doing a fantastic job writing these articles. It's quite refreshing to have some actual thought behind a story rather than just regurgitating information.

Well Done!

Posted on Nov 08, 2011 | 10:39 AM EST (#82351254)

[Techno's](#) reply:

+1.

Sipping on The-Verge-Kool-Aid.

Posted on Nov 08, 2011 | 11:20 AM EST (#82354198)

[mattkicksass's](#) reply:

mmm..... Kool-Aid...

Delicious article, Paul!

Posted on Nov 08, 2011 | 2:22 PM EST (#82369737)

[alex buckner](#) says:

Paul. Wow. Mind=blown. Love this article.

Posted on Nov 08, 2011 | 10:40 AM EST (#82351276) via mobile

[Bazinga!](#) says:

Damn it Verge.. !!

Because of your amazing articles I just can't get my work done..

Posted on Nov 08, 2011 | 10:47 AM EST (#82351790)

[pvpman22's](#) reply:

I agree, this article is too good for me to stay productive :)

Posted on Nov 08, 2011 | 11:57 AM EST (#82357144)

[periahdark](#) says:

That was pretty fascinating. Also, THAT BLACK ROBOT IS SO DAMN CUTE!

Posted on Nov 08, 2011 | 10:48 AM EST (#82351845)

[hong.dennis's](#) reply:

It's called the "DARwin-OP" and it is fully open-source, i.e. plans and instructions to make one is provided on-line for free! Also it is commercially available...

Posted on Nov 08, 2011 | 3:10 PM EST (#82373576)

[vladi's](#) reply:

Your lab looks awesome, Dr. Hong! As soon as I read the article I went straight to the sourceforge repository to check out what it would take to make a Darwin. Its amazing how much tech there really is in that little guy... And those Dynamixel servos don't come cheap! Nevertheless, it looks like a great platform for humanoid research/experimentation. Do you think Darwin can be used to do any non-ZMP locomotion?

Posted on Nov 09, 2011 | 12:38 PM EST (#82438403)

[zourtney's](#) reply:

Is it perfect because it's black?

/random-80s-movie-reference

Posted on Nov 09, 2011 | 6:21 PM EST (#82462572)

[CraigB](#) says:

This is an awesome article. And I literally can't wait for domestic robots in the home, that's the future.

Posted on Nov 08, 2011 | 10:59 AM EST (#82352635)

[AzureAlert](#) says:

The Verge is amazing! That video is awesome! Paul M. is a boss! That is all.

Posted on Nov 08, 2011 | 11:02 AM EST (#82352864)

[adcustom](#) says:

PAUL MOTHERLOVIN' MILLER. This feature was glorious. I love robots, and unashamedly...I love you.

Posted on Nov 08, 2011 | 11:08 AM EST (#82353341)

[Laura June's](#) reply:

I agree. I love this article so much. I've read it like 25 times. I think I'm going to print it out. BRB.

Posted on Nov 08, 2011 | 11:10 AM EST (#82353465)

[Thomas Houston's](#) reply:

26

Posted on Nov 08, 2011 | 11:43 AM EST (#82355932)

[HerbieDerb's](#) reply:

I'm going to memorize it and recite to my friends.

Good job P Mil. btw, you don't need so much gel.

Posted on Nov 08, 2011 | 3:03 PM EST (#82373029)

[funnyandspicy](#) says:

His new smooth curves give him a pot belly. Much more realistic! I would be dead of thirst by the time my drink was poured for me.

<http://goo.gl/pGkp1> (<http://goo.gl/pGkp1>)

Posted on Nov 08, 2011 | 11:17 AM EST (#82354007)

[KaiserKappel](#) says:

All these articles are so well crafted, I feel like I need to buy some kind of magazine sized tablet to read them on. I applaud you guys and can't wait for your e-magazines ;)

Posted on Nov 08, 2011 | 11:27 AM EST (#82354746)

[Dasaii](#) says:

Best article yet!

Posted on Nov 08, 2011 | 11:28 AM EST (#82354789)

[Funderful](#) says:

I miss 'Caprica' so much.

Posted on Nov 08, 2011 | 11:29 AM EST (#82354841)

[Hidd3nFury](#) says:

I can't help but wonder if all these fantastic features that we're seeing have been saved up over the last few months for the launch of the site and we're going to start seeing them far less frequently as time goes on. I hope not! Another fantastic piece.

Posted on Nov 08, 2011 | 11:36 AM EST (#82355455)

[JPenguinCA's](#) reply:

That's crossed my mind too but I hope it isn't the case (well actually a slightly slower pace probably wouldn't be a bad thing, finding time to read these features can be difficult).

I think we've definitely seen articles that have been worked on over a bit of time but I imagine a large reason for these articles is because the editors don't spend 24x7 just reporting about all the tiny little bits of news in tech. These articles are probably the result of "a slow new day" (which guarantees that none were written over the end of August through September ;)).

These features are what make The Verge much more than a blog, there's actual journalism involved instead of regurgitating PR and rumours.

Posted on Nov 08, 2011 | 12:43 PM EST (#82361029)

[Joseph L. Flatley's](#) reply:

Don't worry, we have a whole team working to ensure that writing of this scope continues. In fact, it's one of the reasons we started the site!

Posted on Nov 09, 2011 | 10:00 AM EST (#82426345)

[kivimaki](#) says:

Content. Writing. Layout. Readability. Video.

You're giving this to me for fee?

Posted on Nov 08, 2011 | 11:39 AM EST (#82355633)

[jordanswk](#) says:

Awesome stuff!!! Thanks Paul!

Posted on Nov 08, 2011 | 11:40 AM EST (#82355705)

[Lord Vader](#) says:

I'd take any of these robots over C3PO any day

Posted on Nov 08, 2011 | 11:46 AM EST (#82356259)

[JPenguinCA's](#) reply:

It's your own fault, you built that idiot.

Posted on Nov 08, 2011 | 12:44 PM EST (#82361075)

[davidEchols](#) says:

You always have a flow of people graduating and new people coming in. Which is great, because you have this constant inflow and influx of new ideas, but it also makes it difficult at times to maintain continuity and really develop an idea or develop a system beyond the prototype stages.

...damn straight. Building this amount of knowledge takes an incredible amount of time and hard work (usually unpaid or paying someone else). In my opinion this is the main limiting factor that's holding back extremely complex fields like robotics — it's just too damn expensive to do it, and there's no way to go make a startup company or really commercialize your knowledge very well.

TLDR: Complex research needs more than ramen noodles to do well.

Posted on Nov 08, 2011 | 11:50 AM EST (#82356564)

[shu8i](#) says:

They should enclose the PETMAN with charlie's enclosure... then we'd have an i Robot :)

Posted on Nov 08, 2011 | 11:51 AM EST (#82356619)

[shu8i](#) says:

January 12th, 1992, John Connor is born

October 30th 2011, the PETMAN prototype is realised

December 21 2012, Google becomes self aware

Posted on Nov 08, 2011 | 11:51 AM EST (#82356662)

[Arek](#) says:

Incredible piece! Enjoyed reading it very much...

Posted on Nov 08, 2011 | 12:26 PM EST (#82359533)

[aclick](#) says:

Excellent article. So glad the Verge is doing these feature pieces! Note about the Navy training ship mentioned above : While I love the name USS Shagwell, I believe the name you're looking for is USS Shadwell. <http://www.nrl.navy.mil/field-sites/ex-uss-shadwell/> (<http://www.nrl.navy.mil/field-sites/ex-uss-shadwell/>) (I know, I was disappointed that wasn't the real name, too)

Posted on Nov 08, 2011 | 12:53 PM EST (#82361853)

Paul Miller's reply:

Hah, thanks!

Posted on Nov 08, 2011 | 12:59 PM EST (#82362383)

hong.dennis's reply:

Yes, USS Shadwell is the ship we use for testing SAFFIR... Thanks!

Posted on Nov 08, 2011 | 3:07 PM EST (#82373329)

CharlieS says:

This might be the best thing I have ever read on the internet! Awesome article!

Posted on Nov 08, 2011 | 1:07 PM EST (#82363050)

CharlieS's reply:

I wanted to add.. I really appreciated how the video at the end wasn't just a summary of the article in video form. It showed exactly what I wanted to see after reading – only things that are better communicated by video than by an image or text!

Posted on Nov 08, 2011 | 3:07 PM EST (#82373335)

Peter Baricic says:

I see Cylons

Posted on Nov 08, 2011 | 1:11 PM EST (#82363300)

Arbee's reply:

They don't look anything like Tricia Helfer or Grace Park. Still a ways to go I guess.

Posted on Nov 08, 2011 | 3:14 PM EST (#82373846)

TrustTheRobot says:

I thought, "What could top an article on rocket jet-packs?" I now know. Thank you, Mr. Miller.

Posted on Nov 08, 2011 | 1:42 PM EST (#82366014)

iCello says:

This is pretty much the best thing I have ever read on the internet. Paul Miller, you are my hero. Also, I love robots.

Posted on Nov 08, 2011 | 1:54 PM EST (#82367074)

iCello says:

*you, not you.

The Verge: I love you, but could you please, please, please add an edit button to comments?

Posted on Nov 08, 2011 | 1:59 PM EST (#82367476)

nerdmagic says:

this was great! it actually reminded me of a popsci article i read last year, 'the lonliest humanoid in america', about american universities' research on humanoid robots ([link \(http://www.popsci.com/technology/article/2010-07/loneliest-humanoid-america\)](http://www.popsci.com/technology/article/2010-07/loneliest-humanoid-america)). it's certainly relevant to this article. again, great work.

Posted on Nov 08, 2011 | 2:04 PM EST (#82367984)

hong.dennis's reply:

Thanks! We are the same group from that Pop Sci article...

www.romela.org (<http://www.romela.org>)

Posted on Nov 08, 2011 | 3:06 PM EST (#82373235)

Kenny G Jr. says:

Paul, this was the most funniest article/video to read (and watch). If by 2050 they actually have robots playing soccer with human, I will be the 1st in line to buy a ticket. Of course I'll have the senior citizen's rate, cause I'll be about 70 something, but it'll be totally worth my pension money. ;-)

Thanks for the feature post.

Posted on Nov 08, 2011 | 3:30 PM EST (#82375119)

[hong.dennis's](#) reply:

It's a very ambitious goal, but we are working hard to make it happen! :-)

Posted on Nov 08, 2011 | 4:20 PM EST (#82379251)

[slipslip's](#) reply:

I was astonished to see the PETMAN prototype video when it came out, but didn't pay much attention to the fact that it was completely reliant on it's tether and seemingly a LOT of extraneous equipment above the "waist". What is all that stuff and what will it take to reduce it such that it can operate in a tetherless fashion? I realize it isn't your (Dr Hong's) project, but perhaps you could shed some light.

Posted on Nov 08, 2011 | 10:45 PM EST (#82412167) via mobile

[atomicsolar](#) says:

Dammit, I've avoided getting sappy so far, then along comes DARwin-OP. I've always felt this way about the team at the Verge, and this article is getting me to admit it.

I love the passion exhibited by the Verge staff, it comes across in everything that they do. Thanks for building this site.

Paul Miller – thank you. I know very little about robots, but I feel like I learned a lot today. You rock.

Posted on Nov 08, 2011 | 4:40 PM EST (#82381043)

[sagi](#) says:

Aww, poor DARwin getting hassled at the end of the video. It looks so cute.

Posted on Nov 08, 2011 | 5:06 PM EST (#82383405)

[Dylan Spronck](#) says:

Amazing writing. Breathtaking photos. Beautiful videos. Extremely interesting. Great job Paul, I hope you're not still mad about Steve Jobs rejecting 3 awesome robots.

Posted on Nov 08, 2011 | 6:17 PM EST (#82388014)

[Kwetech1](#) says:

Hey, this is my current school!

Posted on Nov 08, 2011 | 9:04 PM EST (#82402728)

[iamjackstechnology](#) says:

Phenomenal work on this post! Hands down, you guys run the best tech blog out there!

Posted on Nov 08, 2011 | 11:35 PM EST (#82415380)

[bethted](#) says:

BRAVO

Posted on Nov 08, 2011 | 11:36 PM EST (#82415454)

[jkwakopo](#) says:

Hokies just dont play footnall we also make robots!!!

Posted on Nov 09, 2011 | 5:13 AM EST (#82421570)

[runsweetleu](#) says:

Never would have thought watching robots play soccer would be fun. Turns out it is better than watching humans play soccer.

Posted on Nov 09, 2011 | 1:25 PM EST (#82441957)

[enlight10ment](#) says:

Great article, but I find the two of the quotes you chose to highlight leave a mixed message (Sorry for all caps but that's how its copy and pasted)

“ROBOTICS IS SUCH A BIG, WILD FIELD YOU CANNOT BE AN EXPERT ON EVERYTHING.”

“IF YOU LOOK AT OTHER ROBOTICS RESEARCH LABS, THEY’RE EXPERTS IN ONE FIELD... IN OUR LAB I KEEP IT OPEN.”

So you can’t be an expert at everything, and all other labs realize this which is why they expertise in one thing, and the only lap not to realize this is his own?

Posted on Nov 09, 2011 | 3:12 PM EST (#82450213)

[hong.dennis's](#) reply:

One individual can’t be an expert on everything... Thus collaboration is important.

Posted on Nov 14, 2011 | 5:12 PM EST (#82900422)

[samfishman](#) says:

I just spent 30 minutes on poring over this amazing piece of literature. I enjoyed every minute of it. Awesome job, Paul!

Posted on Nov 09, 2011 | 5:48 PM EST (#82460953)

[wilkinsonseth](#) says:

Content this rich would be worth a subscription fee. I'm not trying to give you any ideas, but seriously. This story was a phenomenal read. Keep it up!

Posted on Nov 09, 2011 | 6:50 PM EST (#82463998)

[Andreu's](#) reply:

I second this!

Posted on Nov 09, 2011 | 7:30 PM EST (#82466056)

[engineerd364](#) says:

This article alone has sparked an in interest in robotics for me. This is a great article Paul, I look forward to hearing more. An article on the current influx of quadcopters would be really cool.

Posted on Nov 09, 2011 | 9:07 PM EST (#82472663)

[xi. Slick ix](#) says:

Paul !?!?!?

I’m a freaking ME @ VT, and there no announcement of you coming here!? Jeez.

Posted on Nov 09, 2011 | 11:20 PM EST (#82484297)

[Neuron](#) says:

Just an awesome article and video! I could not be more happy with these long form features. Also- it was great to get an “inside look” into this thrilling academic environment.

Posted on Nov 10, 2011 | 9:42 AM EST (#82501701)

[Norcallights](#) says:

I’m totally blown away by this article. I had no idea we would be treated to such fantastic feature-length writing when The Verge launched. This is what Wired was a decade ago, and so much more.

Can’t wait to see where you go with all of this.

Posted on Nov 10, 2011 | 12:34 PM EST (#82513571)

[thebee|21](#) says:

To The Verge: I’ve been reading tech websites and rss feeds for the last 10 years. There are many sites that I enjoyed reading, but I never felt completely satisfied. I would read an article/post, think about it for a minute, then move on to the next one. I might send a link to some of my more geeky friends.

With the things you guys are doing with these features, I feel like this is the end game. This is how tech journalism should have been all along. When I’m done reading one of these features, I no longer look for the next article to click. I sit and think about it for a couple hours. I send links to not just my geek friends, but to pretty much everyone I know. This stuff goes above and beyond the geek community. I know there is a lot of well deserved love going on right now for this site, but I wanted to say my piece as well. Thank you.

To Mr. Hong and his team, amazing stuff sir. The amount of intelligence and work you guys put into what you do is truly inspiring. After reading the first half of the article, I watched the game video before reading the results, and I actually felt invested, like I was rooting for my home team. When your team was down 4-2 at halftime, I’m thinking to myself, cmon guys, we can do this. Kudos.

Fantastic article

Posted on Nov 10, 2011 | 1:37 PM EST (#82518566)

[hong.dennis's](#) reply:

Thanks! Even more impressive stuff to come in the next few years from RoMeLa! Stay tuned...

Posted on Nov 14, 2011 | 5:10 PM EST (#82900247)

[ScottG](#) says:

Excellent article. It's very exciting to see these advances being made in robotics and the dedication of great minds like Mr. Hong to the field. Keep up the good Mr. Hong and VT students. Keep up the good work Verge.

Posted on Nov 10, 2011 | 1:49 PM EST (#82519580)

[lhl](#) says:

Wow, love the feature-length! This is a fantastic article, and the soccer match videos are laugh out loud hilarious (and quite impressive, of course).

So, the locomotion and all the robot stuff is great, but I am a bit curious as to why the robots seem to play soccer so badly, purely in terms of basic game-playing AI. I saw that Dr Hong was in the comments a bit earlier, so maybe he or someone else that knows more about the robotic software can jump in. Maybe there's something I'm missing about the rules or other limitations (although from the sounds of it, the embedded hardware platform makes it sound like it should have plenty of computing power, and the fact that the robots are networked should make coordination possible).

The robots don't seem to have a conception of the field, where they are, game state (ie did someone just score), where their teammates/opponents are, or where the ball is? In the semi-game for example, the Darwin goalie seems to spend a fair amount of time walking around in circles even when it's teammates are playing the ball. Is there no shared world state that's tracking this stuff?

There doesn't seem to be much (any?) teamwork/strategy involved? Even basic individual strategy in terms of say knowing if there's defensive pressure or if you're surrounded by opponents, vs if you have time to aim and kick, to more complex stuff, like passing or setting up a screen.

What's the current state of the art there, and what are the roadblocks for that are keeping basic video game-style AI engines from being used for the actual game-playing part of things?

Posted on Nov 10, 2011 | 5:56 PM EST (#82536738)

[hong.dennis's](#) reply:

Thanks for your notes. They do team play and they do know where they are on the field using vision (localization) The reason why you see the 'bots having a difficult time is because it IS difficult! :-)

When the lighting condition changes they often lose track of the ball and get confused. When trying to implement robotics technology in 'real life' we always run into such problems. This is why simulation and simply publishing papers on work is not good enough, and thus we actually build and test them – at events like RoboCup. Thanks!

Posted on Nov 14, 2011 | 5:09 PM EST (#82900162)

[radderthanrad](#) says:

What a great article! One of my roommates literally shouted out proudly during a commercial for VT while we were watching the Hokies beat Georgia Tech a few days ago because the commercial featured the robotics program and his former roommate, JK, who was mentioned in the article. If JK reads this, tell him Brian and other folks in the vet school think what he's doing is awesome!

Posted on Nov 12, 2011 | 9:12 PM EST (#82716723)

[hong.dennis's](#) reply:

I'll let JK know! :-)

Posted on Nov 14, 2011 | 5:04 PM EST (#82899827)

[acslater017](#) says:

- 1) Awesome video. Keep up the good work!
- 2) When he first started talking, it immediately reminded me of Guy Kawasaki.
- 3) I don't want my robot to pick up a pair of scissors. It's just creepy.

Posted on Nov 14, 2011 | 4:58 PM EST (#82899252)

[jrellegood](#) says:

This was a fantastic article! Being in computer engineering, I recognize a lot of the problems currently faced by robotics, and it is immensely fascinating.

As a side note, I am loving the long-form articles The Verge posts. The length really allows the writer to tell a complete story.

Posted on Nov 19, 2011 | 2:36 AM EST (#83238145)