Robotics Trends for 2012

By Erico Guizzo and Travis Deyle

What's in store for robotics in 2012? Nearly a third of the year is already behind us, but we thought we'd spend some time looking at the months ahead and make some predictions about what's going to be big in robotics; or, at least, what we think is going to be big. Lacking divine powers (or a time machine) to peek into the future, we had to rely on our experience as long-time observers of the robotics landscape, covering the field on two of the world's top robot blogs: *IEEE Spectrum*'s Automaton and Hizook.com.

To make sure our forecasts aren't too far off, we asked a group of roboticists with different backgrounds for their predictions for 2012. This panel of experts provided invaluable insight and, after we tabulated everyone's suggestions, we narrowed it down to the final 12. It was not an easy task as there were so many great ideas. (Thanks, panelists!)

In making our selection, we tried to avoid the perennial trends—areas such as environmental robotics (the theme of this special issue), entertainment and toy robots, and others that are always thriving with activity. We focused on emerging areas and we followed the money—looking at where funding is going. For example, the U.S. National Robotics Initiative (NRI) has put a lot of resources into robots that can collaborate with people. The Defense Advanced Research Projects Agency (DARPA), for its part, has multiple programs that involve manipulation and bionic devices. Europe's Framework Programme is funding the development of cognitive systems and robots that can assist people in everyday tasks. In Asia, the decade-long funding of health-care robots for older adults has intensified.

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Again, we're not trying to present a comprehensive survey of the state of robotic research in 2012. We're hoping that the trends described here are helpful as a heat map that highlights promising areas and technologies in robotics and artificial intelligence. We know that many readers may disagree with our choices and that some might feel outraged at our selections; others will just want to learn more. In either case, we want to hear from you. Write us or go to http://spectrum.ieee.org/robotics2012 to see an expanded version of this article and join the discussion.

As predictions go, only one thing looks certain: robotics is going through an amazing time, and things should only get more exciting.

1) Co-Robots: Robots as Coworkers and Coinhabitants

Typically, robots fall somewhere on a spectrum between direct teleoperation and full autonomy. Unfortunately, teleoperation can be cumbersome and full autonomy is often illusive. Somewhere in the middle lies a compelling tradeoff, where humans and co-robots can collaborate to perform practical tasks (Figure 1). Co-robots are at the heart of the US$70-million NRI, spearheaded by the U.S. National Science Foundation (NSF), and they represent a definitive step toward robots migrating out of factories and academic laboratories and into our everyday lives. According to the NRI, co-robots must be safe, relatively cheap, easy to use, available everywhere, and able to interact with humans to leverage their relative strengths in the planning and performance of a task. "A lot of us are turning our attention in that direction," said a researcher from our panel of experts. (No wonder so many U.S. roboticists spent the latter portion of 2011 drafting proposals!) The program's scope is broad, but the key aspect of co-robots is clear: they must interact with humans. So expect to see a big jump in activity in human–robot interaction in all its myriad forms throughout 2012.

2) 3-D Sensing: The Kinect Revolution Continues

Last year, a curious adornment started appearing on the heads of many robots. It was Kinect (Figure 2), the

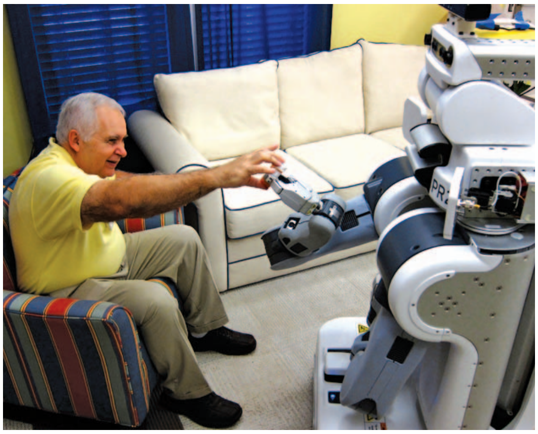

Figure 1. A study by Georgia Tech's Human Factors and Aging Laboratory used the PR2 robot to interact with older adults in the Aware Home. (Photo courtesy of Keith Bujak.)

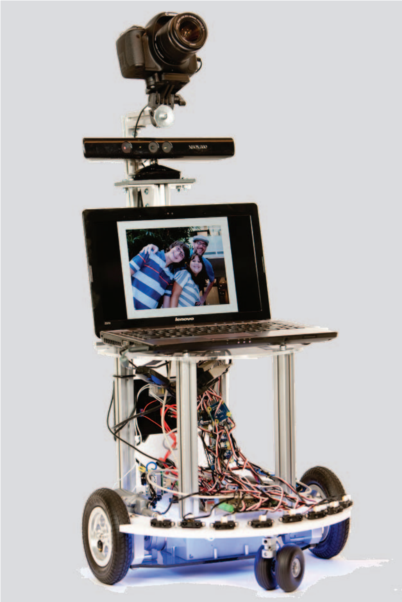

Figure 2. Microsoft's Roborazzi robot features a Kinect for navigation and a camera for snapping pictures of people. (Photo courtesy of Microsoft.)

now-popular Microsoft three-dimensional (3-D) sensor. Being cheap and easy to use, Kinect made 3-D mapping and motion sensing accessible, and the robotics community embraced it wholeheartedly. "People have been searching for a low-cost alternative to laser rangefinders, and now we have one (for indoor use, at least)," one of the panelists commented, adding that she expects to see a surge in usage. Indeed, the Kinect 2, which may appear sometime this year, will feature a higher resolution and frame rate that will allow the device, if you believe the rumors, to read lips. New types of cameras also promise to expand the possibilities of 3-D sensing. The so-called computational cameras—such as the Lytro, based on technology developed at Stanford—capture both intensity and angle of light and allow the refocusing of already-snapped pictures and the creation of 3-D images. The new wave of 3-D sensors may not only give robots better eyes but could also provide an effective way of 3-D scanning everyday objects, generating libraries that robots would access to finally understand the thing we call the real world. "3-D sensing is already hot," said another one of our researchers, "but with the Kinect and the next generation of similar cheap sensors, the sky is the limit."

3) Cloud Robotics: The Forecast Calls for Clouds

Several research groups are exploring the idea of robots that rely on cloud-computing infrastructures to access vast amounts of processing power and data. This approach, which some are calling cloud robotics, would allow robots to offload compute-intensive tasks such as image processing and voice recognition and even download new skills instantly (see *IEEE Robotics & Automation Magazine*, vol. 18, no. 2, June 2011). A lot of activity should be happening in this area this year. As one of the researchers said, "the cloud will explode." In particular, Google has a small team creating robot-friendly cloud services that, if they become popular among roboticists, could cause a tectonic shift in the field (imagine every robot using "Google Maps for Robots" for navigation). In Europe, a major project is RoboEarth, whose goal is to develop a World Wide Web for robots, a giant cloud-enabled database where robots can share information about objects, environments, and tasks (Figure 3). Many other projects are taking shape and we expect that, in 2012, cloud robotics will sound less like a buzzword and more like a serious research domain.

4) Compliant Actuation: Robots with a Soft Touch

When robots interact with humans, safety is a key concern. Conventional position-controlled arms, such as the ones that dominate factories, just won't cut it. Making robots that have a soft touch is key to a future where humans and robots can share spaces

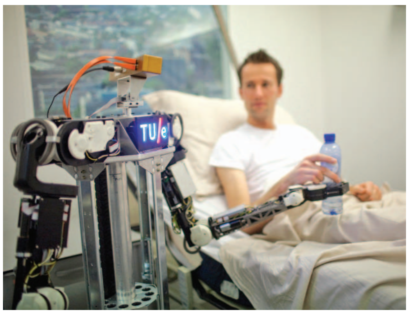

Figure 3. A robot connected to RoboEarth serves a drink to a patient during a trial of the system. (Photo courtesy of RoboEarth.org/TU Eindhoven.)

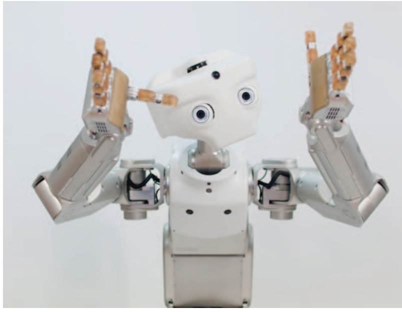

Figure 4. The Meka M1 compliant robot with custom series-elastic actuators. (Photo courtesy of Meka Robotics.)

and collaborate closely. For this reason, we expect to see numerous improvements to compliant actuation and tactile sensing technologies in 2012. Examples of this include better series-elastic actuators (Figure 4) and tactile skin. In addition, we expect researchers to think outside the box—developing new, clever types of compliant systems far removed from electromechanical motors. For example, in 2011 we saw a number of soft-bodied robots that, much like their meat-bag biological counterparts, are inherently squishy. These include iRobot's Hexapod JamBot, based on particle-jamming actuators, and OtherLab's Ant-Roach Pneubot, an inflatable robot made of fabric and pneumatic actuators. These and other projects point to a tantalizing future filled with compliant and soft-bodied robots that we expect to start taking shape in 2012.

5) Smartphone-Based Robots: The New Robot Brains

Almost every robot these days needs a combination of sensors, CPU, display, and network connectivity. Smartphones and tablets offer a combination of sensors, CPU, display, and network connectivity. Do you see where this is going? At one end of the spectrum, iRobot has demonstrated a remote presence prototype robot called Ava, which uses a tablet to control its mobile base. At the other end of the spectrum, two Seattle engineers quickly raised more than US$100,000 on a fund-raising Web site, Kickstarter, with the promise of developing a cute little smartphone-powered robot (Figure 5). These are just two

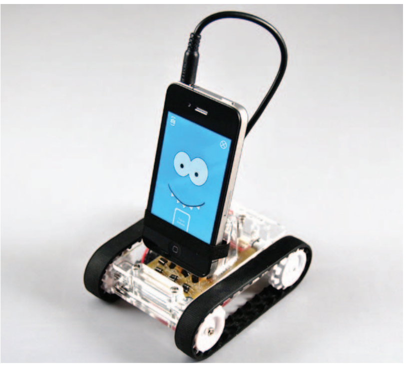

Figure 5. Romotive, a Seattle start-up, created a tracked mobile robot powered by a smartphone. (Photo courtesy of Romotive.)

examples of a trend that we believe has an earth-shattering potential for robotics. Mobile devices—based on Apple's iOS and Google's Android—are riding an extraordinary, unprecedented wave of innovation. We think (and hope) that robotics can take advantage of this same wave. The result would be many more robots moving out of the laboratory and into the marketplace. "More and more smarts in cell phones, such as [Apple's voice assistant] Siri, will impact robot toys and research this year," one of our panel members commented. Indeed, thanks to smartphones, robots will only get smarter.

6) Low-Cost Manipulation: A Robot Arm You Can Afford

With the ever-improving economics of computing and developments such as the popularization of 3-D sensors, the overall cost of a robot is dropping precipitously. Except for one thing: actuators seem to be holding up the show. This is most evident with grippers and high degree-of-freedom (DoF) arms for manipulation. We're not talking about hobby servo solutions; we're talking about what many roboticists want. They want a powerful system for mobile manipulation: human-type form factor, compliant actuation, respectable payload (at least 5 kg). Oh! Did we mention cheap? Like, all for less than US$5,000. In other words, could a new robot arm do for manipulation what the Kinect is doing for 3-D sensing? The IEEE International Conference on Robotics and Automation 2011 paper by Stanford researchers on a low-cost compliant manipulator suggests that it is possible (Figure 6). Indeed, there is a fair amount of funding in this direction—from the NRI of the NSF to DARPA's three manipulation-centric programs [Autonomous Robotic Manipulation Hardware (ARM-H), ARM Software (ARM-S), and Maximum Mobility and Manipulation (M3)]. As one of the researchers explained to us, all this funding should lead to "interesting new hand designs and autonomous manipulation systems." (Mobile manipulation will be the theme for the June special issue of *IEEE Robotics & Automation Magazine*.)

7) Self-Driving Vehicles: Coming to a Street Near You

Okay, you probably won't see autonomous vehicles driving near you anytime soon; unless you live in Silicon Valley, where Google has been extensively testing its famous self-driving Toyota Prius (Figure 7) and also a fleet of autonomous golf carts. But one thing's for sure: autonomous vehicles have proliferated in the past few years, with projects in the United States, Germany, France, Italy, and China. Last year, Nevada became the first U.S. state to permit autonomous cars to be legally driven on public roads (though some speculate that Europe might prove more friendly to this type of vehicle than the United States). Either way, autonomous driving features are already showing up on regular mass-produced cars. Some models of the Prius currently have a driving-assist function that keeps the car centered on its lane and another function that can park the car all by itself. Though carmakers will insist that these are not autonomous driving features, it's clear that cars are becoming more robotic. Furthermore, it's likely that autonomous vehicles will drive another trend as well. As one of the panelists explained, we should start to "map, and perhaps even instrument, our environment" to help autonomous cars and robots navigate. "This is a shift," he said. "The emphasis used to be solely on local algorithms and computation. Folks are starting to realize that this is not the low-hanging fruit." Driving, we'll soon be able to say, is so 20th century.

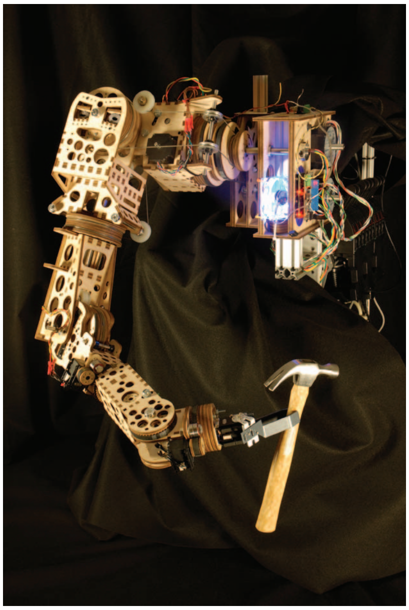

Figure 6. Stanford researchers developed a low-cost compliant 7-DoF arm. (Photo courtesy of Morgan Quigley.)

Figure 7. Google demonstrates its self-driving car at the TED 2011 Conference. (Photo courtesy of Steve Jurvetson/Flickr.)

8) Factory Robot Helpers: The Future of Manufacturing

Last year, an announcement from electronics manufacturer giant Foxconn took the robotics community by surprise. The Taiwanese company said it was going to add 1 million robots to its assembly lines over the next three years. One million robots is a lot of robots—in fact, it's double the current industrial robot population. Many uncertainties remain about Foxconn's plans, including whether they can pull it off. What's clear, though, is that there's a huge need for flexible, capable, and safe manufacturing robots—a

Figure 8. The ABB FRIDA concept is a 14-axis dual-arm robot designed for working alongside human workers in manufacturing environments. (Photo courtesy of ABB.)

new generation of industrial machines different from the big, expensive manipulators in existence. Also, it looks like this new generation is beginning to arrive. Examples include Kawada Industries' Nextage, ABB's Friendly Robot Industrial Dual Arm (FRIDA) (Figure 8), and Yaskawa's Motoman SDA10D. But the factory robot that everyone wants to see? It's the mysterious robot that Rodney Brooks is developing at his supersecretive start-up Heartland Robotics. Is 2012 the year he'll unveil the machine? We hope so.

9) Rapid Prototyping: A 3-D Printer in Every Home

Rapid prototyping is incredibly useful; being able to quickly fabricate a part can save thousands of dollars, eliminate days of waiting, and allow you to figure out whether your neat design is indeed brilliant—or a flop. There is one rapid prototyping device (a robot in its own right) that will likely make a significant impact in 2012: MakerBot Industries' Thing-O-Matic 3-D printer (Figure 9). Three-dimensional printers are a mainstay of academic and industrial robotics laboratories these days, but they're expensive (some cost above US$20,000). The Thing-O-Matic (and its ilk) make 3-D printing available to the masses, retailing for as little as US$1,000. Low-cost 3-D printers could very well be the next big trend in home robots. MakerBot forecasted that 10,000 units would be sold in 2011, but we're guessing that they have shattered their estimates since they were already ahead of schedule in March 2011 and raised US$10 million in venture capital to expand their efforts. At the forefront of the do-it-yourself (DIY) maker movement, 3-D printers such as the MakerBot are fulfilling the personal fabricator scifi visions set forth in Neal Stephenson's Diamond Age, allowing people to mock-up, share, and refine digital products—using Web sites such as Shapeways and Thingiverse—for home fabrication. Our bet is that 3-D printing is going to keep moving in one direction—up.

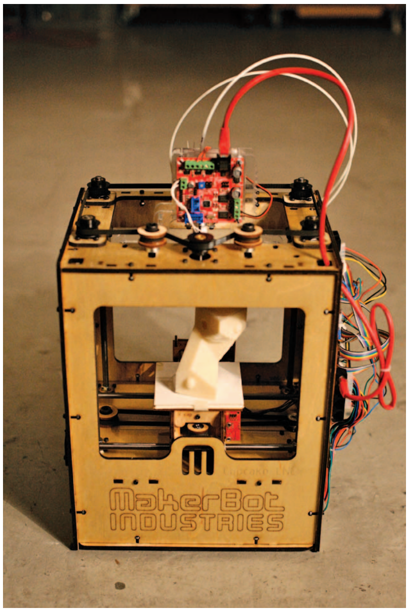

Figure 9. One of the open-source 3-D printers created by MakerBot. (Photo courtesy of Bre Pettis/Flickr.)

10) Unmanned Aerial Vehicles: Crowded Skies

Small unmanned aerial vehicles (UAVs), and in particular, quadrotors (Figure 10), were huge in 2011. "They provide an entry path to UAVs for people who couldn't have worked on them in the past," said one of our researchers. "I would expect interest in that to continue and grow." Last year was just the beginning. In 2012, we expect to see additional UAVs uptake by both professional and citizen researchers looking for inexpensive robot platforms. Consider DIY Drones, a popular Web site for UAV enthusiasts; it boasts more than 20,000 members who design, build, and fly their own autonomous UAVs. Buyers looking for already-assembled models have lots of options too. Walking through the mall during the holiday season, we saw literally a dozen stores selling UAVs, from Air Swimmers remote-controlled (RC) blimps (below US$40), to small smart-phone-controlled helicopters (about US$100), to Parrot's AR Drone quadrotor (US$300). Brisk holiday sales created thousands of new UAV enthusiasts who, bolstered by ever-expanding open software and hardware resources, will work hand in hand with professional researchers to unveil some amazing flying machines in 2012. (The quadrotor platform will be the theme for the September special issue of *IEEE Robotics & Automation Magazine*.)

11) Telepresence Robots: Your Avatar in the Real World

Telepresence robots—mobile machines that act as your stand-in at a remote location—first became prominent in 2010, when Silicon Valley start-up Anybots introduced one of the first commercial offerings, an alien-looking robot called QB (Figure 11). In 2011, more robots hit the market, including the Vgo from Vgo Communications and the Jazz from the French company Gostai. "It's an important technology with a strong business case and will save both time and money for business travelers," said a researcher. Indeed, we think that 2012 will be a milestone for telepresence robots and robotics, in general. By the end of the year, hundreds of QBs, Vgos, Jazzes, and others

Figure 10. A quadrotor helps assemble a tower as part of an art project by ETH Zurich roboticists and architects. (Photo courtesy of Markus Waibel.)

Figure 11. The QB telepresence robot by Anybots. (Photo courtesy of Randi Klett/ *IEEE Spectrum*.)

will be roaming around offices—a place where robots were nonexistent—all over the world. It's a first in robot history. In 2012, a new entrant promises to make this market even more competitive; it's likely that Suitable Technologies, a Willow Garage spin-off, will introduce its much-awaited remote presence system as well. So expect to see more telepresence robots near you—if you don't become one yourself.

12) Bionics: The Line Between Humans and Machines Gets Blurry

Cyborgs and other man–machine hybrids have long captured people's imaginations. We're still far from the technology envisioned in science fiction shows such as "The Six Million Dollar Man" and "Robocop," but researchers have made significant progress in the past two years. Areas such as robotic prostheses and brain–machine interfaces seem to be building lots of momentum, and we expect to see some promising milestones in 2012. In particular, exoskeletons are literally strutting out of the laboratory. This year, Ekso Bionics (formerly Berkeley Bionics) will begin selling its robotic suit first to rehab clinics in the United States and Europe, hoping to have a model ready for at-home physical therapy by the middle of 2012 (Figure 12). At the same time, a DARPA-sponsored project by Johns Hopkins University and the University of Pittsburgh has been testing a brain implant that allows patients to control an advance robotic arm with their thoughts alone. Many other groups are also working on technologies that promise to blur the line between humans and machines; it won't happen overnight, but now the promise is not just science fiction anymore—it's real.

Figure 12. A test pilot tries the exoskeleton created by Ekso Bionics. (Photo courtesy of Ekso Bionics.)

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structures and mechanisms, such as bones, joints, muscles, and tendons. We've already built two robots, and now we want to figure out how to control them and give them humanlike cognitive features.

EG: **Is ECCE going to assemble my next iPhone?**
RP: ECCE is a research platform. It uses cables with a certain degree of elasticity as tendons. There are 45 motors embedded in its body that pull on the cables to make the body move. As for your future iPhone, I don't think it makes sense to put humanoid robots in factories. The next-generation factory robots could be just a pair of arms or hands, or other kinds of manipulators, which don't even have to look humanlike. However, maybe it could be an ECCE hand.

EG: **How do you control ECCE's movements? How many degrees of freedom does it have?**
RP: Too many. That's one of the biggest challenges. For example, when the robot lifts one arm, the torso and the other arm wiggle a bit. It's very biological and realistic in how it works, but it doesn't make control easy. Lifting the arm requires the actuation of multiple muscles that need to be coordinated, actuated to varying degrees. The way the body and muscles interact is difficult to model using classical control methods. There are lots of nonlinear behaviors, the tendons have static and dynamic friction, and the mechanics are not precise. This is where learning becomes critical. The robot needs to figure things out by itself, at least some things. To be able to do that, we