The Royal Society of Edinburgh
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Professor Sethu Vijayakumar FRSE
Professor of Robotics at the University of Edinburgh,
Director, Edinburgh Centre for Robotics and
Royal Academy of Engineering Microsoft Research Chair in Robotics

Shared Autonomy: The Future of Interactive Robotics

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Report by Jennifer Trueland

In the very near future, the next generation of robots will work much more closely with humans to transform areas of life ranging from disaster recovery and space exploration to driverless cars. But robots with increased autonomy come with risks as well as benefits, so how do you get the balance right to reach the shared autonomy sweet spot? Professor Vijayakumar discussed the latest technology and future directions in a fascinating lecture which showed that what was once considered science fiction is very close to becoming fact.

Robotics is having a significant impact on today's society and is becoming ubiquitous, contended Professor Vijayakumar. In evidence, he cited a huge array of settings where robots are playing a role. These range from mining, underwater and inside the core of nuclear power plants, where they are being used in decommissioning, to agriculture, for example, in more targeted interventions for weeds, and in the 'smart city' of the future, for example, using drones to deliver goods. Other areas include factories, where robots are key to manufacturing, and the hospital operating theatre.

And robots are getting better and more sophisticated all the time. The Professor showed footage from the DARPA Robotics Challenge finals of 2015, showing humanoid robots making their way through an impressively difficult set of tasks with greater or lesser success. There's a sliding scale between tele-operation, that is, lots of activity in the background with an operator effectively making the decisions, to an autonomous robot. There are significant challenges in achieving the move from the 'joystick' to increasing autonomy, and it might be that, in the near future at least, shared autonomy is the solution; that is, automation, but still with user input.

Co-working between humans and robots could mean, for example, that the robot can tell from the human's gaze what he or she wants. But there are challenges with this, including the environment, ambiguity, guarantees for safe operation, and the need for close interaction with multiple objects.

Professor Vijayakumar described work that is taking place to tackle these challenges, before talking about some actual projects involving a degree of shared autonomy. The first essential area is to understand and represent the world around you and plan how the robot will be able to move in this. This involves segmenting the terrain and using sensors to build a local map of the environment.

The second challenge is using topology – focusing on where the parts of the robot are in relation to objects and the environment. This is particularly useful with snake-like robots, and is economically important. For example, checking that a plane engine is safe to fly is a time-

consuming process, involving dismantling it and putting it back together again; but if a robot could examine the whole engine *in situ*, this would save time and money.

It's also important that robots can deal with uncertainty. Professor Vijayakumar cited a 2013 paper from his group that shows how compliant actuation design and stiffness control can improve efficiency, safety and robustness. Humans are good at learning to predict consequences and adapting their actions accordingly, and some of the cutting-edge research his group has been doing enable robots to achieve just that in a real time, data driven manner. Putting it all together, you could end up with robots that have some of the capabilities of humans, but can also carry out tasks and activities in ways that humans simply can't.

Professor Vijayakumar described several projects that are showing real promise in making real and valuable use of robotics. These include the University of Edinburgh's collaboration with the space agency NASA to work on the Valkyrie, one of the most advanced humanoid robots in the world. As NASA seeks to find out if it would be possible to set up human colonies on other planets, robots would be essential for exploration. It would be vital to build in significant autonomy, because the time-lag (between Earth and Mars, for example) would mean it was impossible to use tele-operating systems.

Space walks are becoming increasingly hazardous for humans because of space debris, he added – so it's safer to get robots to do it. The robot needs to be programmed with many core capabilities to ensure it can do these things; for example, if it is reaching for an object, you need to plan where it should stand, how it will reach it, how to avoid obstacles and then how to reach for it. Live data from cameras providing constant feedback can assist, but the big challenge is to get the robot to do it largely autonomously, with only high level human input. 'There is a long way to go,' said Professor Vijayakumar.

Quoting David Mindell from MIT, he said that "full autonomy is a 20th-Century rhetoric", and that the real frontier is collaboration, which "includes autonomy, but different levels of autonomy at different moments under the control of a human operator'. 'Such systems should have the ability to turn on autonomy where it can be helpful. Autonomy should aim to reduce human cognitive workload and fatigue, but humans should still be present in the loop."

Professor Vijayakumar described how shared autonomy is already being used in healthcare and demonstrated – with the aid of volunteers from the audience – how to control a prosthetic hand by using sensors that gauge muscle activity. This has huge positives, but also carries risks – what if someone 'hacks' into the hand, for example? But the possibilities are "tremendous."

The third project highlighted involved shared autonomy for remote operations using assisted tele-operation and autonomous behaviours. This could be useful for disaster situations; for example, where robots could go into hazardous environments to search for survivors in the aftermath of an earthquake. The human wants to sit away from the danger zone and operate systems with shared autonomy. This involves the robot adapting to the environment and taking 'decisions' on the ground on how to achieve the high-level task that is based on the high-level decision taken by the human operator.

Current projects involve applications in a number of areas, including nuclear decommissioning, remote operation of heavy machinery (for example in the construction of Crossrail in London) and collaborative manufacturing. Professor Vijayakumar went on to describe the ORCA Hub, a newly-funded project to run offshore plants from the shore. The idea is to develop quadrupeds, flying robots and underwater team of robots that can work in

tough and hazardous environments. He also spoke about using robots in the airline industry for inspection, repair, certification, assembly and decommissioning.

Professor Vijayakumar ended by considering some future debates, such as the impact of robots on our everyday lives, and on society. He said it is important to educate students to consider the ethical dimensions of their research on robots. As an example of some of the new initiatives driving this, the Edinburgh Centre for Robotics is an approximately 100-million-pound joint venture between Edinburgh and Heriot-Watt universities, creating 'innovation-ready' postgraduates, bringing to bear disruptive innovation in robotics and artificial intelligence, working across a number of fields and sectors. We are living in exciting times with numerous life changing possibilities through innovation in technology and Robotics and Artificial Intelligence is at the heart of it, the Professor concluded.

Questions

Asked about the best and the worst that could happen as a result of shared autonomy (between humans and robots), Professor Vijayakumar pointed to defence, saying that the right autonomous target system could be "more accurate" than cluster bombs, but that there is a question of what level of control humans have. He said there is a difficult debate on the social side; for example, on what happens to the data that systems collect. "The popular view is that your data is the new oil," he said, saying that citizens have to provide a certain amount of data to get personalised services – but what if control over this was taken out of the hands of individuals? Robots do a lot of good, he added, citing their use to improve laparoscopic surgery and reduce errors.

Asked about the development of standardised algorithms, Professor Vijayakumar said that robotic operating systems (e.g. ROS) are getting to be more standardised, and that we are "doing less and less of reinventing the wheel."

Asked whether security tends to be a priority, or added 'at the end', Professor Vijayakumar said that unfortunately at the moment it is the latter, because are so many technological challenges to overcome to create a robust, working system. We should be thinking about it much more, he added, and we need the right level of expertise to make that happen.

Vote of Thanks

Professor Marion Scott OBE FRSE thanked Professor Vijayakumar for delivering a "fascinating walk" through the field of robotics and its implications for society.