The next big thing(s) in Robotics

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The **second wave** of robotics has started. The first wave got going around fifty years ago with industrial automation – exemplified by assembly line robots – the kind that build cars and washing machines. A hugely successful technology; first generation robots have revolutionised industrial and warehouse automation. And, more recently, first wave robotics technology has brought automation to the science lab – think of gene sequencing. There are few areas of human endeavour not touched by first wave robotics. From undersea exploration to robot milking machines, from robot surgery to space exploration, first generation robots are hugely sophisticated machines.

But something even more exciting is happening. Now underway, the second wave represents a kind of Cambrian Explosion in robotics: an astonishing and bewildering exploration of new forms, functions and materials. This explosion of diversity means that it's impossible to characterise the new wave as one kind of robot. Many are bio-inspired; together these comprise an extraordinary artificial zoo. Any prediction about which of these robot forms will successfully evolve to become mainstream is more or less impossible.

One thing we can be sure of is that second wave robots will be working with people, up close and personal. This contrasts with their first wave ancestors that, by and large, are dangerous for humans. In the vanguard of this second wave are workplace assistant robots like Baxter. This robot doesn't need to be behind a safety cage. Sharing a human workspace, Baxter acts as helper and co-worker.

[suggest show pic of Baxter]

Second wave robots will be networked (no surprise there), made of very different kinds of stuff (I'll have more to say about this later), and smarter - although not as smart as some would have you believe.

They will also be ethical. The way we think about robots will be different. As a society we will need to decide what robots should *not* do; a good example of how this is already happening is the current debate over autonomous robot weapons. We will expect our robots to understand us better, and to behave ethically – even if that means a robot occasionally does not do what we ask of it.

Having set out the landscape I will now attempt the very thing I claimed impossible: prediction. So, with a health warning, here are a few areas that I suspect will be very significant in the near future.

Wearable robots

Wearable robotics is one of the most exciting current developments in robotics – and one that could move from lab to real world application within the next five to ten years. Wearable robots are not new – they've been around for a while in the guise of exo-skeletons, often intended for military applications. However, a new generation of wearable robots is beginning to exploit new materials and better human-robot interfaces. These wearables will I think bring huge benefits for the disabled, elderly or those recovering from orthopaedic surgery.

Wheelchair users, for example, experience all kinds of access problems, as well as the disadvantage of not being eye-to-eye with other adults. Imagine instead a simple wearable strap-on leg-chair. Light and self-powered, the leg-chair (the Right Trousers?) senses when its user wants to stand-up and, well, stands up. Learning from its user while continuously adapting to her capabilities the leg-chair senses when she wants to stand, walk, run for the bus, do cartwheels (well, why not..?), or any of the things most of us take for granted. Then makes it so, safely and intuitively.

An example wearable robot from the Bristol Robotics Lab is the hand exo-skeleton, designed as a rehabilitation aid for people who have lost hand-function because of a stroke. Made from 3D printed plastic parts, the exo-hand senses the finger movements of its wearer and very gently adds a little extra power to those movements, thus reinforcing the user's efforts and – over time – helps to restore lost hand function. This is just a one-off prototype to prove the principle but it provides a wonderful illustration of the potential of wearable robotics.

[show image of Bristol hand exo-skeleton]

Immersive tele-operated robots

Teleoperated robots are the unloved poor relations of intelligent autonomous robots. Neither intelligent nor autonomous, they are nevertheless successful and important first wave robots; think of remotely operated vehicles (ROVs) engaged in undersea exploration or oil-well repair and maintenance. Think also of off-world exploration: the Mars rovers are hugely successful – the rock-stars of tele-operated robots.

I think tele-operated robots need to be brought in from the cold and reinvented for the second wave. Anyone who has tele-operated a robot in real-world applications knows it is headache-inducingly frustrating; peering at a screen (or even worse, at three) with low-resolution images and viewpoints that make making-sense of where the robot is and what it should be doing is next-to impossible. It's no surprise that skilled robot tele-operators are hard to find. Immersive human-robot interfaces will, I think, change all of this.

Roboticists are good at appropriating technologies or devices developed for other applications and putting them to good use in robotics: look at WiFi, mobile phone cameras and the Kinnect. There are encouraging signs that immersive Virtual Reality (VR) is about to become a practical, workable proposition. Of course VR's big market is video games – but VR could revolutionise tele-operated robotics.

Imagine a tele-operated robot with a pan-tilt camera linked to the remote operator's VR headset, so that every time she moves her head to look in a new direction the robot's camera moves in sync; so she sees and hears what the robot sees and hears in immersive high definition stereo. Of course the reality experienced by the robot's operator is real, not virtual, but the head mounted VR technology is the key to making it work. Add haptic gloves for control and the robot's operator has an intuitive and immersive interface with the robot.

Driverless Cars

Nearly-driverless cars are already a reality. Buy a certain top of the range Mercedes and it will be equipped with automatic lane control, called Intelligent Drive. It's like cruise control except that the car can also keep its position in the centre of the lane – on the autobahn – while also checking and adjusting its speed to maintain a safe distance behind the vehicle in front. While in intelligent drive mode this car is doing what autonomous mobile robots do: using its sensors to continuously monitor its immediate environment, analysing all the sensory data, then using its control system to decide how to adjust the car's steering, accelerator and braking systems according to a set of rules for safe motorway driving.

Sounds wonderful (if you can afford a top of the range Merc)? Well no. The problem is that while the car is in intelligent drive mode you can't read a book, or watch TV, or check your emails. That would illegal. This is because even though the car is probably better and safer than you on the motorway, you are still in charge. In fact the car will warn you if you take your hands off the steering wheel for longer than 10 seconds. The law demands that you watch the road and continuously monitor the situation so that you can take over in a second. If there's an accident it is you who is responsible, not the car.

This illustrates the current problem with driverless cars. The technology exists and is pretty well road tested. Contrary to popular opinion Google didn't invent the driverless car. Europe has a long history of driverless car research - *nearly 20 years ago* a research group at University BW Munich demonstrated a Mercedes 500 driving from Munich to Denmark on regular roads, at up to 180 km/h, with surprisingly little manual driver intervention – about 5%. The 2007 DARPA Urban Challenge showed driverless cars coping pretty well with cluttered urban environments, complete with other cars behaving unexpectedly, bicycles, street furniture and so on.

[suggest show image of driverless car from Paul Newman's Oxford lab]

So the technology exists and, in a limited form, you can buy it now. The problem of driverless cars has shifted from one of engineering and technology, to one of legislation and insurance – as well as the human factors of how we all adjust and get used to roads on which some cars (initially most of them) are manually driven, and others driverless (with occupants who are really not paying attention to the road). There is no significant technical reason why, in 5 - 10 years, an elderly person *without a driving licence* couldn't have a small car that takes her from home to the local shop to pick up groceries, then on to a friends house for tea, perfectly safely and automatically.

Soft Robotics

Soft robotics, as the name implies, is concerned with making robots soft and compliant. It's a new discipline that already has its own journal, but not yet a Wikipedia page. Soft robots would be soft on the inside as well as the outside - so even the fur covered Paro robot is not a Soft robot. Soft robotics research is about developing new soft, smart materials for both actuation and sensing, ideally within the same material. Soft robots have the huge advantage over conventional stiff metal and plastic robots, of being light and, well, soft. For robots designed to interact with humans that's a huge advantage because it makes the robot intrinsically much safer.

Soft robotics research is still at the exploratory stage, so there are not yet preferred materials and approaches. In the Bristol Robotics lab we are exploring several avenues, one is electroactive polymers (EAPs) for artificial muscles; another is the bio-mimetic 3D printed flexible artificial whisker. A third approach makes use of shape memory alloys to actuate octopus like limbs, as demonstrated in the EU OCTOPUS project. One of the most unlikely, but promising, approaches exploits fluid-solid phase changes in ground coffee to make a soft gripper: the Jaeger-Lipson coffee balloon gripper.

Unlike the three applications domains I outlined above – wearable robotics, immersive tele-operated robots and driverless cars – soft robotics is a new underpinning technology. A huge number of types of robots will benefit from soft, smart materials – including the wearable robots I outlined above. One of the reasons we need soft, light materials is that robots designed to work closely with humans need, above all, to be safe. A way to make then intrinsically safe is by making the robot soft, light and compliant – so even if the robot were to fall on you it would do no more damage than if a young child fell on you. One effect of soft robotics is that many future robots will look very different: less mechanical and more organic. Most robots in research labs are already 3D printed rather than machined from metal; next generation 3D printers will enable us to print soft robots.

What's not coming soon

Some will be surprised that I have not written about robot intelligence here, apart from suggesting that the second wave of robots will be smarter than the first. My omission is deliberate, and there are two reasons.

The first is that robot intelligence still has a **very** long way to go before the science fiction dream of android robots with human-like AI – like *Data* from Star Trek, or *Bicentennial Man* – become a reality. Some are predicting that human-equivalent AI is only a few decades away, and if you believe the hype, once that point is reached all bets are off. Some believe this event – which they call the singularity – will usher in a new utopia in which super-intelligent machines will solve the world's problems. Others are equally convinced that super-intelligent AI poses an existential risk to humanity; AI, they declare portentously, will be humanity's final invention. The utopians and dystopians are equally wrong, in my view, both about how long it will take to build machines as smart as humans, and the question of what will happen after that.

The reason making really intelligent machines will take a long time is because it is a very hard problem. We don't even understand what intelligence is – only that it is not one thing that humans or animals have more or less of. Nor do we yet understand how intelligence works in animals and humans; to paraphrase a famous SF short story, we don't know how meat can think. But the good news, and this is my second reason for not promoting super intelligent robots in this article, is that there is truly massive potential for really interesting and hugely useful smarter – but still not very smart – robots. It is a myth that robotics is somehow waiting for a breakthrough in AI before its true potential can be realised.

My predicted things that will be really big in robotics don't need to be super intelligent. Wearable robots will need advanced adaptive (and very safe and reliable) control systems, as well as advanced neural-electronics interfaces, and these are coming. But ultimately it's the human wearing the robot who is in charge. The same is true for tele-operated robots: again, greater low-level intelligence is needed, so that the robot can operate autonomously some of the time but ask for help when it can't figure out what to do next (which we call dynamic autonomy). But the high-level intelligence remains with the human operator and – with advanced immersive interfaces as I have suggested – human and robot work together seamlessly. The most autonomous of the next big things in robotics is the driverless car, but again the car doesn't need to be very smart. You don't need to debate philosophy with your car – just trust it to take you safely from A to B.