The Next Industrial Revolution

Giving machines autonomy – and the ability to make decisions
Introduction

- Cambridge Consultants is a multidisciplinary product development company.

- We have been active in robotics for a while – our largest project is a warehouse automation system for a well known name.

- This work is confidential – but today is about another robot development and gives a view on how robots fit an industrial society.
The robot worker – how does it fit in the value chain?

- Aside from inventing economics, Adam Smith is well known for the example of the pin factory.

The idea is that people can become specialised and efficient in one small task.

Existing robots take this to an extreme – they typically take one small task and repeat it to tight tolerances.

But – does this make them ‘useful idiots’?
But robots aren’t as good as the general public expect

- Interaction with the real world is hard, and only narrow areas have been shown to be useful.
‘Robots’ in a wider setting

- ‘Robot’ isn’t a useful word since it covers everything from this to this:
‘Robots’ in a wider setting

... so let’s be clear, by ‘robot’ I mean:

– A machine which can help a person be more economically productive by ‘doing the boring stuff for them’.

And some tasks which a machine might do are:

– Driving to work
– Checking out groceries
– Assembling a camera lens
– Filing a management report

But management need to see a business case before signing a capex for a new machine – and this means it needs to be cheaper (not necessarily faster or better) than a human.
Early 21st Century Robotics
Factory robots

- Typical usage is to plan (or teach), store the program and repeat when triggered by the PLC.

- External sensors sometimes used to take up tolerances or to fine tune positioning.

- The performance is only as good as the program – it’s really just a CNC machine. The flexibility is at the capital rather than operational level – one type of machine can fulfil many roles.
Self-driving cars

- Huge advances have been made in the last few years, notably image classification and collision avoidance. It’s an amazing achievement to do this.

- Cars process a lot of information (LIDAR and multiple cameras): they have much higher ‘awareness’ than a human driver.

- But, there’s a key problem here…
Self-driving cars – map data

- The map of the road is known in advance!
  (is this *really* any better than the 1960’s paper tape?)
Where are the places where robots can make big gains?

- An ideal area is:
  - Has a high total value (can be low value but done in massive quantity)
  - Has been tricky to automate and so is reliant on people.
  - Is margin sensitive so improvements change the bottom line.
  - The businesses in the field are large enough to invest in doing things a different way and meet the cost of ownership\(^1\).

- Look at the hierarchy of needs:

\(^1\) this probably excludes domestic robots!
ANSWER....
Getting robots out of the factories and into the fields
What does a robot need to work here?

1. To be at the right point in the value chain. Performing complex tasks like vine pruning is possible (at an academic level) but isn’t anywhere near a real farm yet.

2. To be able to work without any form of drawing as it’s dealing with random objects and not engineered parts. This means better sensing of the environment and the ability to make decisions without supervision.

3. To have an effector which is useful in the real world – human hands are amazing but haven’t been beaten by engineers yet.
Picking a point in the value chain

- We need a point where we can make a difference – the engineering NRE will be repaid by cost savings within a sensible timeframe.

- Planting? Not really needed as seed is cheap and we can waste some.

- Weeding? Already happening but could be limited by ability to discriminate between plands

- Harvesting? Getting closer, but much is done by machine. Also, seasonal which makes machines hard to amortise.

- Fruit and vegetable handling – yes! Lots of human labour, can be indoors, predictable enough, massively price sensitive. Also, some high value crops (specialist fruit, almonds) where early adopters can see a good return.
Existing machine vision
Existing machine vision

- This, again, has advanced massively. The examples shown fulfil some well defined categories:
  - Binary classification (‘is this bottle full?’)
  - Data extraction (‘what serial number is this?’)
  - Guidance (‘what angle are the threads at?’)

- But these work on a narrow problem space – what is expected is very well defined and so highly programmable / teachable.

- Also, 3D is new-ish to this field and could be essential.
The effector

- Horses have no technology – at least because they cannot use tools.
- Humans use tools and so can control their environment. However, our brains had to be powerful enough to use them.

[Diagram of human and horse limb comparison]

The fruit picking robot
So what are we showing?

- We want to show a demo which:
  - Puts robots into a new context
  - Shows an innovative step such as new machine vision capability
  - Has good system integration...
We’re showing three innovations here today

1. Novel application. Bin picking (the generic problem of getting objects out of stacks or piles) is cutting edge robotics and is typically only attempted for engineered parts.

2. A flexible effector. Can pick up a screwdriver, but also handle a peach without bruising.

3. Cutting edge machine vision – identification and guidance for random objects *without extensive training*. 
Gripper design decisions

**Concept Generation**
- Electro-Rheological Fluids
- Magneto-rheological Fluids
- Granular Jamming
- Electro-Adhesion
- Vacuum Suction Gripper
- Mechanical Gripper
- Cryo-Genic

**Concept Refinement**
- MR fluid Finger tips
- Granular Jamming Fingertips
- Deforming Vacuum Membrane
- Mechanical Claw
- Scooping Gripper

**Concept Development**
- Vacuum Based System
- Roller Gripper
Vacuum suckers

- Suckers / grippers are well established – but there are some difficult circumstances:
How to deal with this is a system design question

<table>
<thead>
<tr>
<th>High mechanical complexity?</th>
<th>High software complexity?</th>
</tr>
</thead>
<tbody>
<tr>
<td>High per-unit costs</td>
<td>Long development time.</td>
</tr>
<tr>
<td>Likely to be fragile and therefore expensive to own.</td>
<td>Will need extensive testing if it isn’t to ‘keep getting suck’.</td>
</tr>
<tr>
<td>Tricky to adapt to other tasks</td>
<td>Low per-unit costs once it’s written.</td>
</tr>
<tr>
<td>May actually have adverse software requirements…</td>
<td>Flexible (if you can afford the NRE)</td>
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We’ve gone for a compromise – the gripper is soft so it can work from an imprecise location yet wasn’t excessively complex to build.
Multi-finger vacuum gripper
Vision system requirements

- Aim is to pick fruit and vegetables from a pile.

- Vision system has to work out:
  - How the objects are connected (if at all)
  - Which object is best to pick (near the top but not jammed)
  - Where it is
  - What’s the best angle to approach from.

- This requires depth perception – 3D camera.
**Kinect Sensor**

- Projects an array of dots onto the subject, their displacement from their expected position is used to calculate depth.
- Not an ideal sensor as the voxels are a bit big but it already exists.
Image Segmentation

- Well understood technique for conventional images to detect connected regions.
- Can also be applied to depth map to detect and separate objects.
- We have developed this technique and applied to this problem.
Image segmentation

3D view of grabber
Bringing it all together

- Videos from Cambridge Filmworks
What were the key challenges?

- Machine vision – no standard algorithms to do this, needed some research and then new code writing.

- The gripper – getting the right balance between flexible but highly complex and simple but limited in its application.

- Bringing it all together – some standard components, but system integration and getting a smooth outcome is quite time consuming.
Conclusions

- This project shows an appropriate match between ‘what engineers can achieve’ and ‘what the customer needs’.

- This is only possible by thinking at a system level, for example:
  - Right compromise between software and mechanical complexity.
  - Integrated vision, commercial arm and novel mechanics

- New applications for robotics may not be a result of huge software and infrastructure investments – more a result of novel algorithm and signal processing solutions.
Image Credits

- Introduction: CC
- But Robot’s Aren’t... https://www.youtube.com/watch?v=W7NJFG3ZtZ8 http://www.cityam.com/article/how-intelligent-robots-stand-poised-change-all-our-lives-better
- What does a robot need? http://abe-research.illinois.edu/faculty/grift/research/biosystemsautomation/agrobots/AgBoHiRes2.JPG
- Picking a point http://extension.oregonstate.edu/umatilla/mf/sites/default/files/imagecache/preview_500/pictures/tns_packaging_line.jpg
- Image Segmentation: http://cs.nyu.edu/~silberman/images/nyu_depth_v1_preprocess.jpeg
Notes
Notes #1

- TITLE: “The next industrial revolution’ - giving machines autonomy and the ability to make decisions.”

- S1: machines struggle with situations they haven’t been programmed to expect. Neural networks / deep learning can cope to an extent but there’s a lengthy training time.

- S2: Huge steps made (up to self driving cars) but they depend on massive infrastructure (and who owns your data?)

- C: This is about being cheaper than a human not faster / more reliable. (S.D. cars are about overall system costs ie not owning a car)

- Q? Which area spends a lot of money on people but is already ‘cost optimised’?
Definitions

- IoT

- Industry 4.0 – connecting machines, workpieces and systems: create an intelligent value chain. Better status / health info to management. JIT maintenance, near-zero downtime.

- IoS – cloud computing.
Why did we do Scrumping?

- Robots repeatable not accurate, keeping them as CNC machines really.

- Taken picking as a challenge, using new machine vision

- Machine can now take decision of how to pick
  - Which one
  - Position and angle
  - How hard to suck
  - Has it got it?

- Integrates maths, s/w and mechanics.