DECIPHERING INDUSTRY 4.0 PART II HUMAN ROBOT COLLABORATION

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SYNOPSIS & BACKGROUND

Humans and robots are working more closely together as technology improves. This is increasing the productivity of companies and the quality of products, leading to efficiency and growth. In many cases robots increase output so much that more jobs are created in complementary jobs. Researchers and companies like Autodesk and KUKA are improving the safety of robot systems so humans can work close beside robots that become co-workers, more than mere tools.

The next step for robot makers, software companies and engineers is to refine human-robot job augmentation further to achieve a greater shift in productivity, freeing people to do higher value and less dangerous work.

For decades robots have fulfilled one of two broad applications:

1) Large industrial robots, programmed offline, work in defined, linear pathways to typically move, assemble or weld a manufactured component on a production line, and

2) Domestic and service robots. Lighter and softer applications, these help in more nuanced settings, from inspection of hostile environments, to helping humans in the home; from vacuum cleaning to healthcare and even social care applications.

The development of smaller "desk top" robots, known as collaborative robots or "cobots", was brought about from a new application of robots that is rapidly taking hold globally: **human robot collaboration** (or HRC).

There are new business and domestic scenarios where robots are designed to work alongside humans – rather than as a distinctly separate and binary tool behind a cage. "It's like an extension of the human activity, a human working but with added capabilities," says Jeremy Hadall - Chief Technologist - Robotics and Automation at the Manufacturing Technology Centre (MTC).

THE CHALLENGE

Until recently, robots have been constrained in their utility. They perform a limited range of tasks in a linear and literal way. They are programmed offline and could not respond to new stimuli in mid-task. Industrial robots are heavy, fast and potentially dangerous to humans working in proximity.

But many industrial applications demand a robot solution to increase throughput where the human worker is doing tasks that can be replaced, for example where:

- ► The task is simple and repeated identically multiple times but needs to be accurate
- ► Requires more than one worker but not as many as two (e.g 1.2 people)
- ► The task could cause stress or even injury to the operator

The challenge is to modify a robot's parameters to make it sensitive to human presence, to slow its speed and power in proximity to humans and to develop technology that allows the "collaborative robot" or cobot, to assist the human like an intuitive co-worker, not a heavy and dangerous threat.

"Cobots have very sophisticated force-torque sensors, so they sense when people are near them – a person can now interact in the same space knowing that the robot will stop if they intrude within set parameters, and then carries on what it is doing," says Robin Smith, Senior Applications Engineer at Autodesk.

Advances in human robot collaboration (HRC) have led to progress in all these fields

The business case for HRC is greater productivity enabling more output and therefore growth, repeatability, redeploying labour into better jobs, higher profits and reduced exposure to repetitive or physically hard work with – sometimes low but present – safety risk.

Main advantages of using cobots over human-only operations

- ► Increase productivity – frees-up human to work on other operations
- ► Reduce repetitive strain injuries and lifting
- ► Productivity rises without needing extra work space
- ► Human can focus on higher value tasks

FEATURES OF HRC I

Sensitivity sets cobots apart

A robot harnessed to a human operation is often greater than the sum of its parts.
"Together you can achieve something greater than just one of those elements on their own," says Charles Jones, Product Manager – Robotics of the Autodesk Digital Manufacturing Group.

The challenge is to change "binary" or very linear programming to a more intuitive level where robot behaviour adapts to humans during a process, i.e human robot augmentation (HRA).

KUKA's LBR iiwa is KUKA's main cobot solution. It has been engineered with greater sensitivity, to work with and augment human operations. The lightweight iiwa's high-performance servo control is able to detect contours quickly under force control. It establishes the correct installation position and mounts components quickly with high precision with an axis-specific torque accuracy of ±2% of the maximum torque.

The iiwa has been specifically engineered to work with humans as a capability extension. Future improvements will include further simplification of the user interface to make cobots easier than ever to programme.

Augmenting industrial robots like cobots

The number of industrial applications for such cobots is growing. At the moment it is dominated by the automotive industry (see page 7), but retail, food, inspection and laboratory applications are rising.

Large industrial robots are not designed to work next to humans; most are caged off to protect workers, and operate under a hierarchy of regulations covering safety.

"How do you get large industrial robots that normally operate at high speed to work closely with humans?" asks the MTC's Jeremy Hadall. The MTC is researching applications where the iiwa / cobot is too small but HRC is required.

This involves changing the robot programming software to make the robot more intelligent, more understanding of humans, and meshing this together so when the robot needs to move fast and operate high payloads it can, but when it needs to go into a human co-worker paradigm, it can without entering a default "safe" mode where you have to reset it.

"We are tying to make the workspace safe, we want it to understand where the human is and avoid those collisions," says Hadall. " We are aiming to get to the stage where big robots behave in a similar way to an LBR iiwa.

Real-time monitoring of 3D printing

HRA shows real-time adaption to the process. Another application that displays adaptation is in 3D printing. "As the robot deposits material it monitors it and automatically updates and augments itself depending on the measurements and the inspection," says Autodesk's Charles Jones.

Autodesk software can now measure CAD data during an operation, adapting on the fly and creating adaptive toolpaths for the robot in real-time. The software also gives design intent. "Rather than design a bridge that you want, you say you want to "design a structure with these parameters that spans from point A to point B"," says Autodesk's Jones. "The algorithms and the software are free to make the decisions about the best way of achieving that."

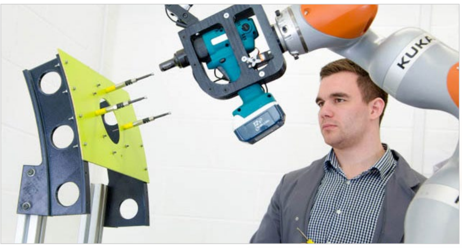
The robot will change its path and the printed structure as the adaptive software corrects it.

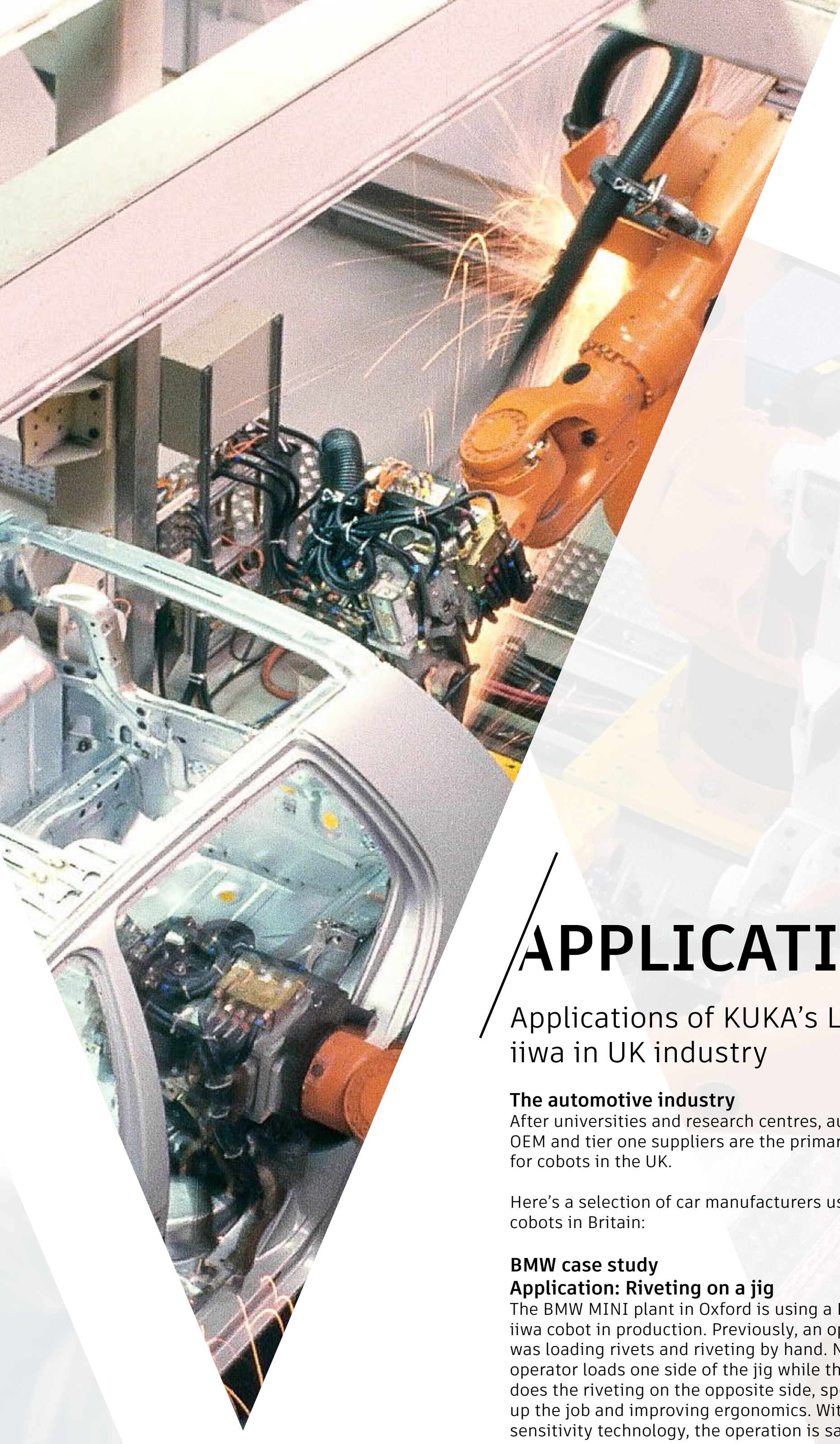
FEATURES OF HRC II

Machine learning and Artificial Intelligence

Tasks that are simple to a human can be complex for a robot. For example, working out what an object looks like among many identical or similar objects, and how to grab that object is very complicated for a robot.

The challenge for a robot becomes increasingly more complex when multiple objects are at an odd angle, other objects obscure their view, and it needs to approach it at a novel angle. Machine learning programmes can help the robot to see the wood for the trees. “With today’s computing power, you can provide many computations of how that object might look in different scenarios and the robot can “learn” that, almost instantly, where it has learned that it can pass it on immediately to any other device in the network,” says Robotics Applications Engineer at KUKA Robotics UK, Julian Dixon-Smith. “A human might take many years to acquire and pass this on as a skill, but robots can do this quicker – within certain limitations.”





APPLICATIONS I

Applications of KUKA's LBR iiwa in UK industry

The automotive industry
After universities and research centres, automotive OEM and tier one suppliers are the primary market for cobots in the UK.

Here's a selection of car manufacturers using cobots in Britain:

BMW case study
Application: Riveting on a jig
The BMW MINI plant in Oxford is using a KUKA LBR iiwa cobot in production. Previously, an operator was loading rivets and riveting by hand. Now the operator loads one side of the jig while the robot does the riveting on the opposite side, speeding up the job and improving ergonomics. With higher sensitivity technology, the operation is safe, and if the rivet is not in the right place the iiwa will carry out a search operation, in a spiral shape. The gun will locate the rivet and then continue.

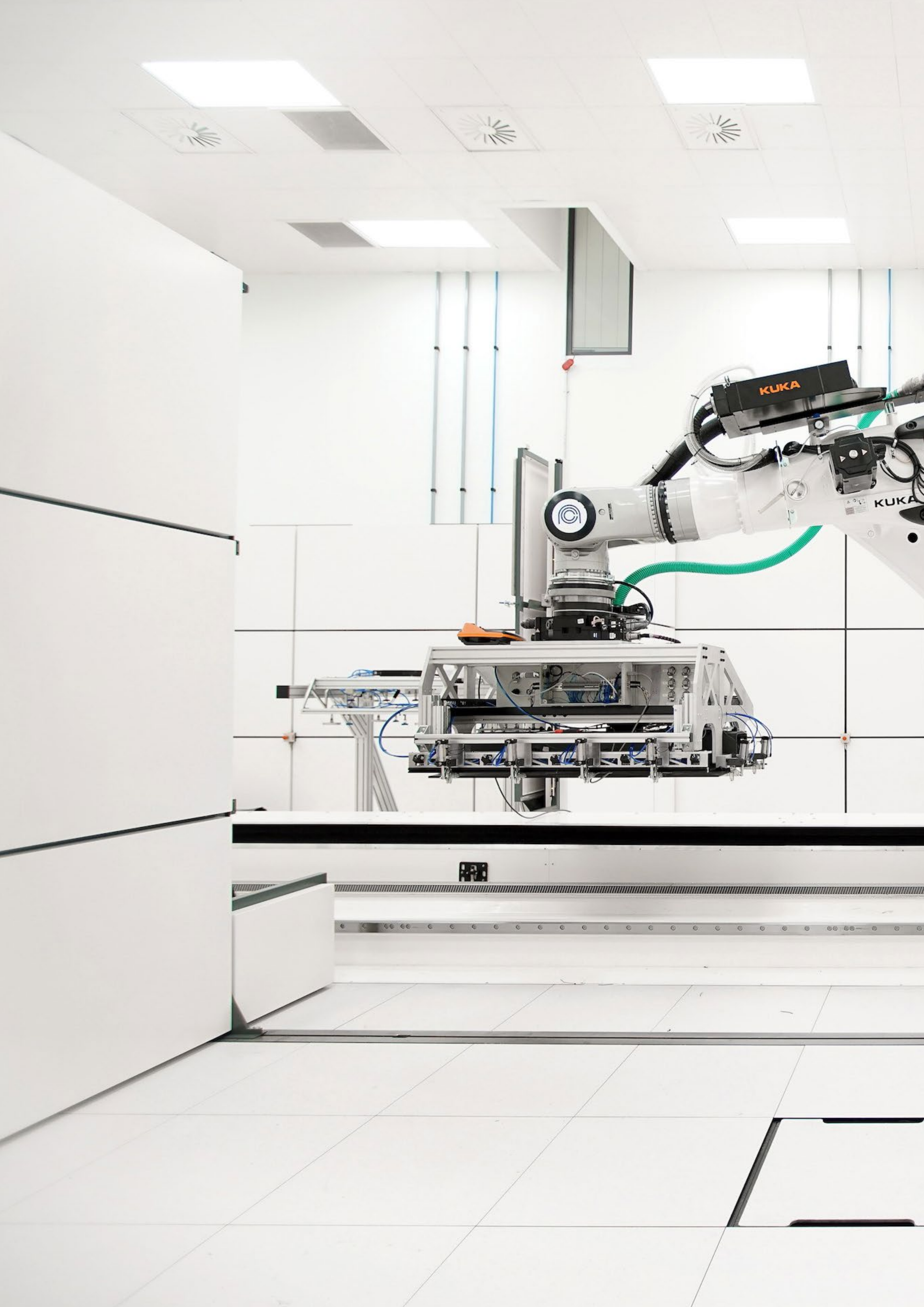
Objectives
The main objectives were to increase productivity, improve repeatability, and liberate a worker from a low value repetitive task to perform a higher value task. The cobot increases repeatability and quality, because it performs the same operation up to 1000+ times per day. This removes strain from the operator who no longer endures the kick-back of the rivet gun for up to eight-hours a day.

More applications where cobots could support humans include pick and place, particularly with heavy loads and other fixing applications like riveting where a heavy tool is involved.

Nissan
The Sunderland factory had several tasks for more than one person, but not enough to justify two people. "If they can eliminate just some of this work it becomes just a one-person job, instead of a second person being active only 20% of the time. If the robot can pick that part up or assemble that part, the second person can now do a different task," says Dixon-Smith. Nissan is researching several different cobot applications.

Tier one suppliers including ZF Lemforder and Federal Mogul are also working with KUKA to identify potential HRC applications.

Workplace health, especially for reducing repetitive strain in assembly, is also a key benefit of cobot use. "Companies using this technology can limit injury," says Dixon-Smith of KUKA. "Our discussions with organisations including the Health & Safety Executive shows manufacturers receive a lot of claims for repetitive strain injuries, so using a cobot for such manual tasks should reduce this."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APPLICATIONS II

For iiwa – non-automotive

Retail sector
KUKA UK's first iiwa customer was an online supermarket to pick grocery orders automatically. Other retailers are also using robots for warehousing solutions, some installed by KUKA partner Swisslog.

These often cube-like robots do not resemble typical cobots, but they are designed to work in both an autonomous and human-present environment to assist workers by preparing very high volumes of orders for delivery.

"Some supermarket warehouses have an urgent need to improve picking speed and accuracy, and I certainly see robotic systems like this becoming a standard method of operating these warehouses," says KUKA's Julian Dixon-Smith.

There are also a growing number of medical applications for cobots, including surgical assistance and remedial massage.

Machining and trimming applications

Trimming, cutting and finishing

CNC Robotics is a well-established industry leader for machining with robots.
CNC Robotics design, integrate and install bespoke turn-key systems that provide businesses with a cost effective automated machining solution.

With a wealth of experience in the robotic integration industry, CNC Robotics provide automated solutions to a wide range of industries, ranging from Plastics and Composites to Architectural and Theatre Prop Makers.

Robots can be used for a variety of different applications and increase productivity, accuracy, and prevent human exposure to unpleasant or laborious working conditions.

'There is often a misconception that robots replace people', said Madina Barker, CNC Robotics. 'Robots increase accuracy and productivity, but resources are still required to program, feed and maintain the system. Robots therefore upskill the current workforce and provide safer and more pleasant working conditions'.

Founder of CNC Robotics, Jason Barker previously owned a set building company and during his search for a low cost CNC Machining solution recognised the potential of using robots as milling machines. CNC Robotics was created to provide a cost effective solution for companies looking for a flexible tool that could be integrated into a companies production processes.

Hybrid manufacturing: Add and subtract

Robots are being used to both deposit material additively and cut metal away. "We are seeing opportunities for our software to run both additive and subtractive machining combined," says Autodesk's Robin Smith.

Aerospace works on a **fly-to-buy ratio**, based on how much of what is purchased is used in the aircraft. "The F2B ratio is generally very low. With the hybrid manufacturing method, you can put a lot more of what you make on an aircraft and there is less waste," says Autodesk's Robin Smith.

Another application is when high value parts are required at short notice and expensive fixturing to build a part is not available, as being used at the Port of Rotterdam Authority's RAMLAB (see page 12).

SOFTWARE

Software development is key to collaborative robot applications. Programming is moving from “command code” to simulation and in the future, artificial intelligence that will enable task learning.

There are three levels of software for robot programming.

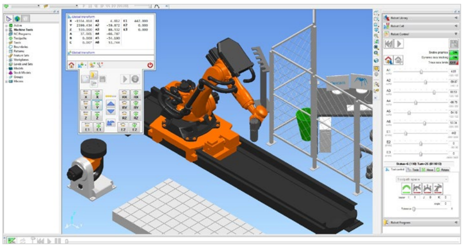
Industrial grade robot programming software that is dedicated to offline programming of robots and often uses a digital representation of a robot cell. “The operator programmes what he/she wants the robot to do then simulates it to ensure there are no collisions, it is safe, there are no singularities, no access limits,” says Autodesk’s Charles Jones. “When he is happy you create the code that can drive the robot.”

There are several levels and the software can control up to 18 axes simultaneously. “We have a solution that can take an industrial robot and treat it just like a complex machine tool to machine complex shapes,” says Robin Smith.

At the mid-level – software is more experimental and is often used by the research institutions such as the Catapult centres.

This software experiments with digital fabrication and computational business information modelling. A product is taken from the design environment and straight to manufacture using a robot. The test cell is connected to sensors, monitors, peripheral equipment and often does not have the robustness of an industry grade application, because researchers want to change parameters quickly.

Future stage – software that uses machine learning algorithms so robots can change their operation to adapt to the changing task, without resetting. The learning could involve risk assessment. In this paradigm, “if there is a robot human collision the robot calculates what the force applied to the human would be and ensures it is within TS/ISO15066, the technical specification that defines how hard a body can be hit,” says Dixon-Smith.



CASE STUDY

Novel uses of robots in industry

Parts on demand: Port of Rotterdam RAMLAB with Autodesk

Shipping companies lose millions of dollars when ships are stuck in port awaiting repairs.

The Port of Rotterdam’s Additive Manufacturing Fieldlab (RAMLAB) and Autodesk are pioneering the use of additive and hybrid manufacturing in the maritime industry. Ship’s propellers being made using a hybrid manufacturing process combining wire and arc additive manufacturing using industrial robotic arms and subtractive machining and grinding techniques.

Autodesk says “We can additively build parts on demand with freedom of form and minimal waste, building the parts such as broken propellers beyond their required size and using CNC machining to reach tight tolerances.”

For more information see: http://blogs.autodesk.com/inthefold/port-of-rotterdam/

HRC AND THE FUTURE OF MANUFACTURING

Further adaptive programming
Autodesk is investigating platform-based utilities where different functionalities are plumbed in, connected with sensors and peripheral equipment, to make it more where programming and operating a robot becomes a completely different experience to the normal offline programming, press and go.

"Here you have real-time updating of the code that is operating the robot – monitoring its environment and what it is doing, responding to the actions it was doing beforehand to make sure it is still achieving its objectives," says Charles Jones. An example of this is Autodesk's P&I lab that is 3D printing adaptively with robots.

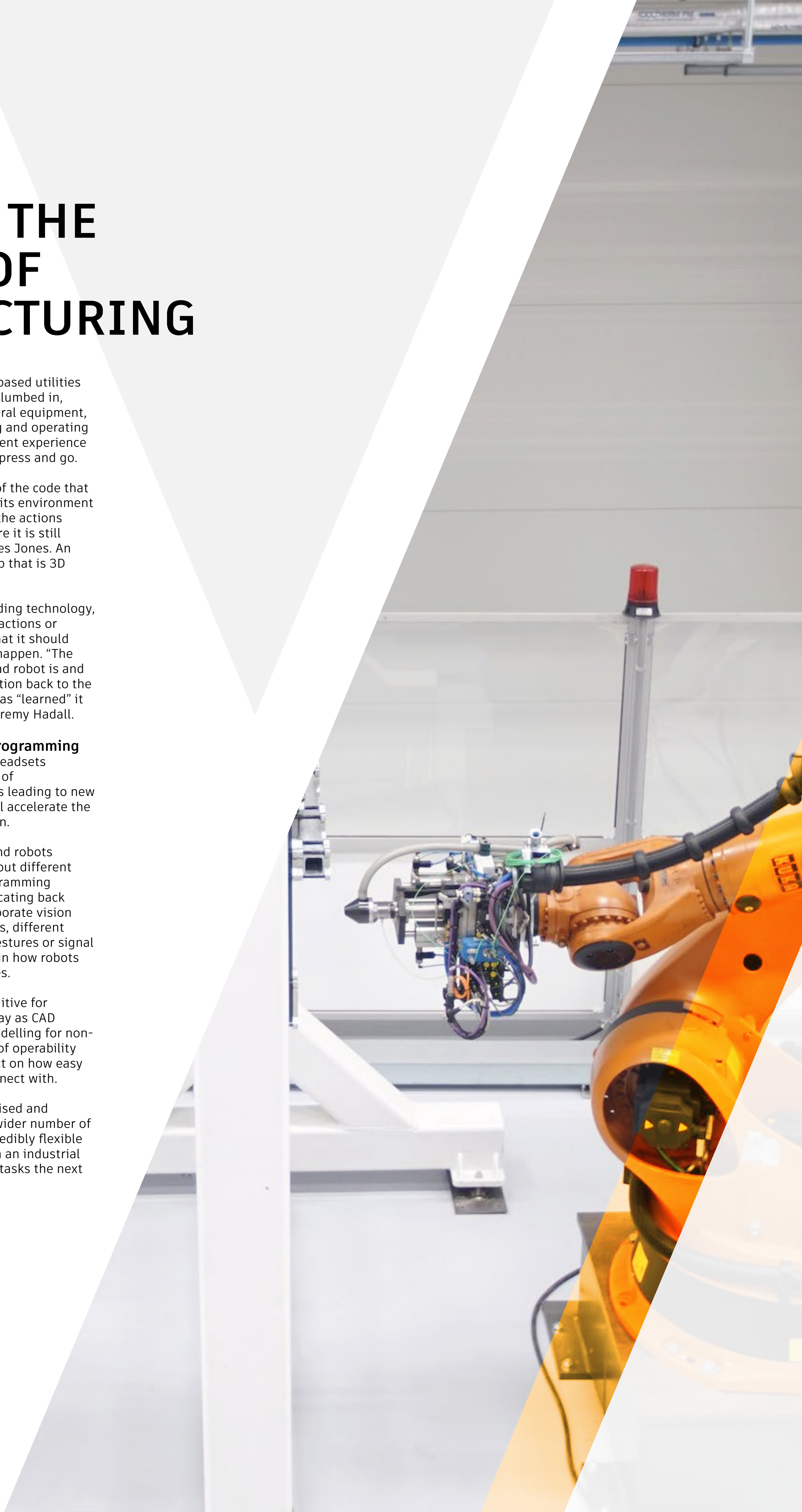
The MTC is using tracking and recording technology, and artificial intelligence to predict actions or interactions, informing the robot what it should be doing at certain times as things happen. "The system tracks where the operator and robot is and what they're doing, feeding information back to the robot. Based on the interactions it has "learned" it would respond accordingly," says Jeremy Hadall.

Augmented reality and novel programming
The use of augmented reality (AR) headsets provides a completely different way of communicating with robots, which is leading to new ways of programming robots. AR will accelerate the speed of robot movement adaptation.

HRC is not just about the humans and robots working together safely but also about different ways of humans talking to and programming robots, and talking to and communicating back to humans. "When we start to incorporate vision systems, speech recognition systems, different ways of programming using hand gestures or signal based methods, you will see a shift in how robots are programmed," says Charles Jones.

Programming will become more intuitive for non-engineers, in much the same way as CAD developers developed parametic modelling for non-engineers to design products. Ease of operability and standardisation has a big impact on how easy or difficult new technology is to connect with.

Robots will become more commoditised and democritized, more accessible to a wider number of people. "Robots will by them be incredibly flexible devices. One day they could perform an industrial job and then more service-oriented tasks the next day," says KUKA's Dixon-Smith.



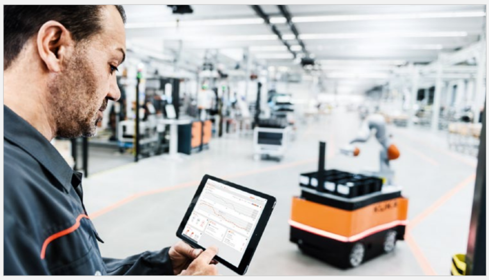
We hope you have found this white paper useful.

Please get in touch with Autodesk and KUKA Robotics if you wish to discuss any part of this report further.

Coming Up Next.....

The third Autodesk and KUKA Robotics paper on Deciphering Industry 4.0 will investigate:

SMART LOGISTICS & MASS CUSTOMIZATION



As throughput increases, companies that make products need to move them more efficiently or bottlenecks are created. New and often ingenious hardware is being developed to autonomously move product and material within a factory or warehouse, and deliver it to the customer. Robots and AVs (automated vehicles) remove labour, keeping deliveries in sync while new, affordable tracking technology tells the customer of the consignment's location.

4IR technology is also enabling manufacturers to achieve the "batch of one", where products that are similar but personalised by a customer can be manufactured in a production line in the same way that identical products are made. This has become essential to companies that make luxury goods like cars and yachts, but increasingly more commodity items such as trainers, spectacles frames and toys.

Reference links

- **3D printing with Autodesk**
  Port of Rotterdam's RAMLAB and Autodesk
  http://blogs.autodesk.com/inthefold/port-of-rotterdam/
- **KUKA LBR iiwa "cobot"**
  https://www.kuka.com/en-gb/products/robotics-systems/industrial-robots/lbr-iiwa
- **Nationwide programme of AI and manufacturing research including extreme environments**
  http://www.lboro.ac.uk/media-centre/press-releases/2017/february/extreme-environment-robotics.html
- **EPSRC Centre for Innovative Manufacturing in Intelligent Automation**
  http://www.intelligent-automation.org.uk/
- **CNC Robotics**
  http://www.cncrobotics.co.uk/

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