Integrated Manufacturing Group

Industrial challenges in robotic accuracy and performance assessment

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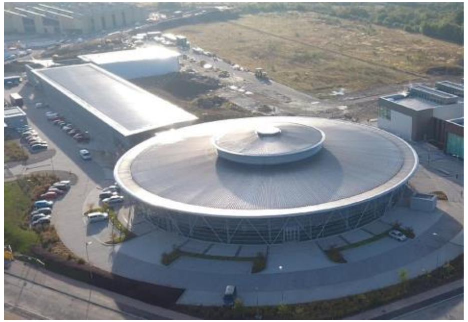
What is the University of Sheffield Advanced Manufacturing Research Centre?



- Established in 2001 as a collaboration between the University of Sheffield and Boeing.
- We work with companies of all sizes – including SMEs, start-ups and large-scale manufacturers – to help them improve their productivity and save time, money and energy.
- Expertise in automation and robotics, additive manufacturing, castings, composites, design and prototyping, digital manufacturing, structural and materials testing, manufacturing intelligence, subtractive manufacturing, training and skills.
- The AMRC is a core part of the High Value Manufacturing (HVM) Catapult, a group of leading manufacturing research centres backed by the UK’s innovation agency, Innovate UK.

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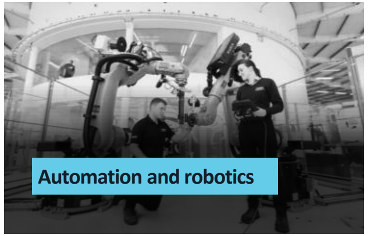

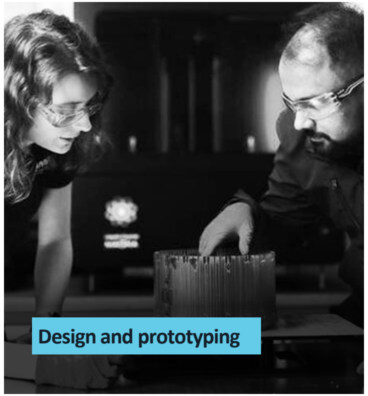

Capabilities

Our research is organised into a number of key capabilities.

Our capabilities span our sites in Rotherham, Sheffield, Broughton and Preston.

Applications and challenges

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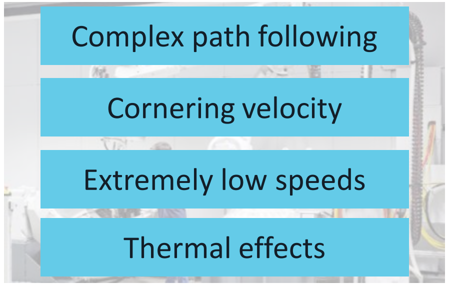
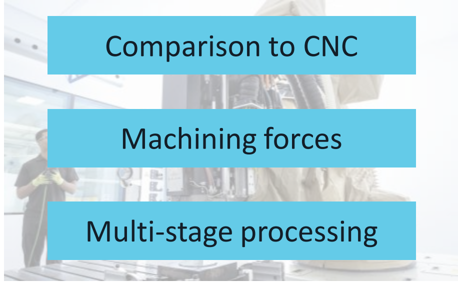
Applications

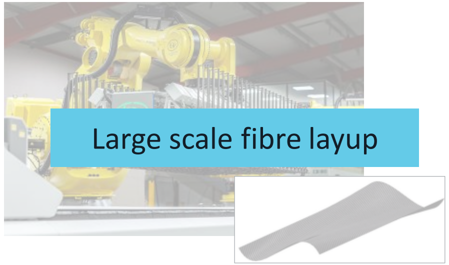
Some of the applications that we see from partners that would benefit from improved accuracy/performance evaluation methods:



Additive manufacturing



Large scale machining



Composites fabrication

(Determinate) Assembly

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Current challenges

What are the issues that we face in measuring robot performance today?

Limitations of the standard

- No standardised method to measure robot base frame
- Current standards do not take into account range of applications
  - Performance of robot can be extremely different depending on end effector mass, reaction forces, types of motion, etc.
  - Standards do not reflect methods used for 'traditional' equipment (eg CNC machines)

Technological limitations

- We're getting to the limits of laser tracker resolution/accuracy (especially robots with secondary encoders)
- Environment is key to getting a good measurement

Workforce limitations

- Workers skilled in this area are not easy to come by

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Current processes

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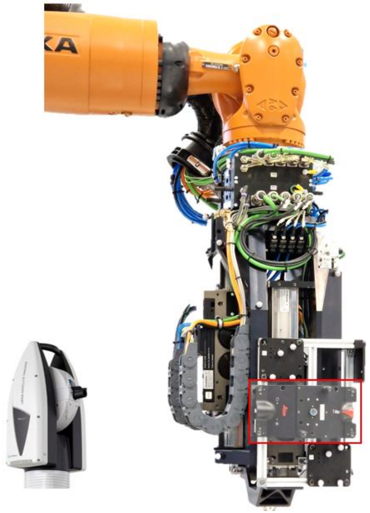
What are we (AMRC) doing currently?

A typical setup for robot measurement/accuracy assessment at the AMRC might include:

- Laser trackers (Leica AT960 or ATS600) with SMR for gauging basic repeatability and positional accuracy
  - Bolstered with TMAC for 6DoF measurements
  - A USMN might be set up in a cell that requires repeated measurement over time, or measurements from different positions
- Often customers only interested in certain aspects of performance (i.e. we'd rarely undertake the full suite of measurements outlined in ISO 9283)
  - Yet we regularly have to deviate from the processes in the standards to meet customer requests due to application requirements.
- Infer the robot base frame by measuring motions of robot during motions of joint 1 and 2



Leica AT960 laser tracker and drilling end effector with mounted T-Mac (highlighted)

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Our research

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Local correction using laser displacement

Robotic cleaning and sealing platform for AIRBUS

- Mounted on AGV (to act as rail) to allow continuous motion during cleaning and sealing operation along wing spar
- AGV only accurate to ~40 mm in path following
- Laser displacement sensors used to provide dynamic corrections to robot TCP to compensate

Robotic ‘Clean and seal’ platform

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Laser tracker

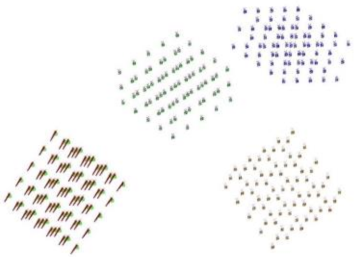
Local corrections for drilling

- Utilised laser tracker to characterise the error of robotic drilling platform in a number of locations around the working volume
- Able to reduce average hole error from **1.9 mm** to **0.47 mm** based on tracker measurements alone

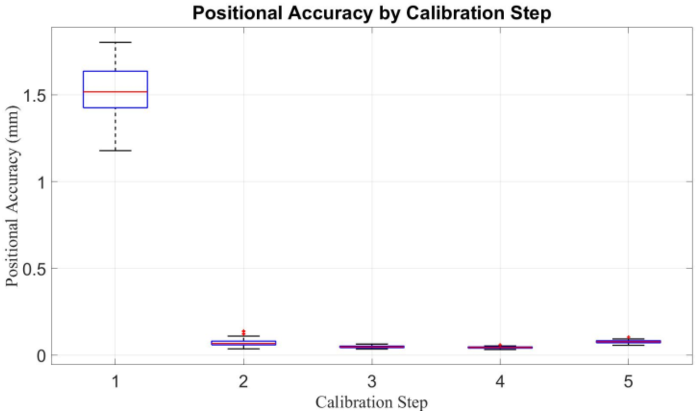
Large scale iterative approach for positioning

- Utilised laser tracker to measure error of robotic drilling platform in across grid of points throughout working volume
- Error corrections were applied at each point and remeasured.
- The maximum error was reduced from over **1.8 mm** with no calibration to **0.058 mm** after three iterations

VIEWS robotic drilling platform



Coupon measurement grids



Iterative error reduction process

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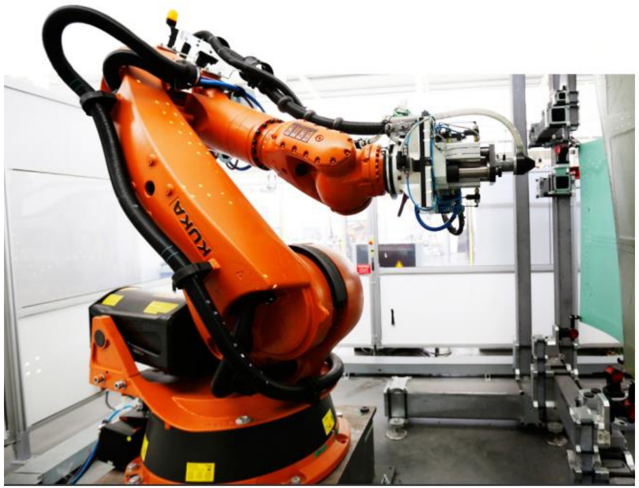
Machine vision

Robotic countersinking platform for BAE Systems

- Utilised machine vision to locate pre-drilled holes in composite components
- Corrections provided by the machine vision system allowed countersinking operation to be conducted to high tolerance



Robotic counter-sinking platform

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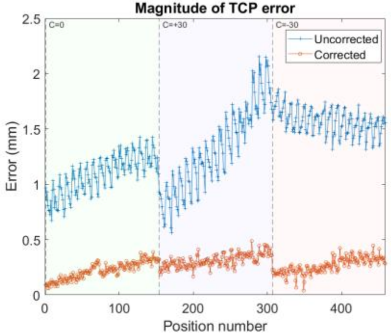
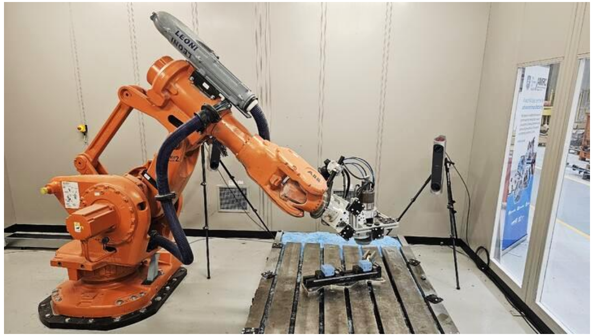
Machine learning (drilling and milling)

- Trained model on TCP position of a robotic drilling platform measured with a laser tracker across the volume of the cell.
- Were able to improve RMS error from a magnitude of **1.36 mm** down to **0.28 mm**



VIEWS robotic drilling platform with graph showing ML error reduction

- Used INSPHERE’s IONA photogrammetry system to measure positional error of a robotic milling platform during milling operations
- Model was able to predict the in-process error of the platform to within **0.3 mm** whilst machining circle, diamond square test blocks



Robotic milling platform with IONA photogrammetry system

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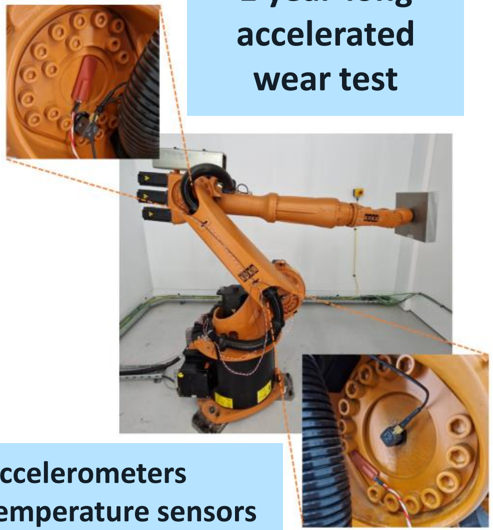
Health monitoring

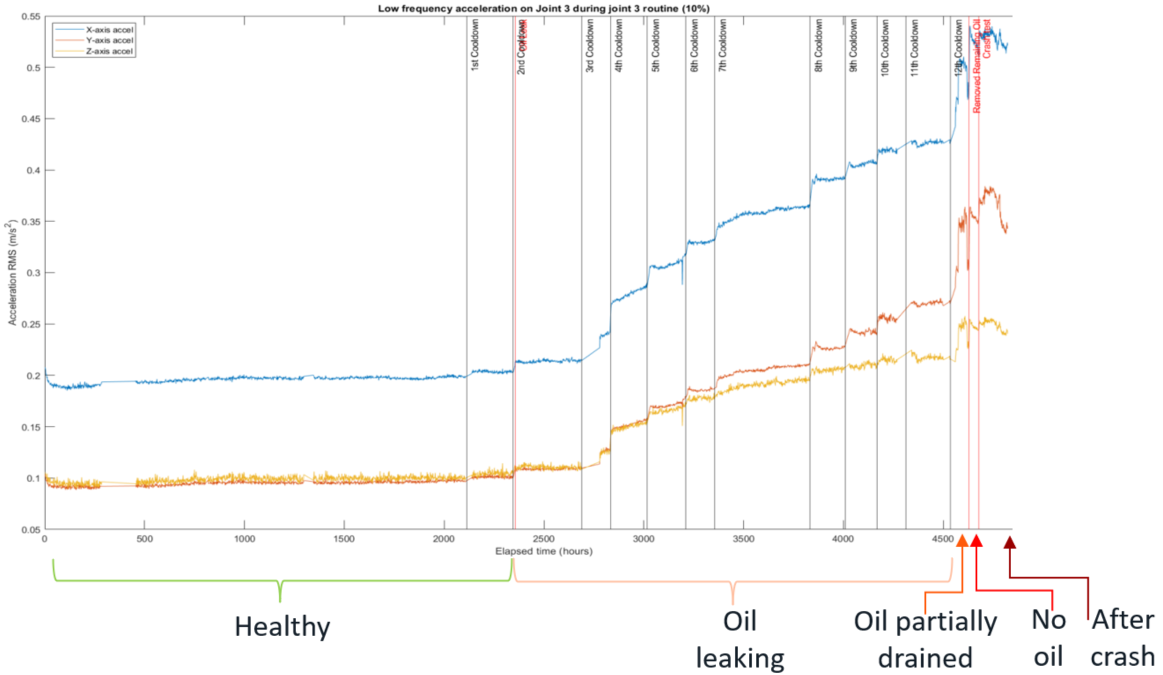
Using process monitoring to detect changes in performance

1 year-long accelerated wear test



Accelerometers
Temperature sensors
Current clamps

Sensor setup for accelerated wear test



Example of signal variation across ~6 months

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Future work

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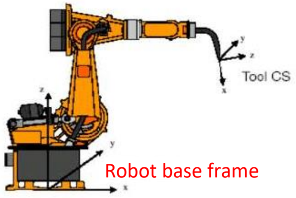
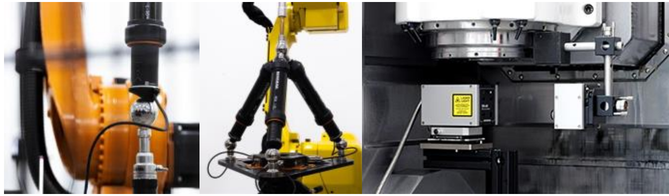
What would we like to see?

Clearer and more comprehensive guidance from standards:

- Standard method for **robot base frame measurement**



- Guidance on the **metrology equipment** to be utilised
    - Including use of things such as ballbars and laser calibration devices where higher accuracy applications are necessary



Single and triple ballbar systems, and multi-axis laser calibrator (Renishaw)

- **Wider range of tests** pertinent to the vast range of applications robotic platforms are now employed within
    - Stiffness testing, thermal effects, wider range of velocities, CDS test piece, etc

Correlation of **process monitoring** data to accuracy/performance

- Can in-process data be used to infer if the robot is still in spec?

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Opportunities at the AMRC

Wide-ranging fleet of robotic platforms aimed at mirroring industry

- KUKA, ABB, FANUC, etc
- Specific (ARMS, VIEWS, VARCITY) and general purpose platforms

Metrology suite

- Laser trackers, TMAC, T-probes, laser scanners
- Robot-mounted probes, triple ballbar system, and shortly multi-axis laser calibrator

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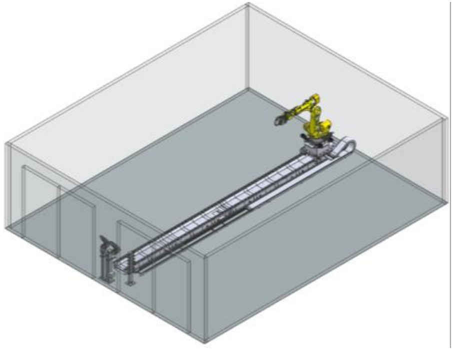
COMPASS [under construction]

Our brand new £80m facility for large scale composite components manufacture will comprise of:

- 5 large industrial robots on rails for the handling of composite materials
    - Including 3 x FANUC M2000iA – 1700L
- 1 robotic machining cell for trimming of finished composite components
- …as well as a cutting tables, oven, and press

This is going to be an open access facility, with unprecedented amount of data being collected from each piece of equipment.

COMPASS high volume deposition cell render



Robotic machining cell

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Thank you.

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