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Capturing craft expertise in an AI system for future autonomous precision surface manufacturing

Project team

University of Huddersfield




David Walker
Ultra-precision Surfaces

Andrew Longstaff
AI for Manufacturing

Wenchang Pan
Stability and System dynamics

Simon Parkinson
Informatics and Manufacturing




Kyle Wilson
Psychology

Gouyu Yu
CNC Polishing and Metrology

Hongyu Li
CNC Polishing and Metrology

Sanja Petrovic
Operational Research
University of Nottingham

Industry partners

ZEEKO Ltd

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Contact

David Walker
University of Huddersfield

d.d.walker@hud.ac.uk

The project is the first to explore the feasibility of capturing craft expertise, concerned with the manufacture of precision and ultra-precision surfaces, within an Artificial Intelligence system. Development of an AI autonomous manufacturing cell is our longer-term aim.

Manufacture of ultra-precision surfaces

The context of the investigation is the manufacture of precision and ultra-precision surfaces, for products such as lenses and mirrors, semiconductors, turbine blades, moulds and dies and prosthetic joint and cranial implants, which are in increasing demand, and subject to ever more stringent specifications. These products are required by many high-value manufacturing sectors, including aerospace and automotive, consumer products, healthcare, defence and space.

Manufacture of precision surfaces is challenging for a number of reasons: the diversity of materials, the need to work to nanometres of precision and the unpredictable nature of available processes at the high precision end. There are three main steps in ultra-precision processing: these are CNC grinding, pre-polishing and corrective polishing. Currently, even modern Computer Numerically Controlled (CNC) machines require the expertise of skilled people to operate them: to design an appropriate process-sequence for a particular design of part, to review intermediate

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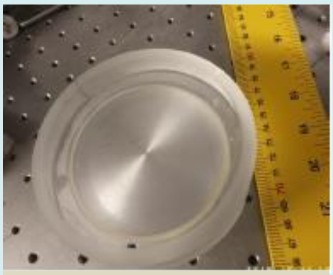
measurement data and take appropriate actions and, at the end, to decide when to stop. These people are now retiring, along with their invaluable knowledge and skills.

To find ways to store human practical knowledge and skills in such a way that they can be re-used in an AI system and, thereby, be automated, is no mean feat. ‘Hard’ knowledge, such as tool paths and speeds, can be captured digitally. This is already possible. This information, however, has to be integrated with ‘soft’ knowledge, such as choices of additives, tools and polishing pads, what to do when some particular defect arises on the surface, and to decide when the surface is good enough and work can stop.

How can we capture the expertise of skilled craftspeople?

It is necessary to find a way to make explicit the polishing machinists’ knowledge and then to represent this knowledge in such a way that it can be made use of in an AI system. The aim is to replicate, through case-based reasoning, the machinists’ decisions, including judging when the surface is considered good enough. The AI software developed must be capable of deciding, for the particular part presented, which tool should be selected and for how long it is to be used.



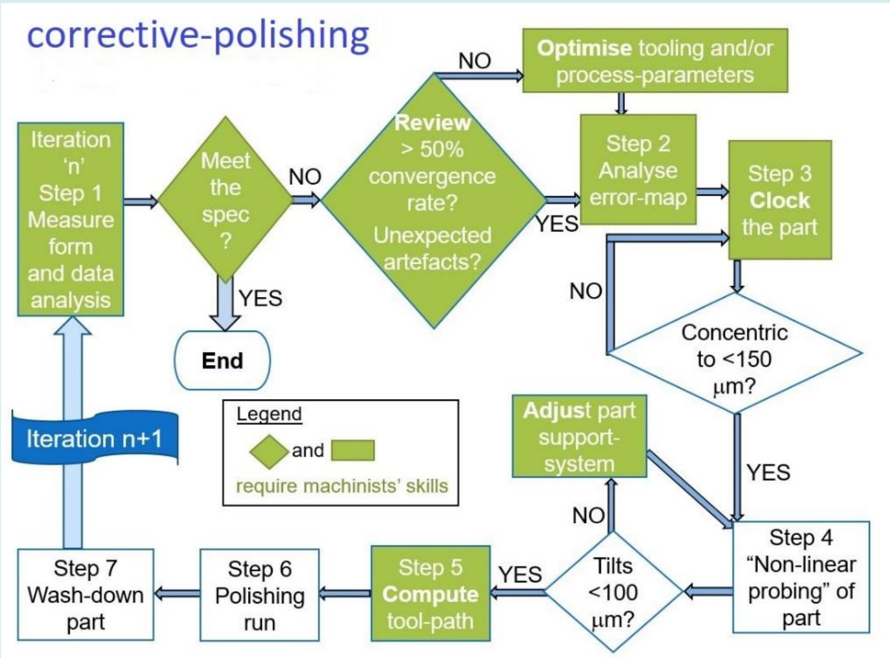
The machinists polished a piece of glass of a particular specification:

Diameter : 110 mm
Radius of curvature: 269mm
Material: BK7 material
Shape: Concave spherical

A manufacturing task was developed. Three CNC machinists completed the task of polishing a piece of glass. While doing so, they were asked to ‘think aloud’. This process was recorded and observed.

Everything was logged: the process operations and decisions, the machine set-up parameters, QR codes of deployed tools and equipment, and how much time was spent on each aspect.

Next, flow charts were constructed from the information gathered, to show the series of process steps worked through by each of the machinists. The flow chart for the corrective polishing stage is shown here. The steps most reliant on the machinists’ knowledge were identified. Each of these steps was assigned a Case Based Reasoning (CBR) system. CBR enables the re-use of information from the past, to be applied to a new task.



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Key finding 1

We can capture knowledge as ‘Cases’, in such a way that it can be re-used in an AI system designed to underpin autonomous manufacturing.

Key finding 2

The similarity measures often used in Case Based Reasoning systems are too simple to be used in the system we designed. A more sophisticated taxonomy of ultra-precision surface manufacturing knowledge is required to guide the selection of which case to apply.

Wider benefits

The results are applicable wherever crafts expertise is important to achieving optimum results and there is also a shortage of skills, even more so, in cases where automation can reduce costs and delivery times. Potential areas range from gastronomy to robotic surgery.

This study proved invaluable in providing first insights into some of the decisions that machinists make and the reasons underlying their choices. It was also very useful in identifying, and overcoming, some commonly experienced difficulties in eliciting knowledge from expert craftspeople who are often not so keen to share their knowledge. Crucial ethical questions are raised: who owns captured data and the inferred relationships? Who has the rights of access and rights of use?

What next?

Given the problematic nature of eliciting knowledge from skilled craftspeople, we suggest that direct elicitation of knowledge is reserved for specialist information, which can’t be captured through digital data logging alone. Where practical, automated digital data-logging of process-variables should be implemented. This should include QR code identification of each fixture or tool. The machinists’ selections can be automatically logged or entered manually. The direct elicitation of knowledge will focus on the logic underlying machinist’s decisions, tricks of the trade and strategies for recovering from unexpected process-errors. One practical scenario in an industrial context, would be for digitally-recorded operator-decision (e.g. select tool X, head-speed Y and so on…) to prompt questions as to the logic underlying a decision, which the machinist would answer verbally before the next step could be executed.

We plan to implement comprehensive pre/post run and in-process monitoring to create a new data-set with the aim of defining new Cases and identifying new relationships.

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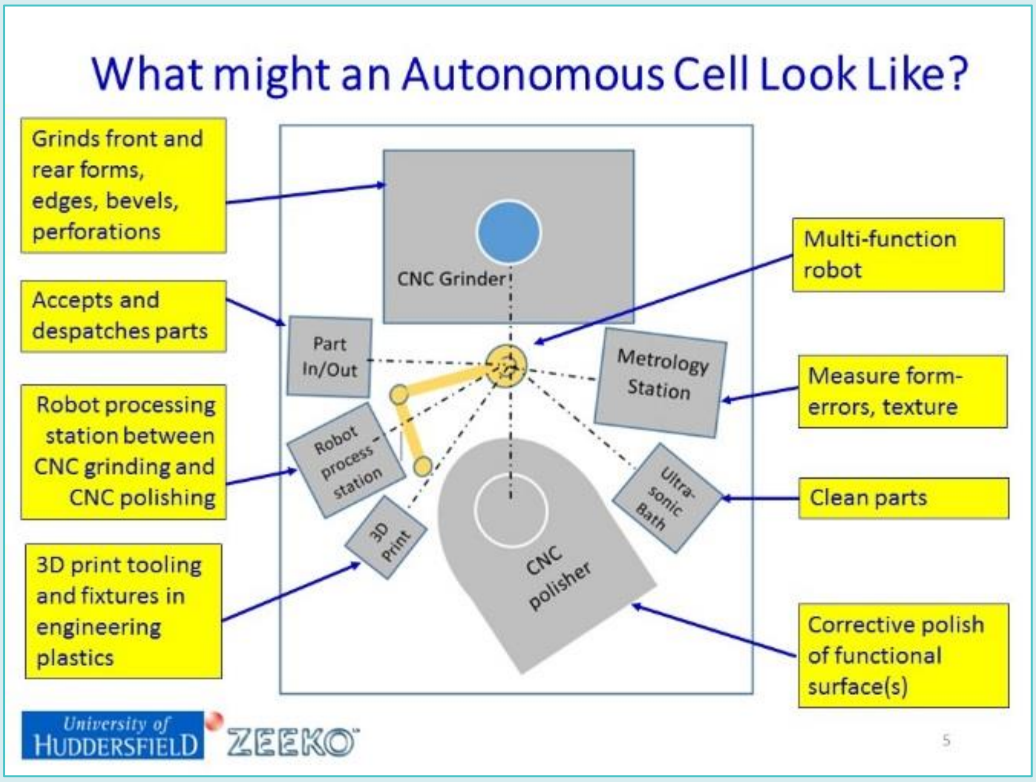
First steps towards the creation of an adaptive autonomous manufacturing cell

Imagine a machine capable of producing, from start to finish, a range of products. At the touch of a button the machine begins its work and ‘ping’ a prosthetic knee joint or finished lens is made. This is the ultimate vision towards which this study is contributing.



Initial stages in realising this vision have already been completed successfully. A robot has been implemented working with a CNC machine for precision surface manufacturing. Its task is to load and unload parts on the machine, wash and dry the parts after processing and place them on a separate station for measurement.

The next step forward is to incorporate the “brain” of the system, to make the complex decisions along the way – Artificial Intelligence.

An Autonomous Manufacturing Cell will be able to diagnose failures, avoid repeated mistakes and self-improve through data-mining. It will have multiple process applications and would thereby deliver a landmark step-change in the UK’s ability to supply goods and services to the global high-value manufacturing sector.

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