Session overview

10:00 - 10:30	State-of-the-art review - Jon Stammers, Advanced Manufacturing Research Centre
10:30 - 10:50	Gorka Kortaberria – IK4-Tekniker "Integrated volumetric error mapping solution for traceable on-machine tool measurement"
10:50 - 11:10	Tim Rooker – IDC Machining Science "Machining centre performance monitoring with calibrated artefact probing"
11:10 - 11:30	Liam Blunt – University of Huddersfield "In process surface metrology for roll to roll manufacture of printed electronic devices"
11:30 - 11:50	Florian Schwimmer – Alicona "In-line measurements with focus variation as enabler for an autonomous manufacturing cell"
11:50 - 12:20	Darek Ceglarek – University of Warwick "Closed-loop in-process quality improvement: 'Right-first-time' production through digital technologies"
12:20	**Lunch**

AMRC
ADVANCED MANUFACTURING RESEARCH CENTRE

The University Of Sheffield.

Integrated Metrology for Precision Manufacturing Conference

22 - 23 January 2019

Process Monitoring

Dr Jon Stammers

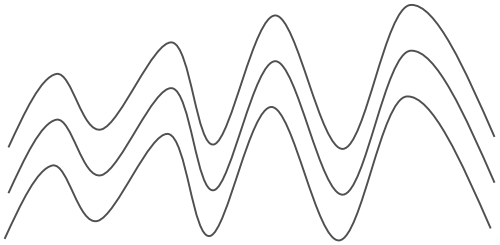
Technical Fellow, Process Monitoring and Control

Supported by the Regional Growth Fund

CATAPULT High Value Manufacturing

European Union
European Regional Development Fund

Process monitoring



Process monitoring

Program

Force

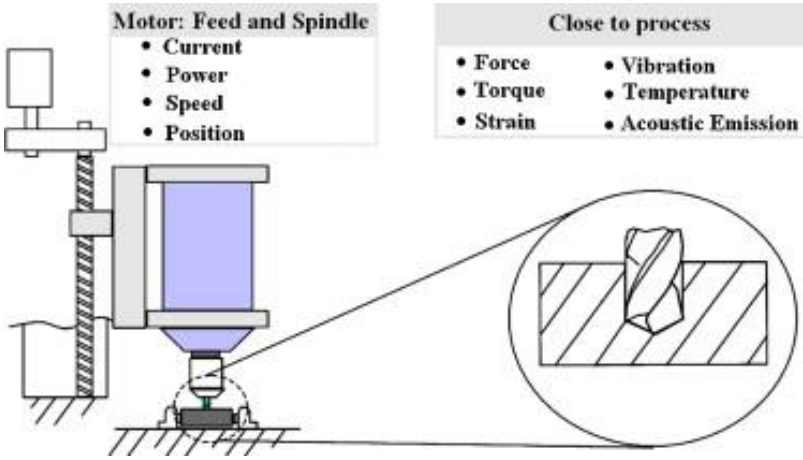
Sound

Geometry

Fluids

Temperature

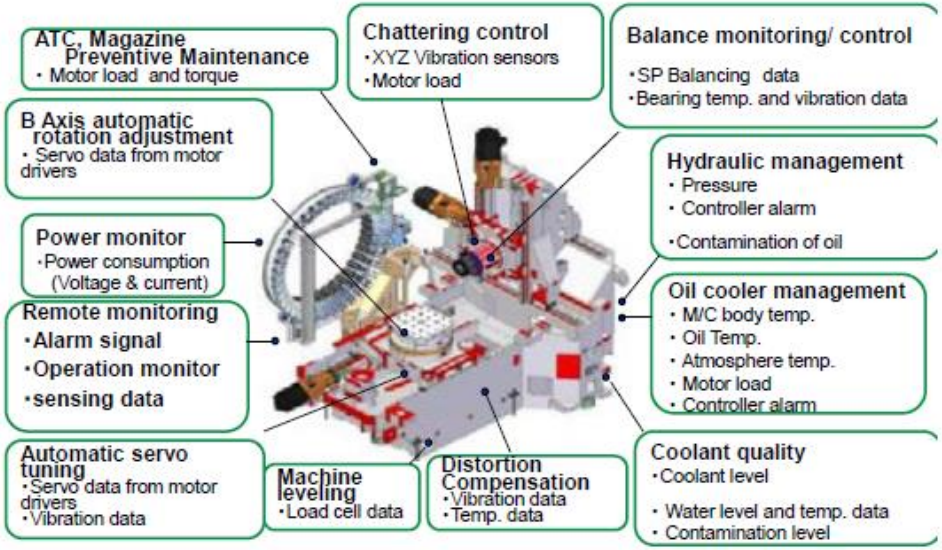
Vibration



Teti, R., Jemielniak, K., O'Donnell, G., & Dornfeld, D. (**2010**). CIRP Annals-Manufacturing Technology, 59(2), 717-739

Typical sensor fusion systems		
Sensors	Fusion methodology	Application
Current sensor, AE	BN	Tool wear diagnosis
Current sensor, accelerometer	BN	Tool wear diagnosis
	BN	Surface roughness prediction
Accelerometer, AE	NN	Tool wear diagnosis
Accelerometer, vision system	NN	Tool wear diagnosis
Dynamometer, AE	–	Tool breakage detection
	NN	Tool wear diagnosis
Dynamometer, AE,	NN	Surface roughness prediction
accelerometer	NN	Tool wear diagnosis
Dynamometer, accelerometer	NN	Tool wear diagnosis
	NN	Surface roughness prediction
	NN	Prediction of dimensional part accuracy
Dynamometer, thermistors	NN	Prediction of dimensional part accuracy
Dynamometer, accelerometer, spindle current, voltage sensor, sound pressure level	NN	Tool wear diagnosis

Abellan-Nebot, J. V., & Subirón, F. R. (**2010**) *The International Journal of Advanced Manufacturing Technology*, *47*(1-4), 237-257



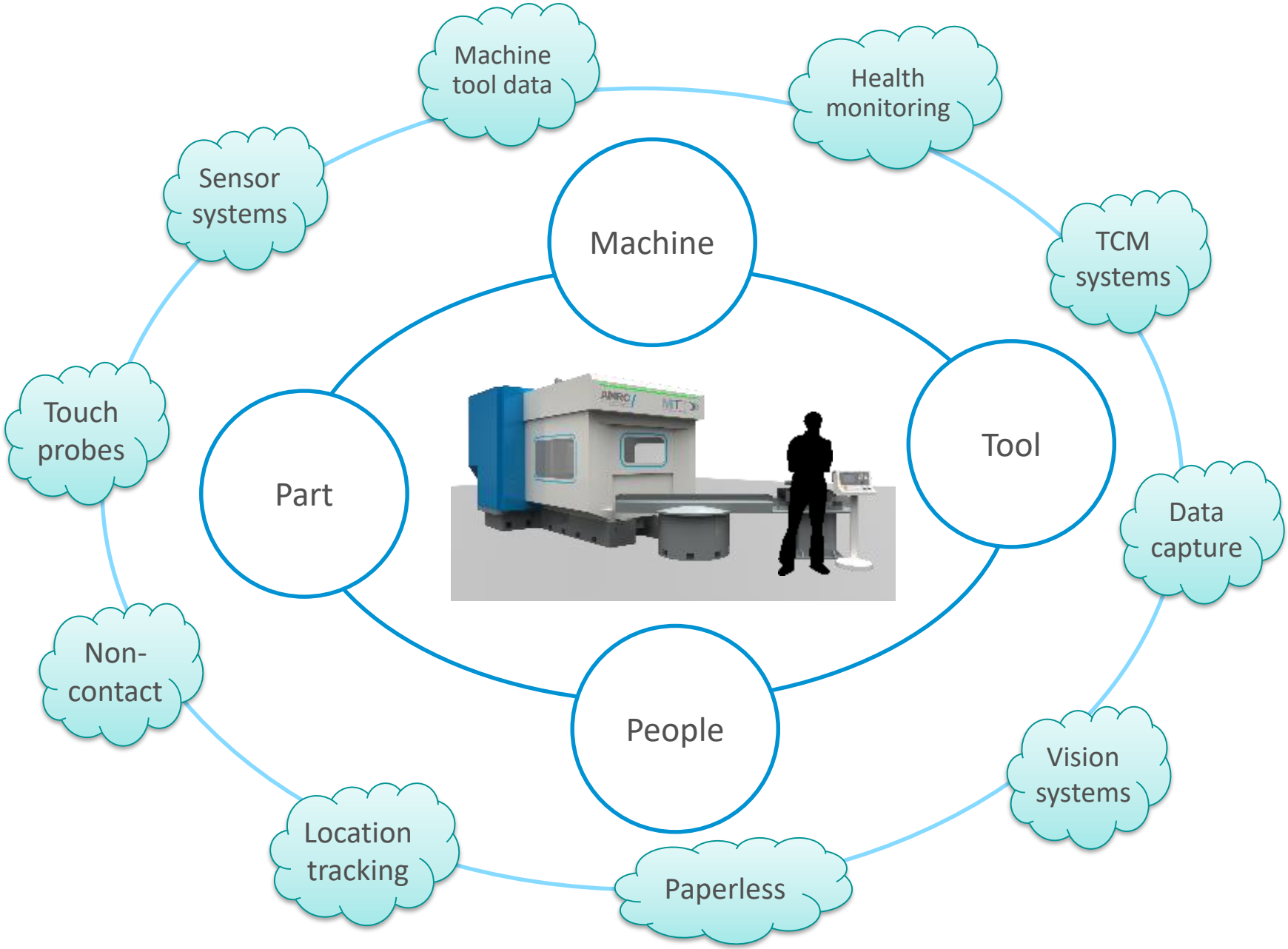
Fujishima M. et al. (**2017**) *24th Conference on Life Cycle Engineering*, Procedia CIRP 61, 796-799

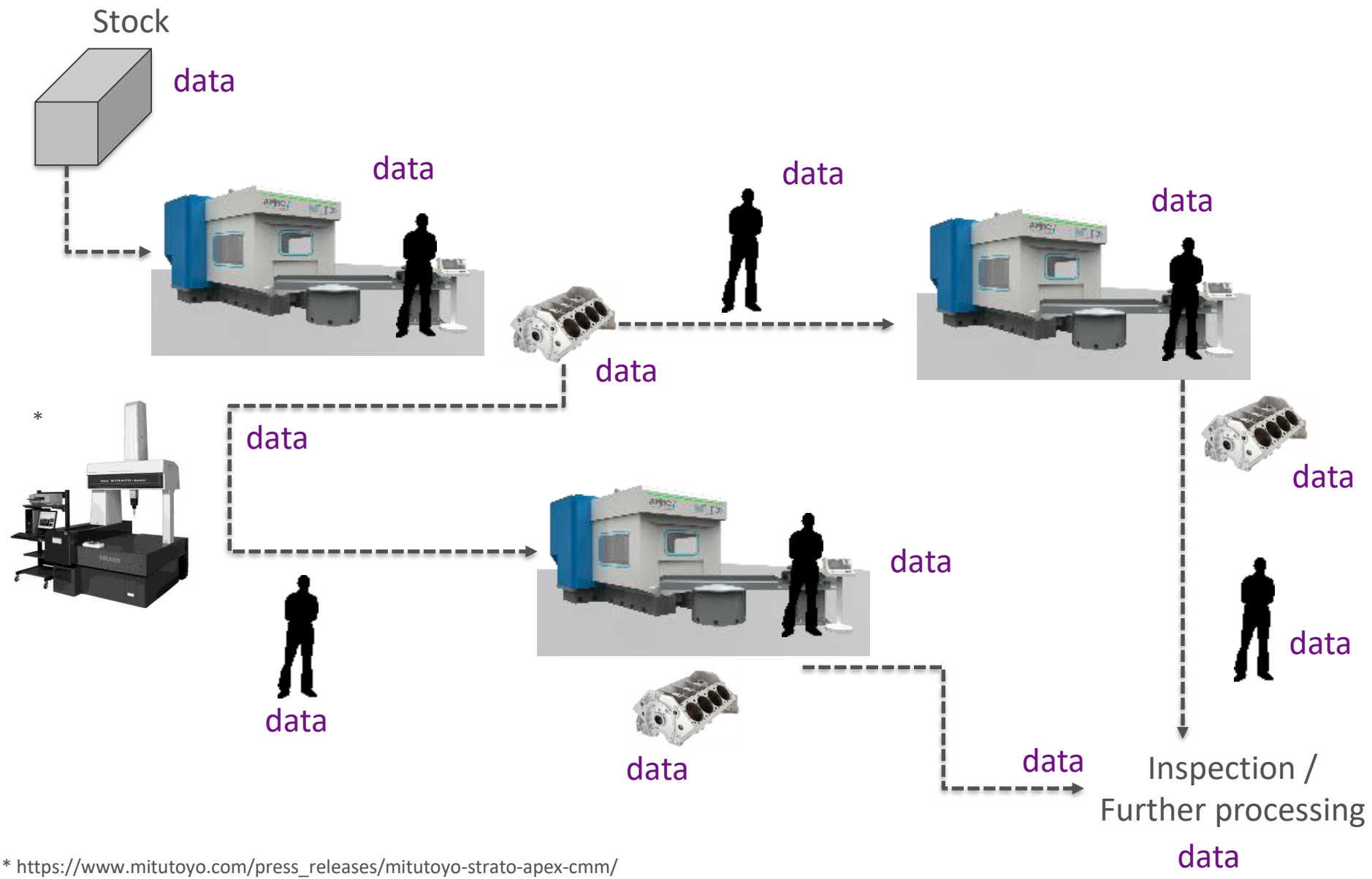
Industry

SIEMENS

Analyze MyCondition

CELOS BY DMG MORI





* https://www.mitutoyo.com/press_releases/mitutoyo-strato-apex-cmm/

Process Monitoring and Control at AMRC

Key themes

Machine Tools and Metrology

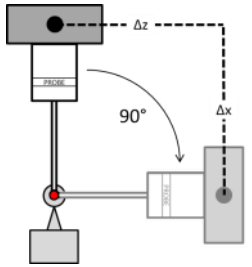
- In-process inspection
- Machine tool verification

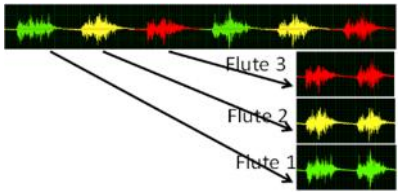
Manufacturing Informatics

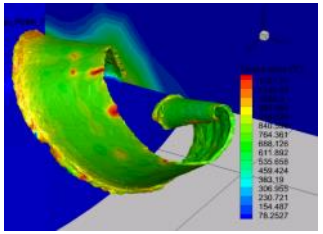
- Machine condition monitoring
- Tool condition monitoring
- Sensing and signal processing
- Instrumentation and connectivity
- Computational intelligence and uncertainty
- Machine tool servitisation

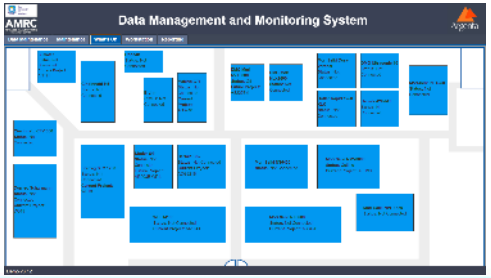
Digital Shop Floor

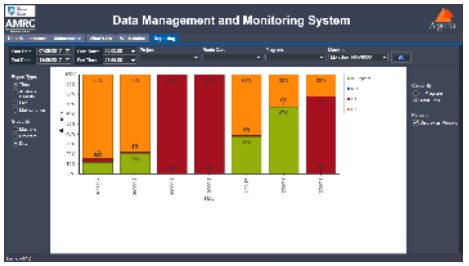
- Paperless shop floor
- Data gathering and presentation











Contents

- On-machine inspection
- Tool condition monitoring
- Machine health verification
- Process health
- Future thoughts

On-machine inspection

- inspection of a part or feature without removing the part from the machine tool

On-machine inspection

Manual gauges

Touch probes

Is this in the right place? How big is this thing? How good is it's surface?

Scanning probes

Roughness gauge probe

Blum TC63-RG roughness gauge

Optical scans

Vision systems

Tool condition monitoring

- continually verifying that the tool condition is within the bounds of the process

Tool condition monitoring

Use-case: Is my tool still OK? Has it worn beyond acceptable limits? Is it about to break or has it broken already?

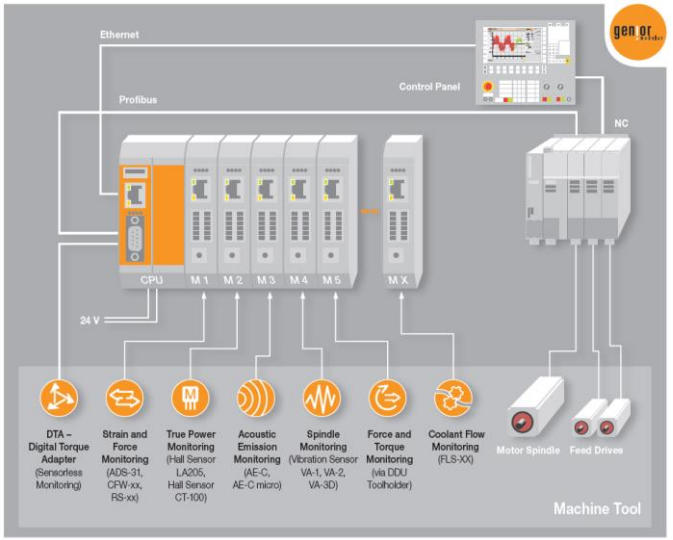
TCM systems

Advantages

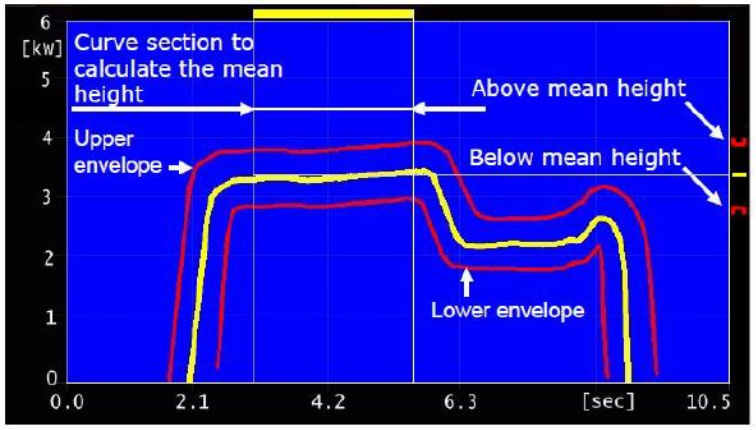
- Many commercial-ready systems available
- Can inform on process condition
- Auto stop of machine if tool breaks
- Machine health often covered

Disadvantages

- Add-on item – additional expense
- Learning time
- Tool wear not always covered



For example, the ARTIS Genior system



Nordmann SEM system screen grab

Tool condition monitoring

Use-case: Is my tool still OK? Has it worn beyond acceptable limits? Is it about to break or has it broken already?

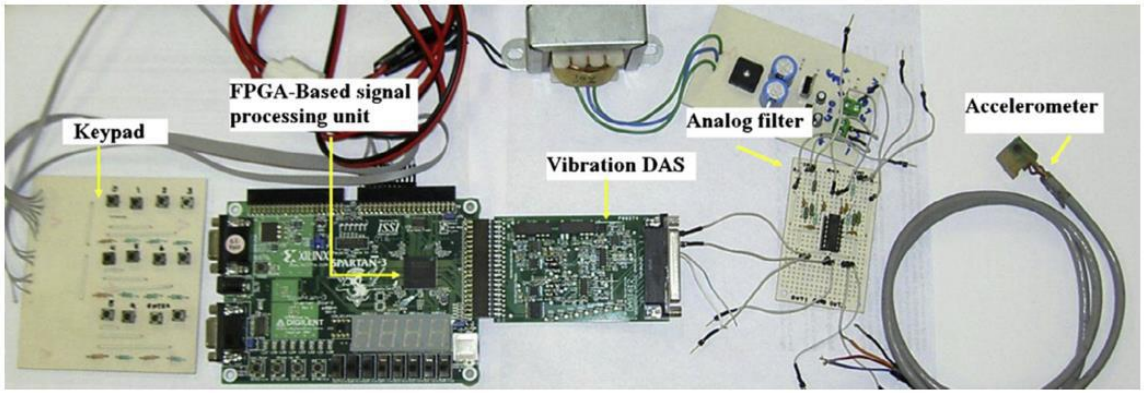
Academic view

Direct vs Indirect[1]

Actual vs. Inferred measurements

- Microscope for actual
  - Accurate
- Sensors for indirect
  - Non-intrusive

FPGA-based system[4]



Indirect

- Forces – dynos[2]
- Acoustic emission
- Vibration[3]
- Machine tool data (eg spindle power)
- Machine learning features heavily

1 – Ambhore N et al. *Materials Today: Proceedings*, 2015, pp. 3419–3428.
2 – Huang PTB et al. *Appl Soft Comput J* 2015; 37: 114–124.
3 – Krishnakumar P et al. *Procedia Comput Sci* 2015; 50: 270–275.
4 – Sevilla-Camacho PY et al. *Measurement* 2015; 64: 81–88.

Machine health verification

- verifying before/during/after machining that the machine tool is performing within the bounds of the process

Machine health verification

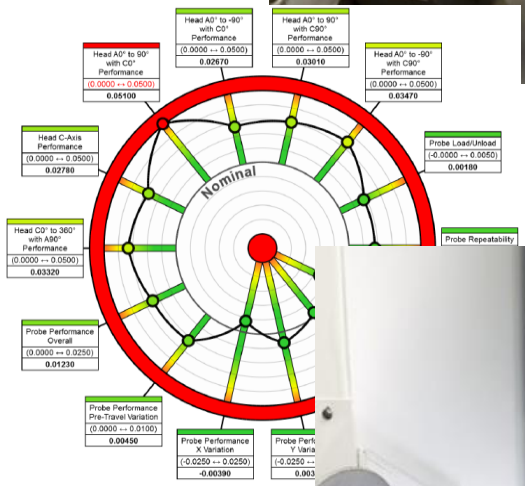
Use-case: Is this machine tool ready to go? Will it make a good part? Is it in need of servicing, either now or in the near future?

www.renishaw.com

Probe tool checks

Advantages

- Probe tool usually already available
- Automated
- Data logging
- Start of shift
- Can use machine bed as artefact[1]



metsoftpro.com

www.industry.siemens.com

Disadvantages

- Time consuming – machine tool not cutting
- Not a diagnosis
- Reliant on probe accuracy

1 – M. M. Rahman and J. R. R. Mayer, *Precision Engineering,* vol. 40, pp. 94-105, 2015.

Machine health verification

Use-case: Is this machine tool ready to go? Will it make a good part? Is it in need of servicing, either now or in the near future?

Spindle health

Advantages

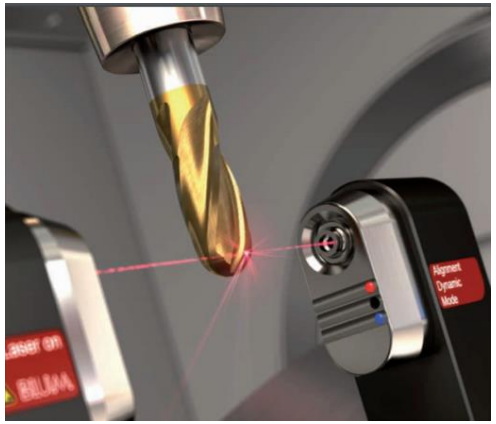
- Can often be permanently mounted in machine
- Rapid verification of spindle runout
- Automated
- Data logging

Disadvantages

- Additional hardware often required
- Can be expensive
- Machine not cutting….

www.ibspe.com

www.apisensor.com



www.blum-novotest.com

Machine health verification

Use-case: Is this machine tool ready to go? Will it make a good part? Is it in need of servicing, either now or in the near future?

Laser measurement

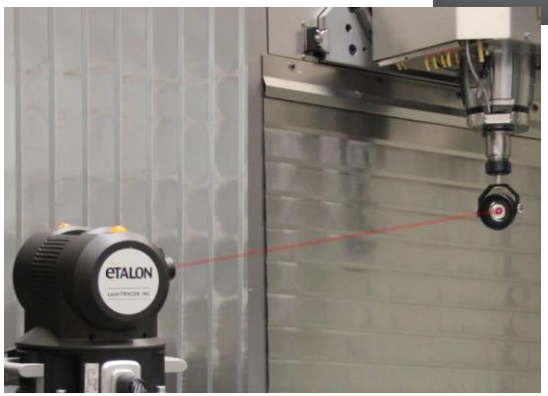
Advantages

- Highly accurate measurement of positioning performance
- Large volumes covered

Disadvantages

- Expensive hardware
- Cannot be fully automated
- Experience required to set up and diagnose

www.renishaw.com



www.etalon-ag.com

www.etalon-ag.com

Machine health verification

Use-case: Is this machine tool ready to go? Will it make a good part? Is it in need of servicing, either now or in the near future?

Sensor systems

Advantages

- Rapid check of machine health
- Indication of change to machine health
- Unobtrusive sensors

Disadvantages

- Diagnosis of error source needs many sensors
- Sensors need to be retrofitted

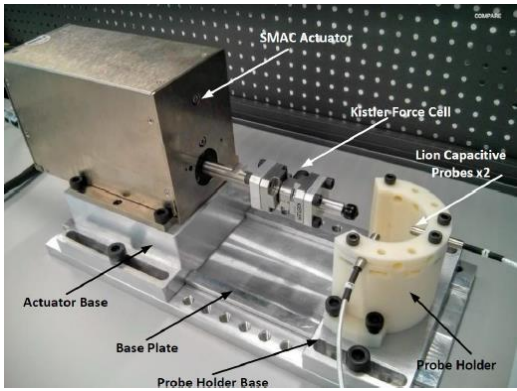
Academic work

Multi-sensor box[1]

- Degradation of linear axes
- Laser interferometer for reference
- Promising results

Auto tap test[2]

- Diagnosis of error source needs many sensors
- Sensors need to be retrofitted

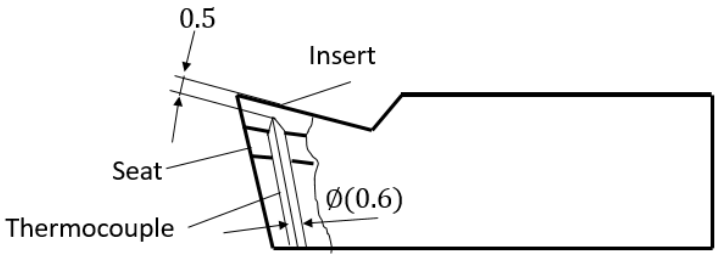


1 – G. W. Vogl et al., *Procedia Manufacturing,* vol. 5, pp. 621-633, 2016.
2 – AMRC with Boeing, "ABG109 - Self-actuated automated system for impact testing at high rotating speeds," 2016.

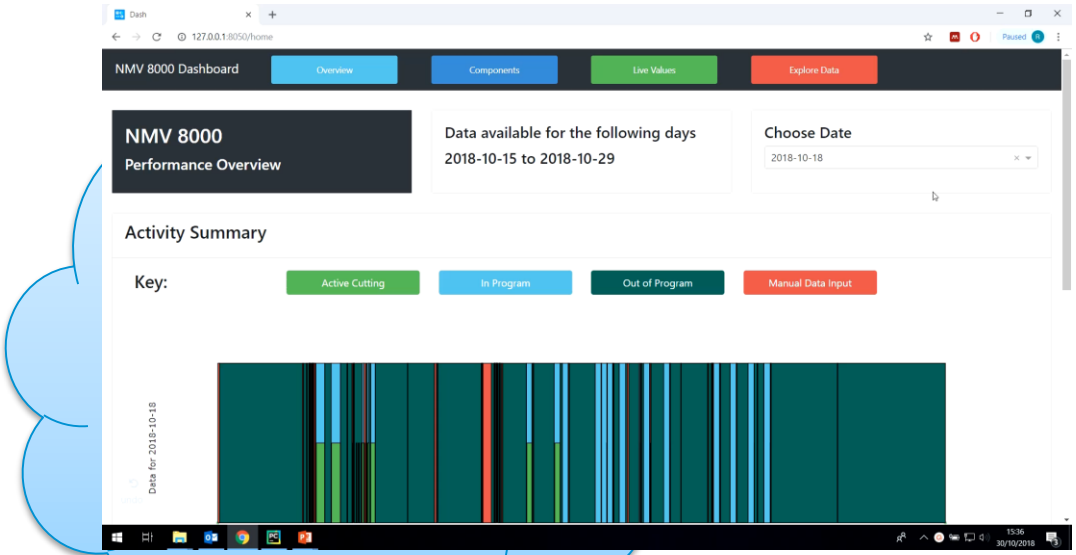
Process health

- continuous monitoring of performance indicators to verify that the process is within acceptable bounds

Process health



Thermocouple embedded in tool insert[1]

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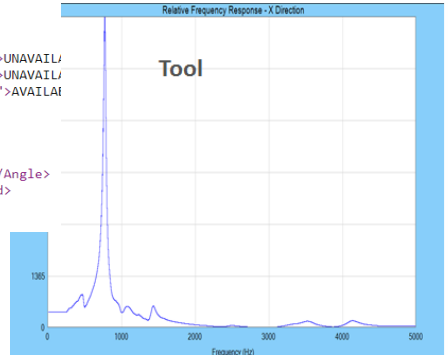
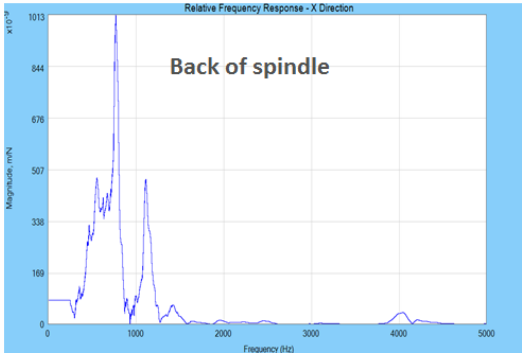




FRF measurements for remote accelerometer[2]

1 –AMRC with Boeing, "ABG2473B – Temperature measurement in milling", 2018.
2 – AMRC with Boeing, "ABG113 – Non-intrusive sensing system", 2016

Future thoughts

Process version control

Version control is not new – very common in software development and server-based document storage.

Can it be applied to all shop floor processes?

- NC programs
- Manufacturing documents
- Drawings
- People?
- Raw stock
- Tools
- Calibration certificates

Complete data trail for all processes

Machine tool servitisation

Power by the hour

A service built around the asset of a **jet engine**

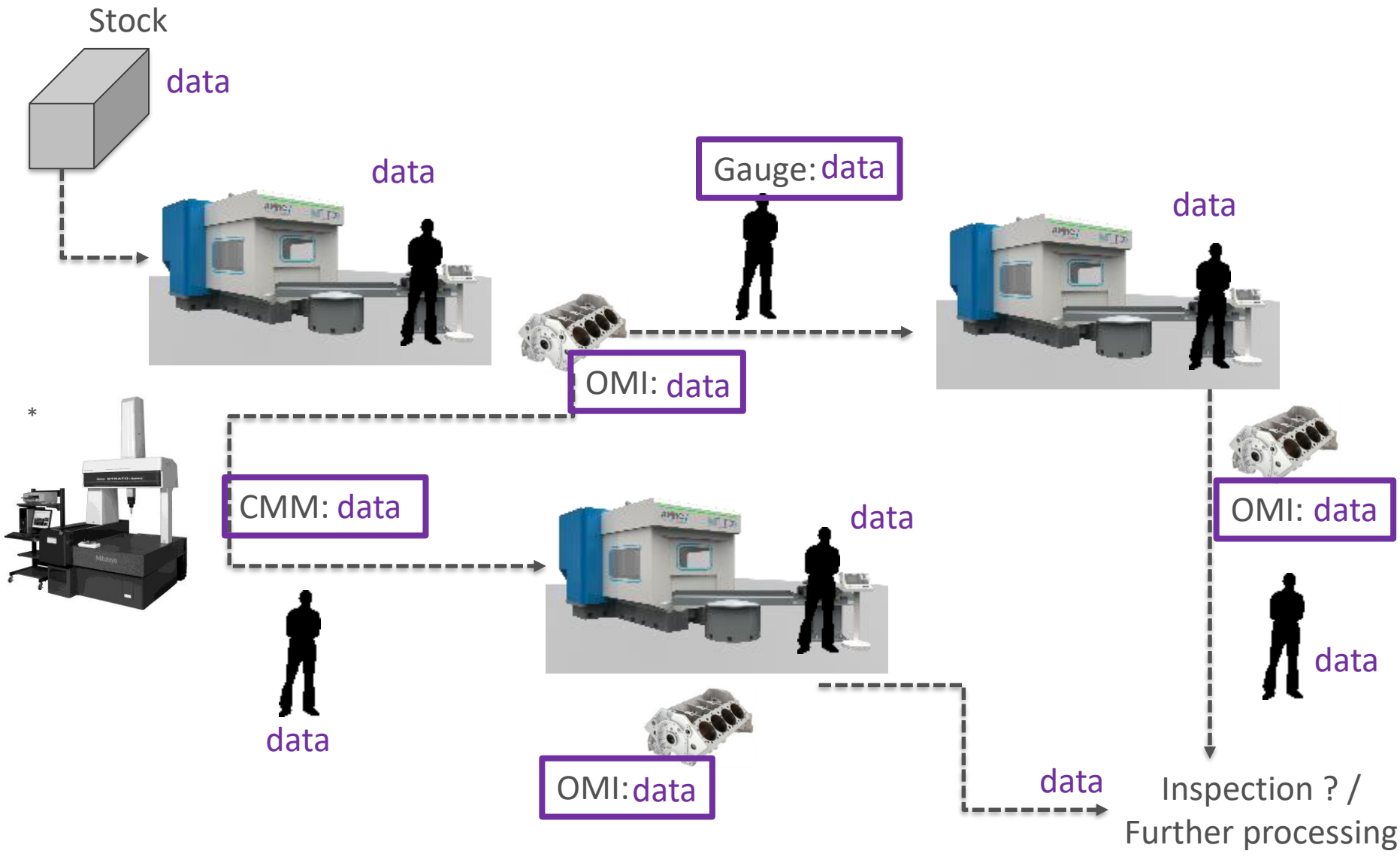
Servitising a machine tool

A service built around the asset of a **machine tool**

Image source: https://www.marposs.com/jpn/industry/machine-tools-machining-processes

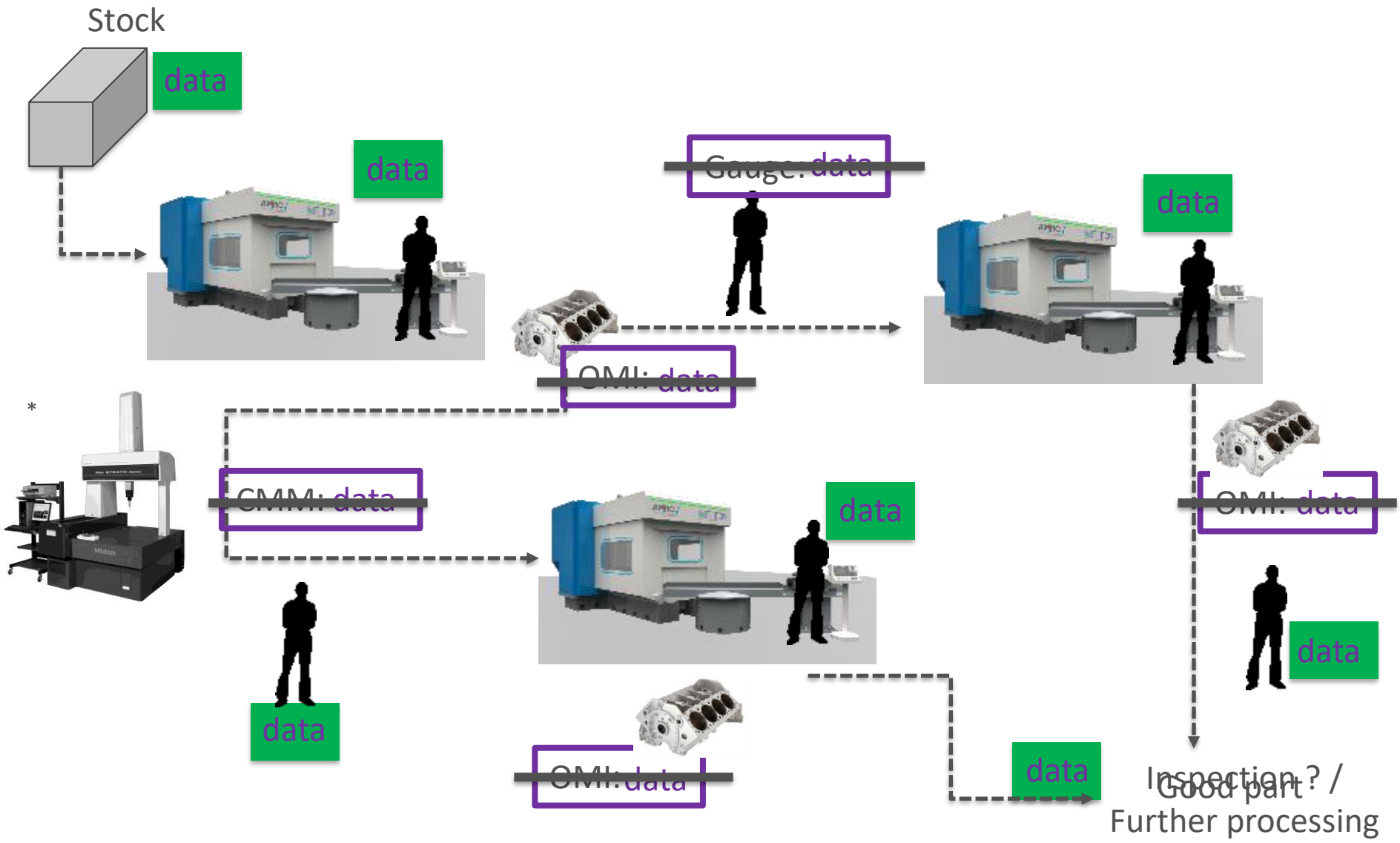
The following slides were not used in the presentation at the conference, but were available for discussion.

Non-geometric validation



* https://www.mitutoyo.com/press_releases/mitutoyo-strato-apex-cmm/

Non-geometric validation



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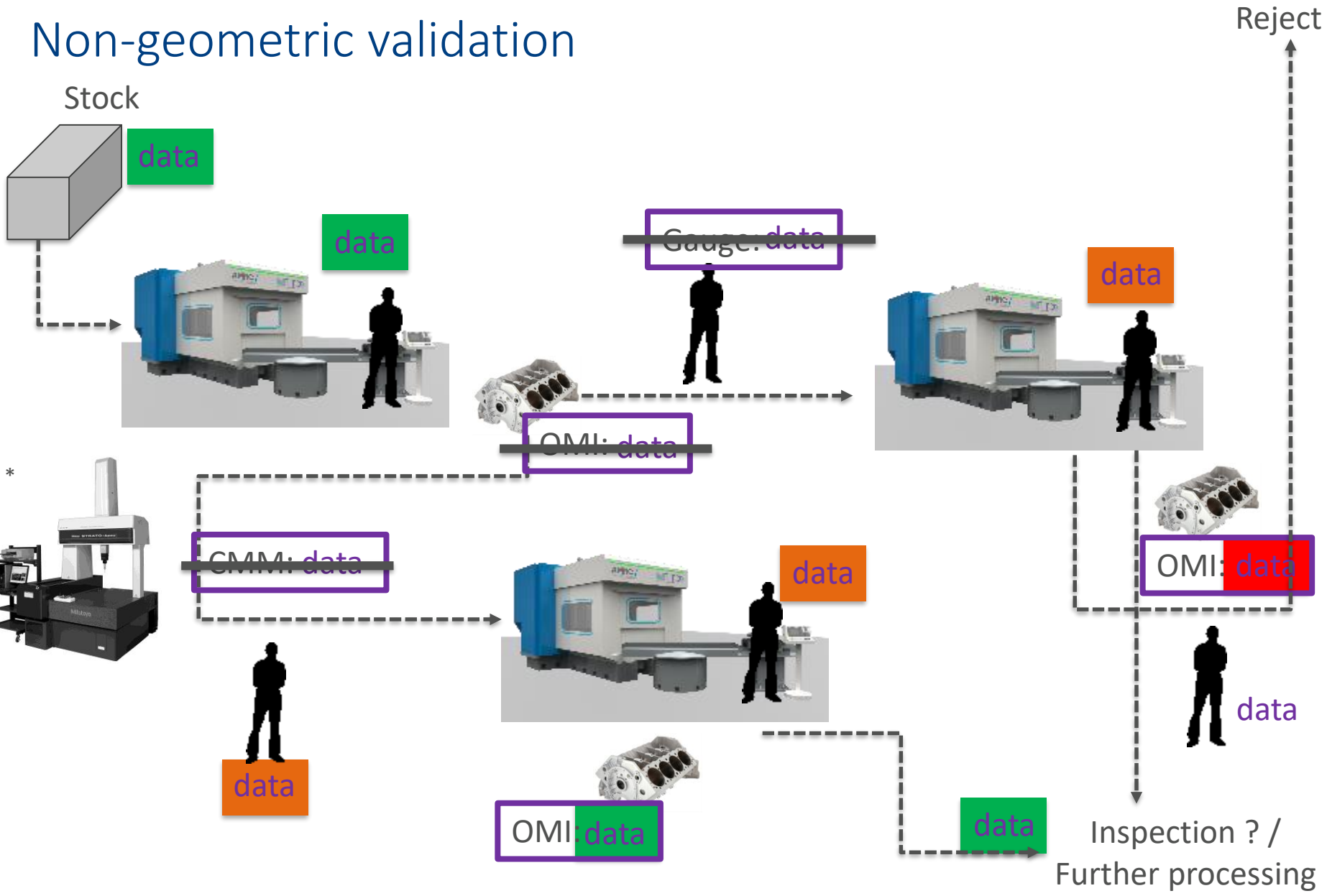


* https://www.mitutoyo.com/press_releases/mitutoyo-strato-apex-cmm/

Non-geometric validation

Can we validate a part without doing any traditional inspection?

Use of sensor data (and others?) to inform on process health.

If no significant change to the data, why would the part not conform?

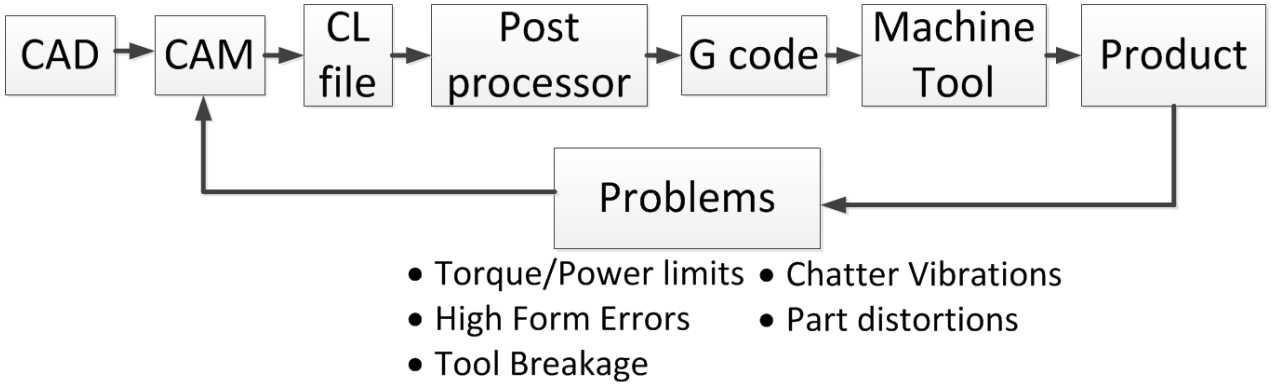
Only inspect when absolutely necessary – *Inspection by Exception*

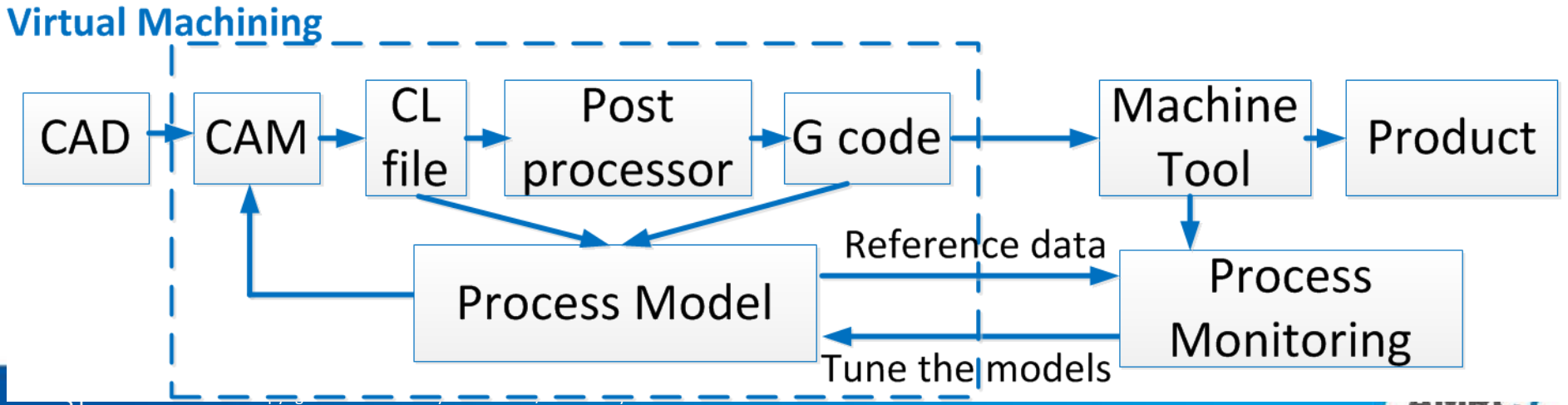
System will need to learn what good parts look like, from a data perspective

Human input still needed as system will continue to learn – correction of false positives / negatives

Sample inspection still needed?

Virtual machining and Optimisation





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The University Of Sheffield.

Thank you.

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web: amrc.co.uk

Twitter: @theAMRC

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