MetMap - Integrated Metrology for Precision Manufacturing Conference, 22 - 23 January 2019, Sheffield, UK

3D positioning for industrial robotics

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Background

- Engineering Photonics - Instrumentation development research centre at Cranfield University
  - Broad research portfolio: Fibre optic sensors, optical gas sensing, optical flow measurement, optical interferometric NDT
  - Wide range of application areas: manufacturing, transport, environmental technology, energy, agrifood, healthcare.
- EPSRC supported research into Novel Manufacturing Instrumentation (Grant number: EP/M020401/1)

Background/Outline

- **Aim:** To develop new positioning instrumentation to improve flexibility and precision in robotic manufacturing …

  … overcome limitations in mechanical stiffness, process/environmental disturbances and kinematics errors

  … however also applicable in other areas

- Primarily focused on two complimentary optical measurements techniques

  Range-resolved interferometry (RRI)

  Laser speckle pattern correlation (LSC)

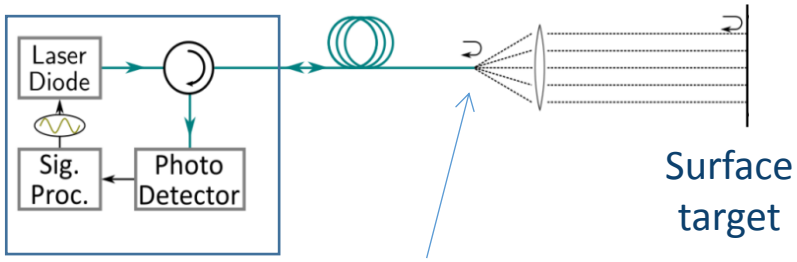
- Combination for multi-parameter relative positioning sensor:

  Workpiece Positioning sensor (wPOS)

Range Resolved Interferometry (RRI)

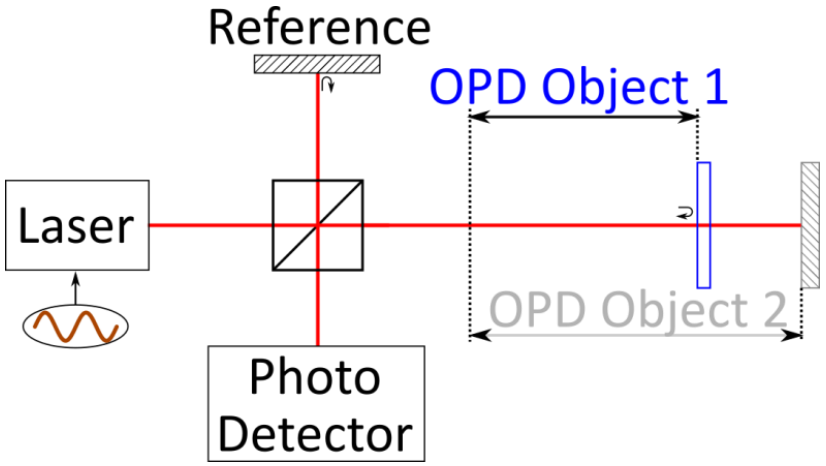
Range Resolved Interferometry (RRI)

- A novel interferometric technique, using optical-frequency modulation
- Complexity in the electronics instead of optics
- Uses standard telecoms industry laser diodes & optical fibre components - cost-effective and compact

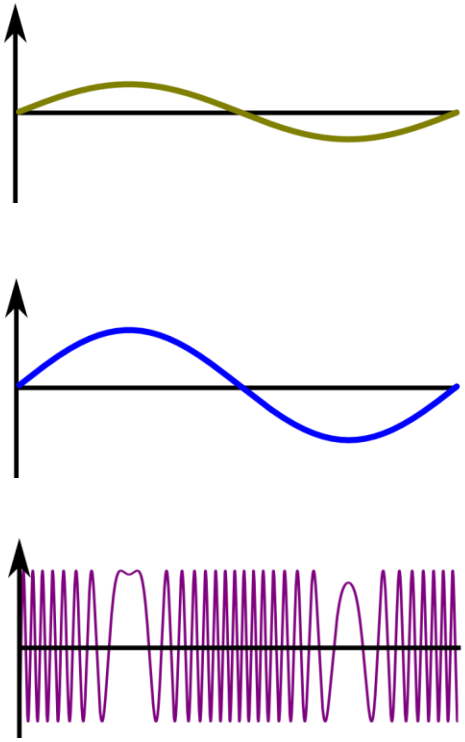


- Combined interferometric measurements and absolute ranging
- Allows signals from multiple sources to be distinguished by range

RRI operating principle



OPD: Optical Path Difference



Applied Optical Frequency Modulation

Resulting Phase Modulation for OPD > 0

Resulting Photo Detector Signal

T. Kissinger, T.O.H. Charrett, and R.P. Tatam, "Range-resolved interferometric signal processing using sinusoidal optical frequency modulation", *Optics Express* **23**(7), 9415-9431 (2015)

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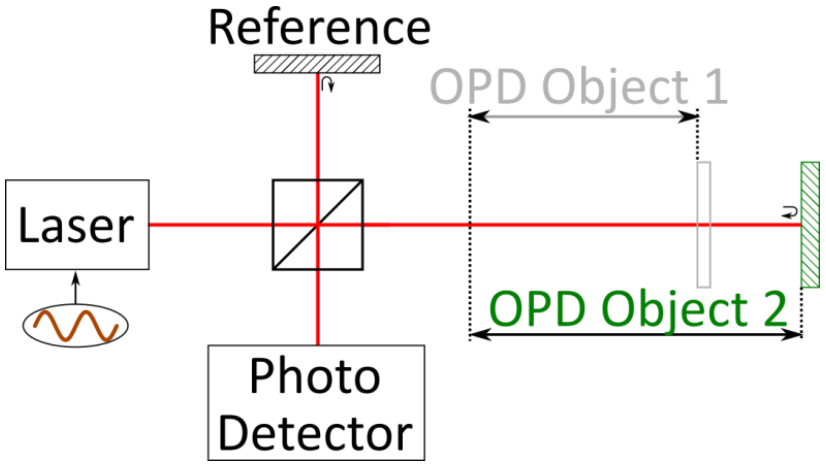

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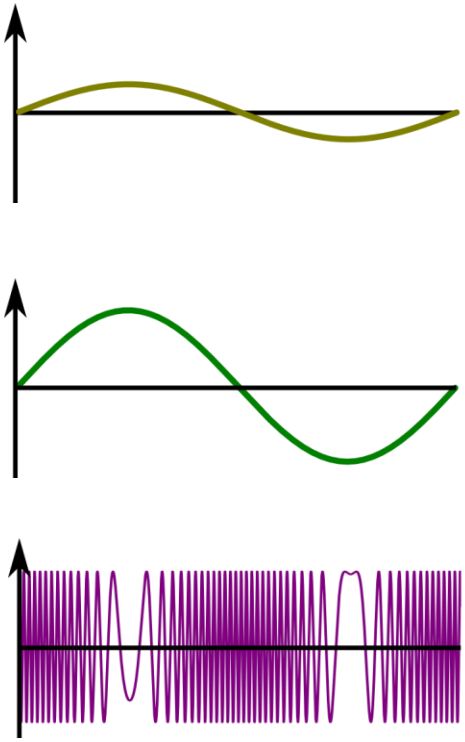

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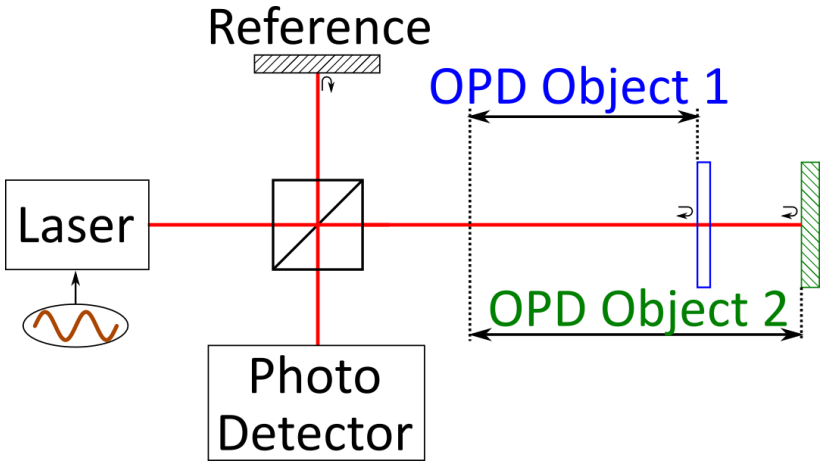

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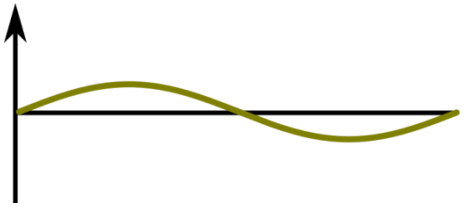

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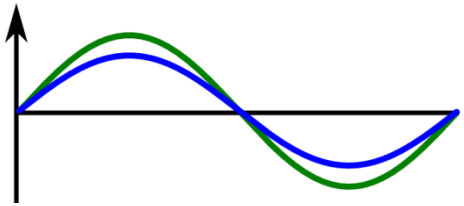
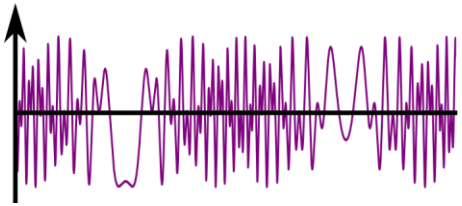


Resulting Phase Modulation for OPD > 0



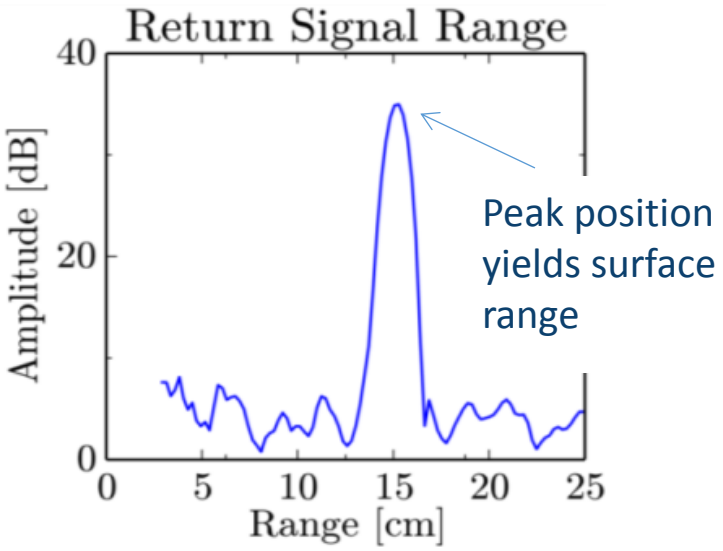
Resulting Photo Detector Signal

Demodulate signal → using complex carrier calculated at the range

T. Kissinger, T.O.H. Charrett, and R.P. Tatam, "Range-resolved interferometric signal processing using sinusoidal optical frequency modulation", *Optics Express* **23**(7), 9415-9431 (2015)

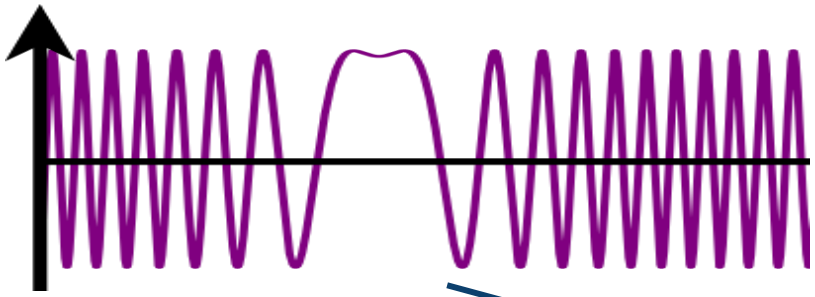
Range Resolved Interferometry (RRI): Ranging Mode

- **<u>Absolute</u> range measurements**
- Signal amplitude evaluated at different ranges → peak fitting yields range
- 10 to 50 µm resolution at kHz data rates
- Large dynamic ranges (>> 10 cm)
- Multiple (semi-transparent) objects can be measured simultaneously
- Can be thought of as a low-resolution, high-dynamic range Optical Coherence Tomography (OCT) technique



Range Resolved Interferometry (RRI): Phase Evaluation Mode

Interferometric signal from single range



Phase evaluation yields relative displacements

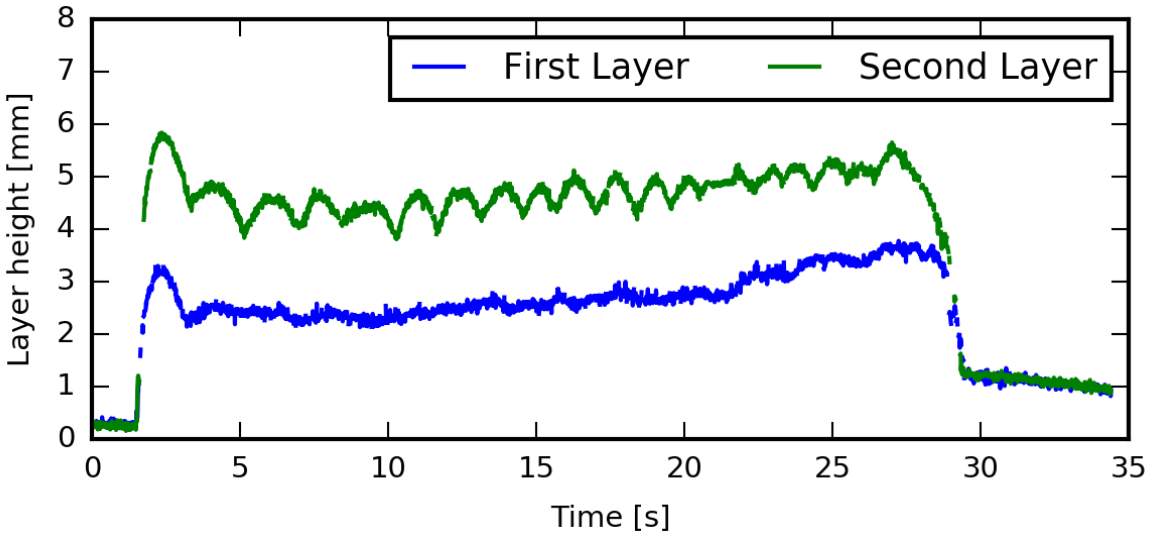
- **Relative displacement measurements**
- Nanometre resolutions at kHz data rates
- Evaluated for a single reflection or for multiple surface

Applications of RRI

In-process layer height measurements

- Appropriate Resolution (10 to 50 µm)
- **Inherently insensitive to arc light**, allows measurement close to welding torch
- Compact fibre-coupled measurement head

Typical Measurement Head

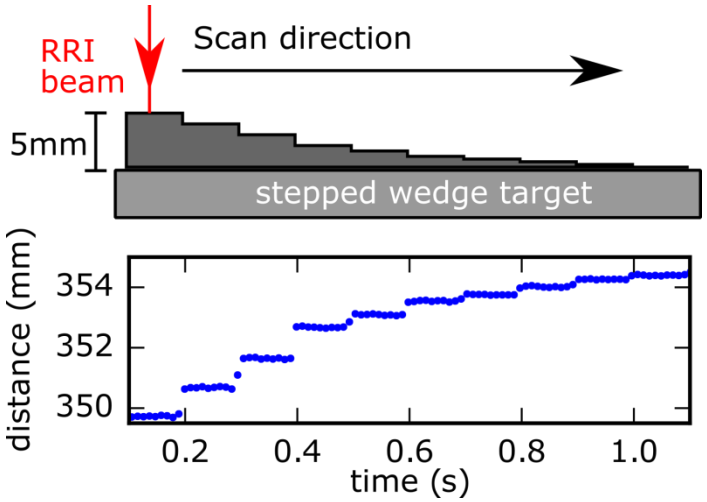


Applications of RRI

In-process measurement through laser processing head

- Collaboration with Welding and Laser processing centre (Cranfield)
- Integrate CO-RRI sensor in the view port of the welding head to be coaxially aligned with laser beam
- Explore different applications for CO-RRI in laser processing. E.g. active focus control, topography measurements during welding)

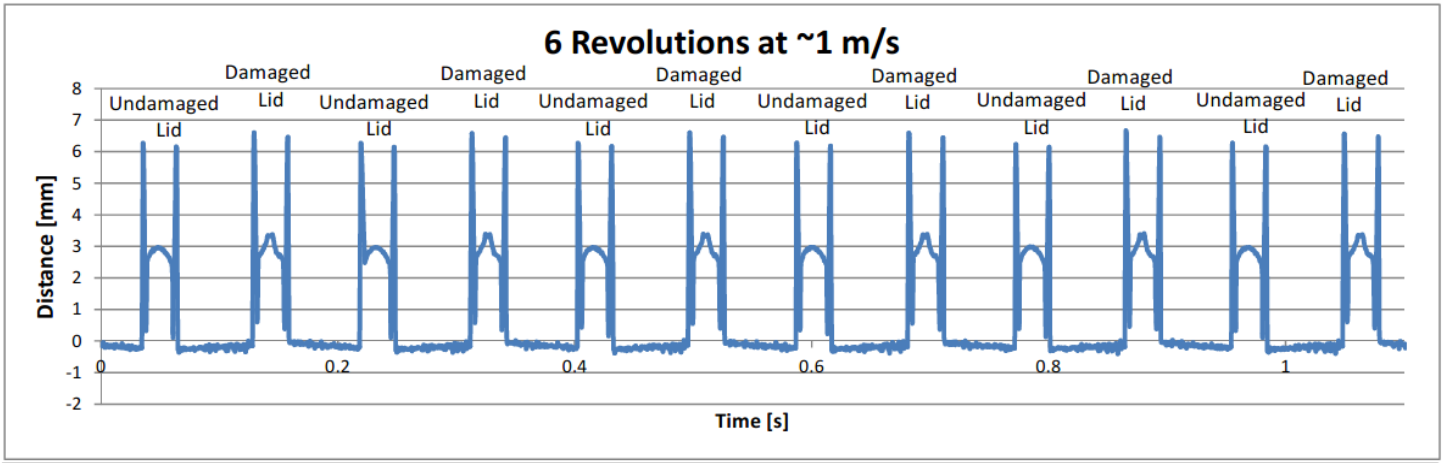
Co-axial measurement calibration

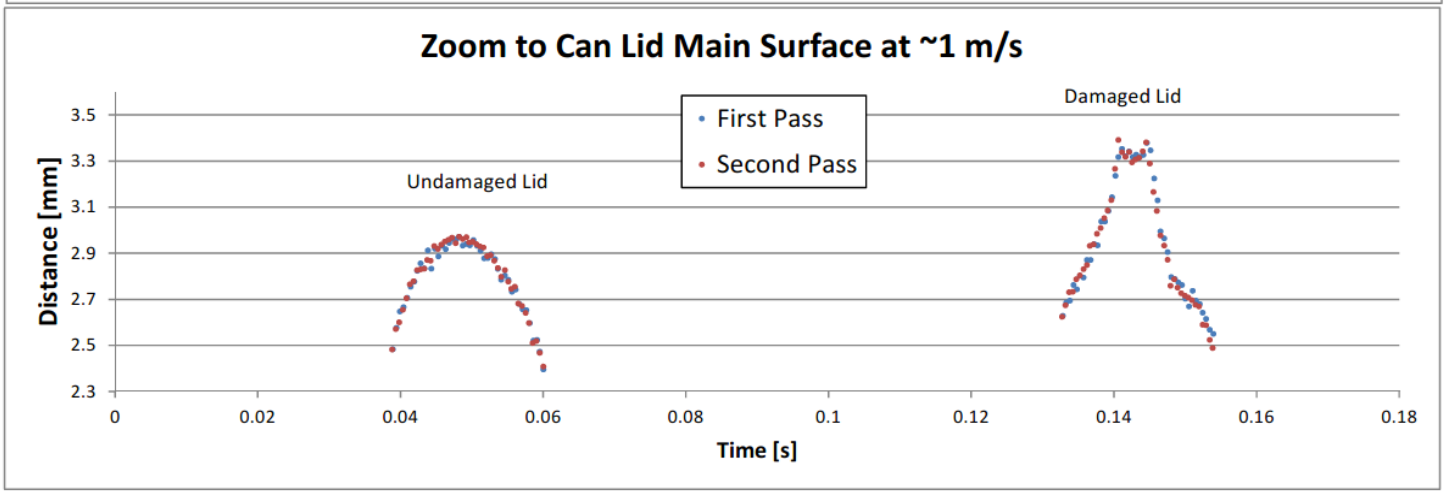


Applications of RRI

Topography of beer can lid during processing

10x Faster (no processing beam present)

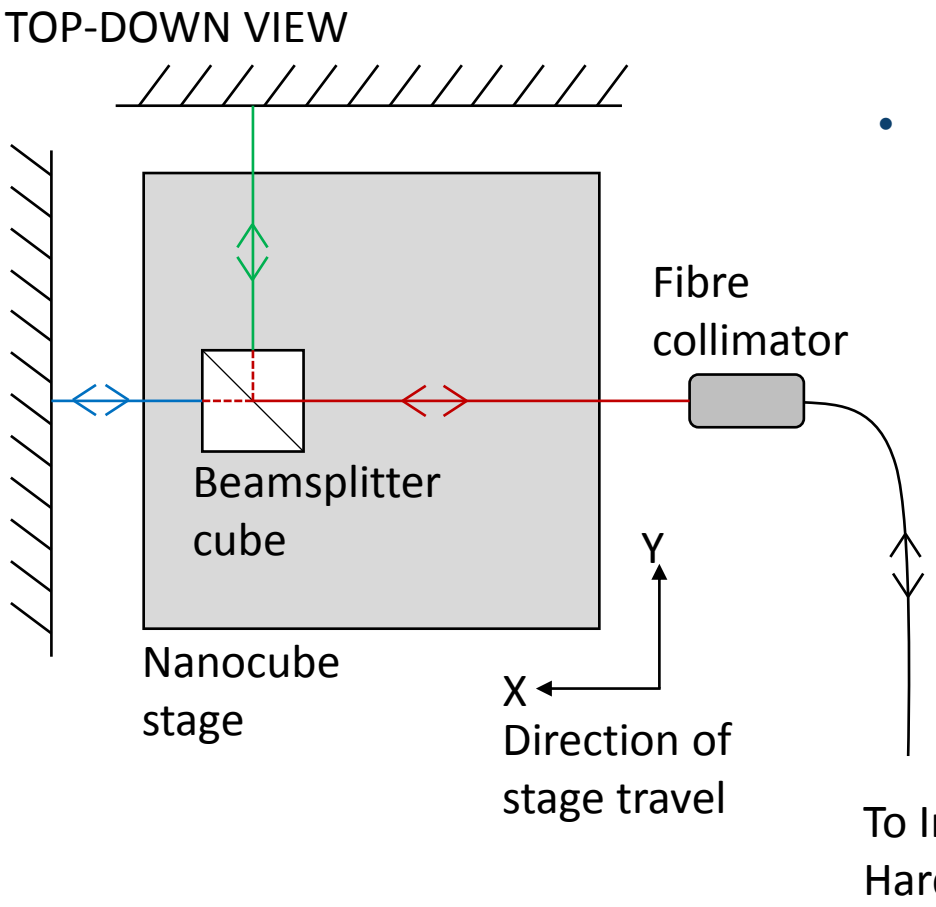


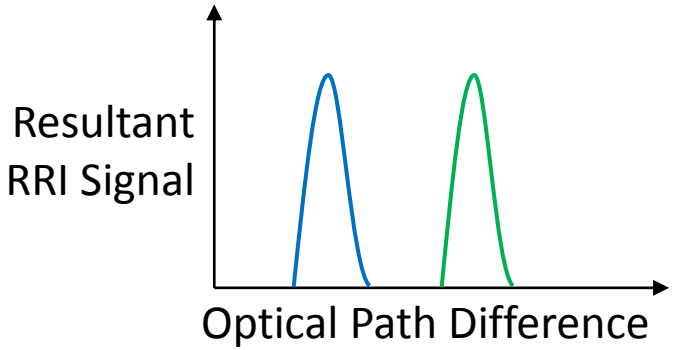


Applications of RRI

Multi-dimensional positioning via single Interferometer

- Components separated by optical path difference
- 2 or 3 dimensions with additional out-of-plane beam





Laser Speckle Correlation (LSC)

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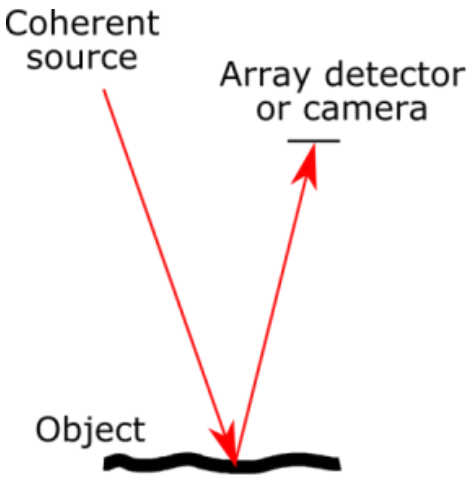
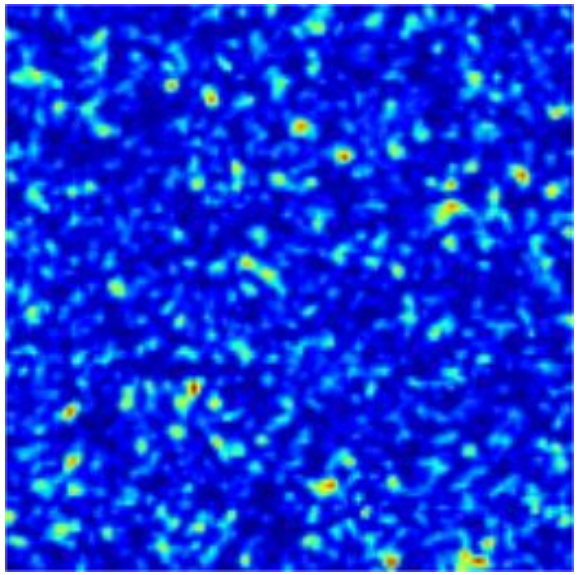


Objective speckle

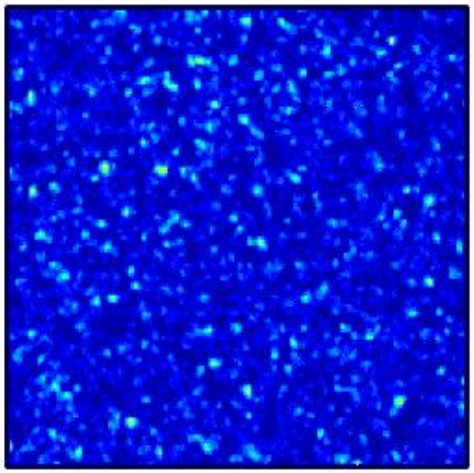
- Object illuminated by coherent light
- Scattered interference pattern recorded by array detector/camera
- Interference from points on optically rough surface leads to characteristic 'speckle pattern'
- **No imaging – objective speckle**
- Speckle size determined by spot size rather than aperture → better signal
- Speckles form from any optically rough surface including: unpolished metal, paper, card, rock



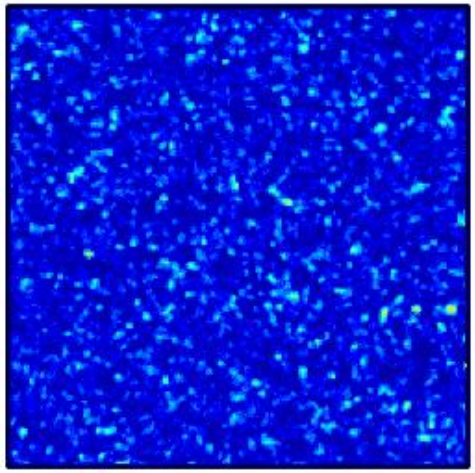
Laser Speckle Correlation: Principle

- Tracking changes between speckle patterns used to determine object deformation

Pattern translation:
from object translation, tilts and strains



Pattern rotation:
from in-plane rotation



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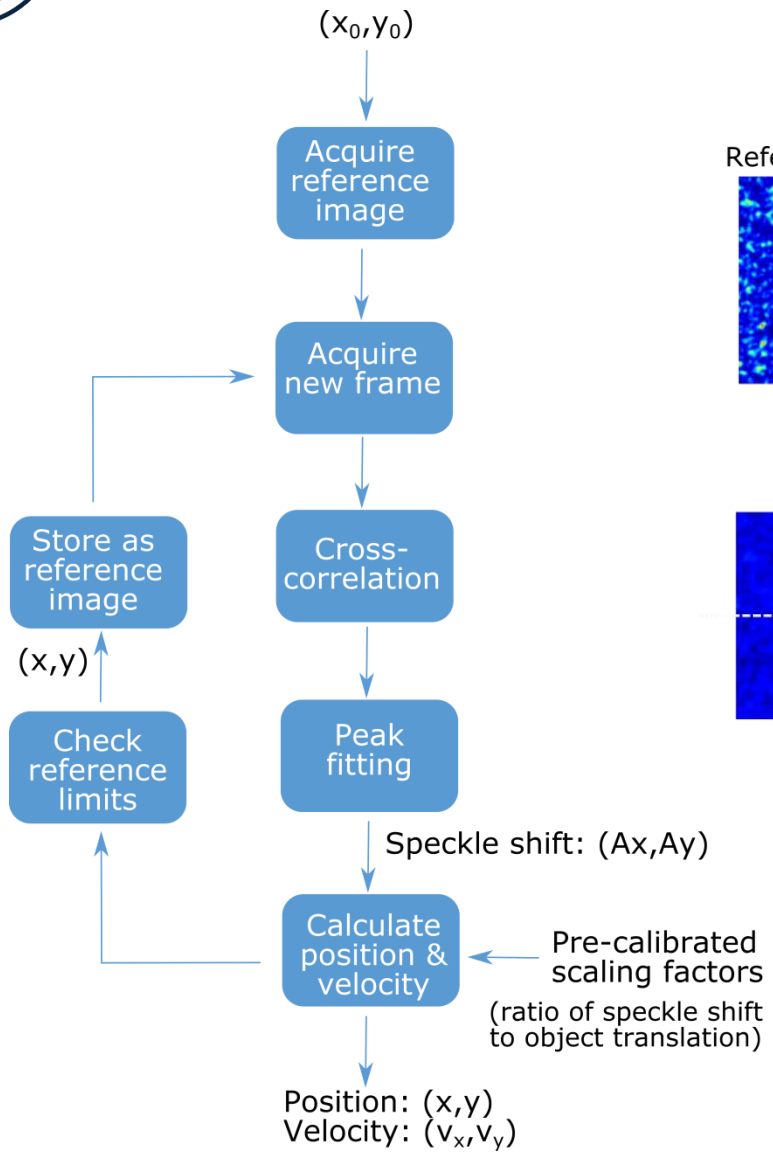
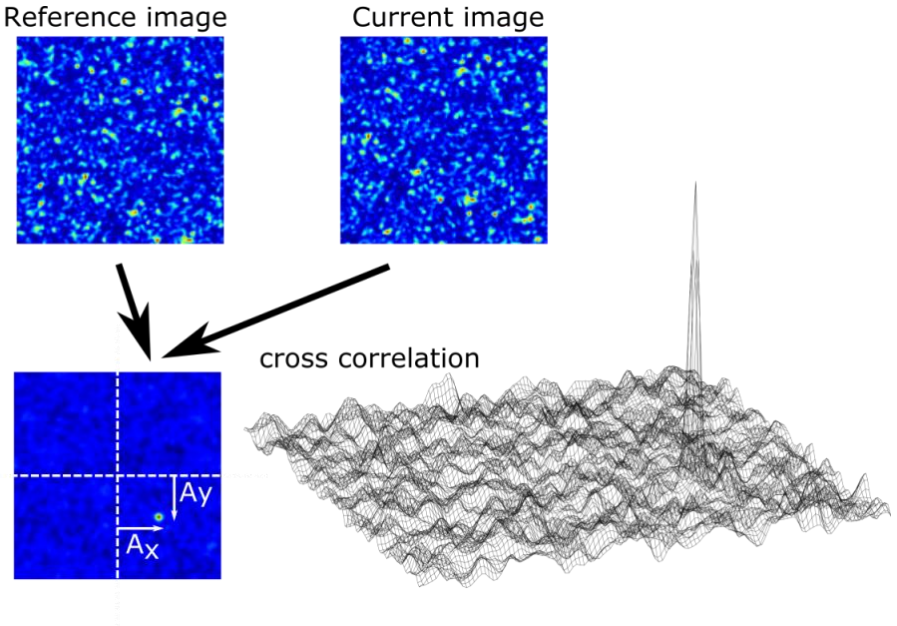
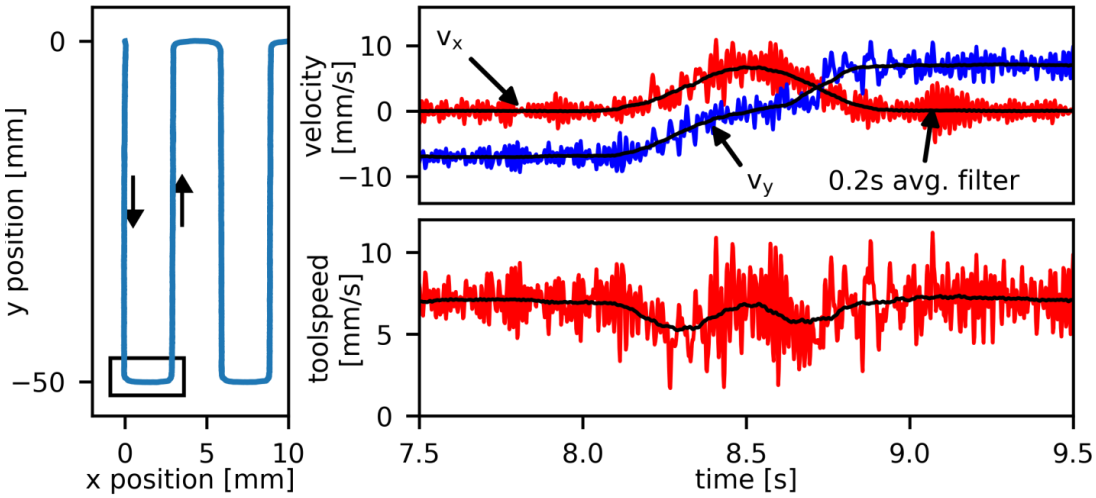
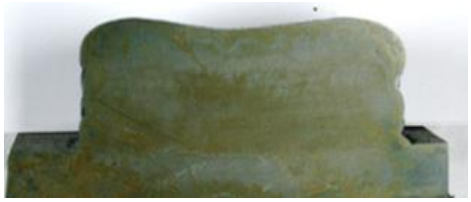




Applications of LSC

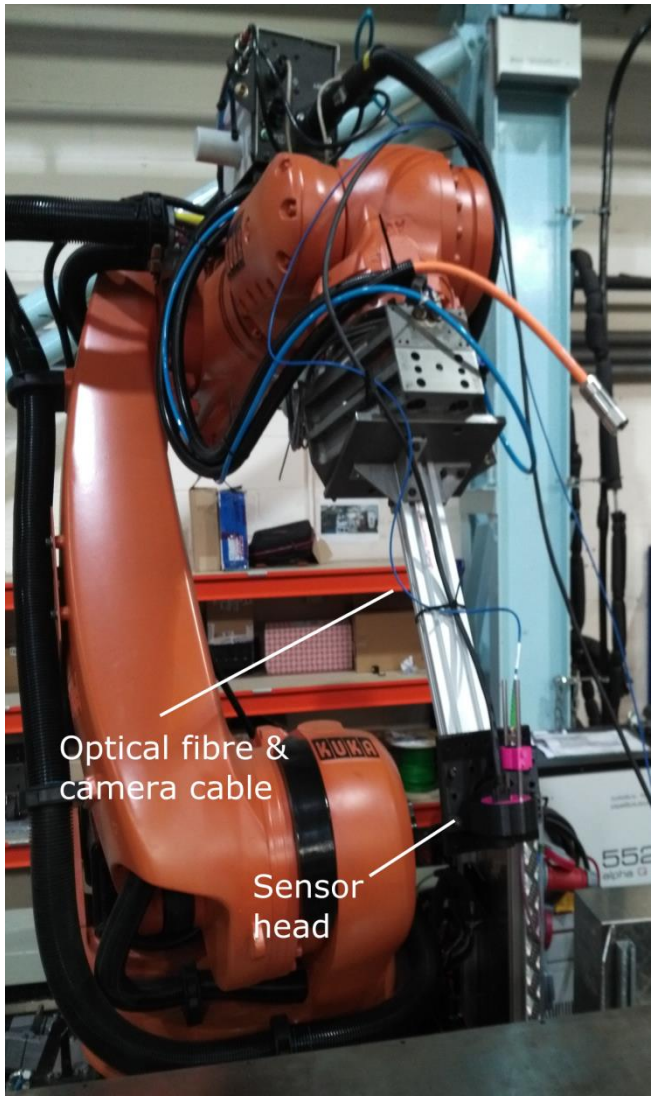
Robotic tool speed sensor





Robot (uncompensated)

Robot (compensated)

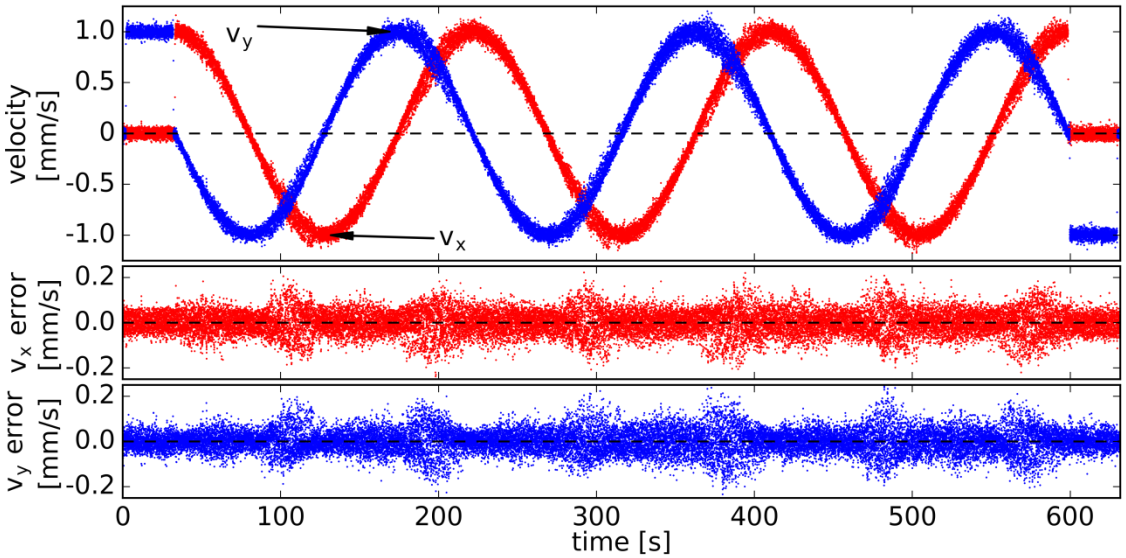


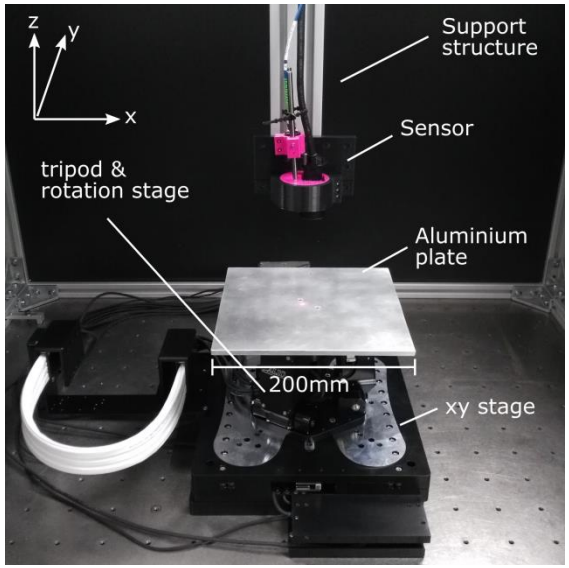
Applications of LSC

Robotic tool speed sensor

- Circular motion at fixed speed 1mm/s
- Accuracy:
- <0.01 mm/s (@ Working distance)
- <0.025mm/s (WD ± 5mm)
- <0.5mm/s (x50) with ±5° misalignment

- Measurement range: ±0.01 - 70 mm/s (current system max.)
- Precision: 3σ: ±0.15 mm/s → position error 0.3µm → 0.06 pixels
- Limited by peak fitting accuracy

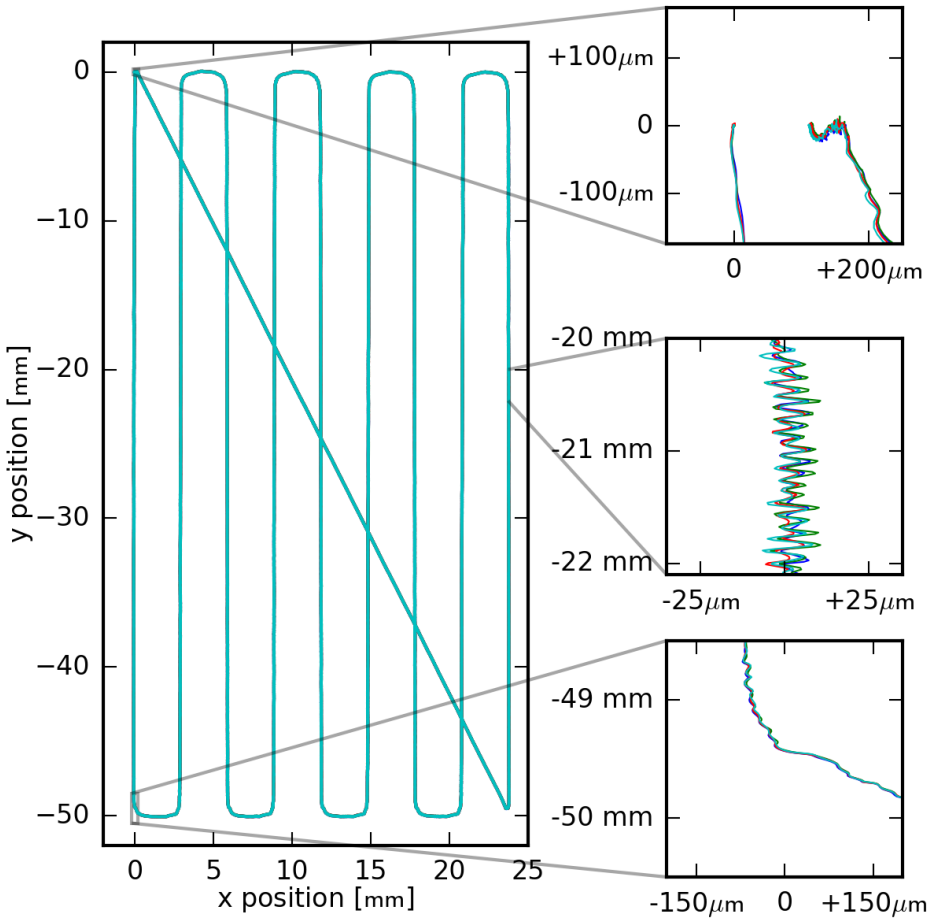




Charrett et al. "A non-contact laser speckle sensor for the measurement of robotic tool speed," Robot. Computer Integrated Manufacturing 53(April), 187–196 (2018).

Applications of LSC

Robot path characterisation - Large displacements (m's)



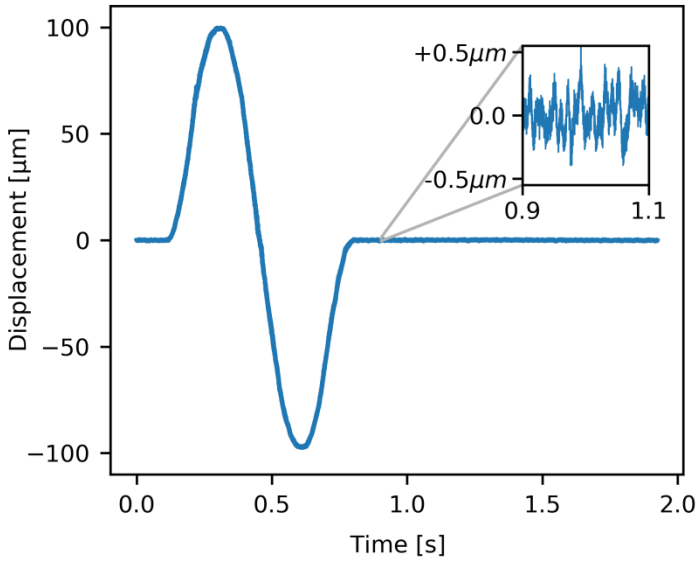
- Example of paths measured using the LSC technique on KUKA KR150 L110-2 robot
- Multiple repeat measurements of same path shown.
- Accumulated error ~120 µm after ~0.5m travel
- Mostly due to misalignment between robot *xy* plane and build plate.
- Accuracy over shorter ranges much higher…

Applications of LSC

Small displacements (mm's)

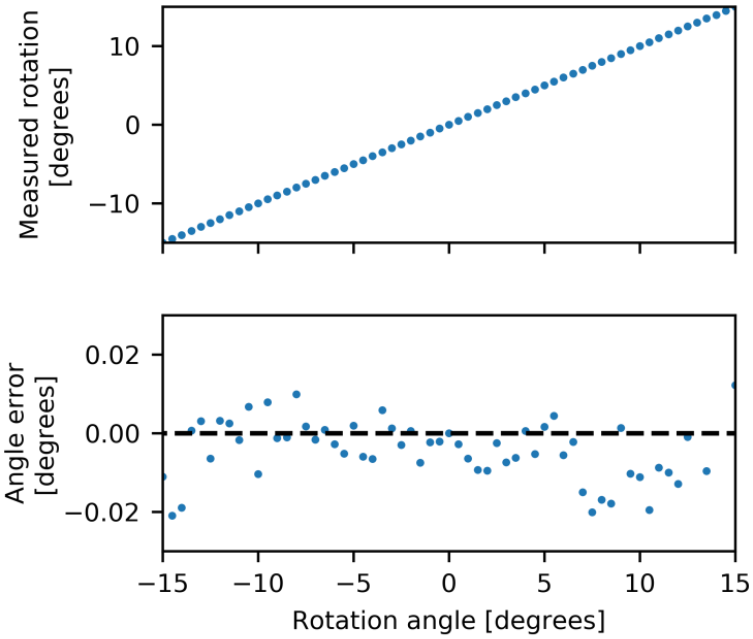
E.g. robotic drilling of high relative accuracy component mounting holes at lower absolute position accuracy of robot or Vibration monitoring

- Translation stage / Aluminium sheet
- ±100µm displacement
- Accuracies <0.5µm
- Improved peak-fitting ~10's nm seems possible



Object motion tracking/stabilisation

- No need for key-points/ markers
- Higher update rate than visual servoing



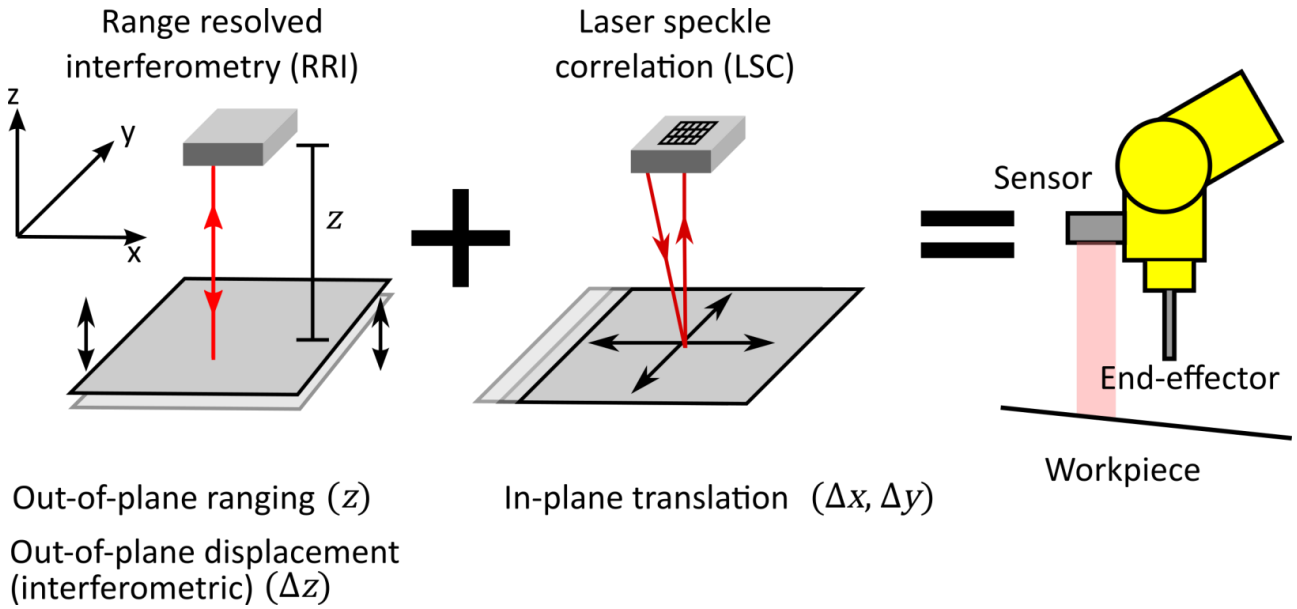
In-plane rotation

- Work-in-progress
- Accuracies of < 0.01° over ±10° range

Workpiece Positioning Sensor (wPOS)

Workpiece Positioning Sensor (wPOS): Concept

Aim: a new, widely applicable, end effector mounted, real-time, three degree-of-freedom position sensor



- RRI absolute range (out-of-plane) measurement
- LSC relative in-plane measurement
- RRI range measurement used to correct LSC scaling factors

wPOS: Development System

Signal processing unit

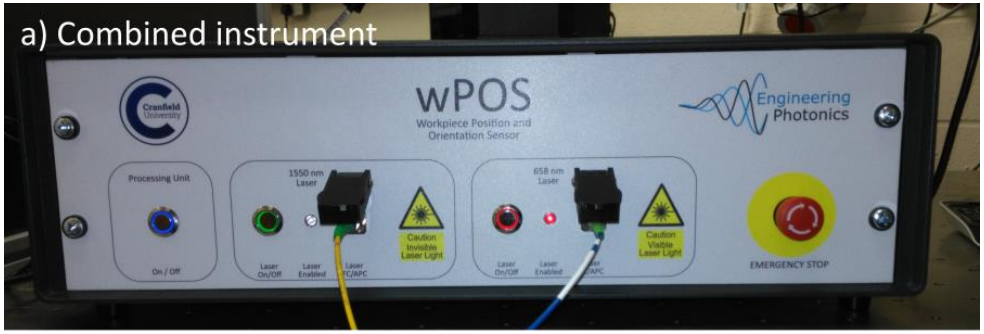
- 19” rack mounted unit.
- Containing lasers, PSUs and control & processing PC.
- Armored optical fibre delivery to sensor head

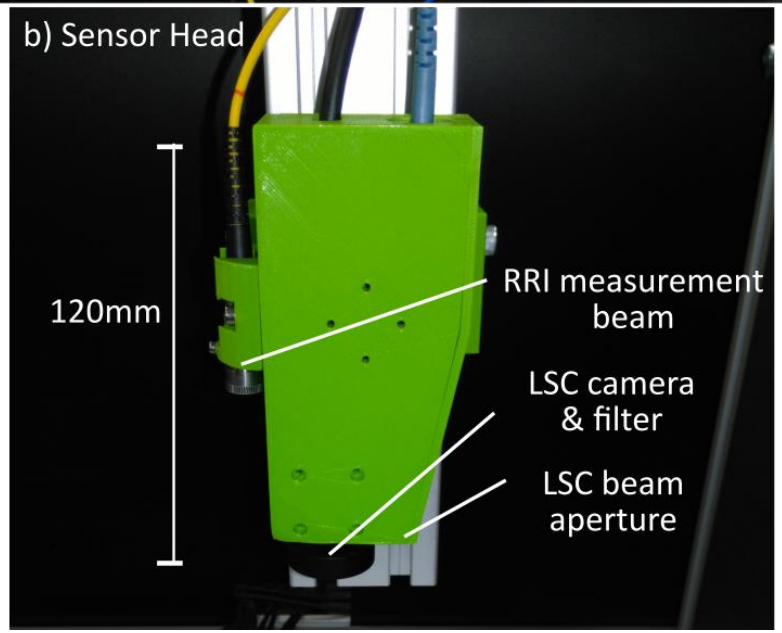
Range-resolved interferometry

- 1550nm telecoms diode and driver
- Hi-speed ADC and FPGA signal processing

Laser speckle correlation

- Fibre-coupled diode laser, 658nm, max output 50mW, typical 0.5mW
- USB3.0 CMOS industrial camera & laser line filter

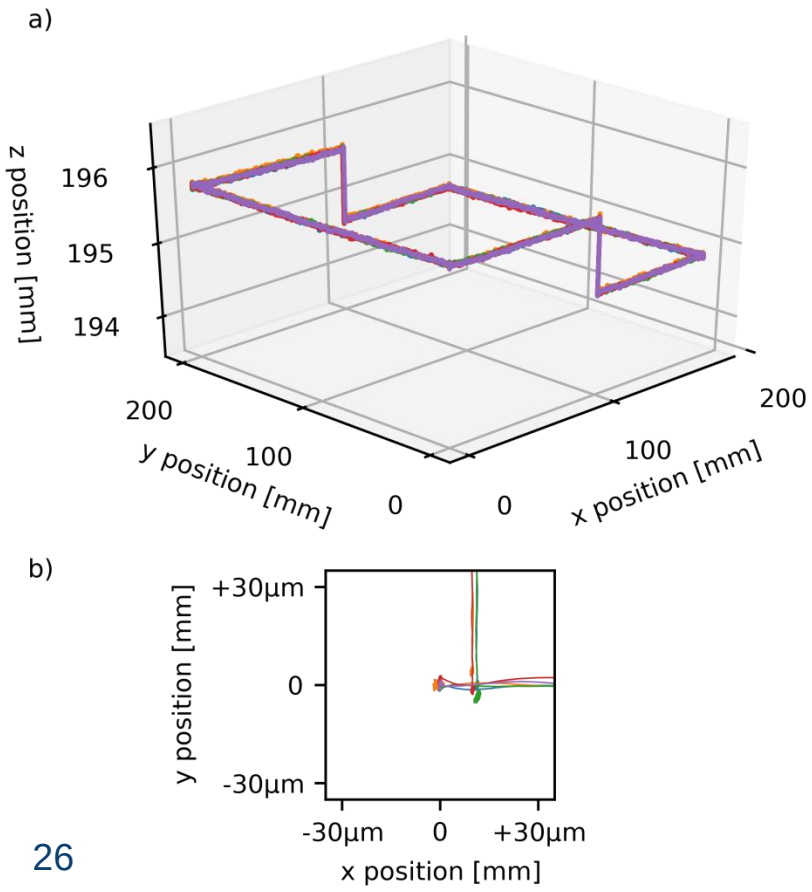




wPOS: Example results (6 DoF stages)

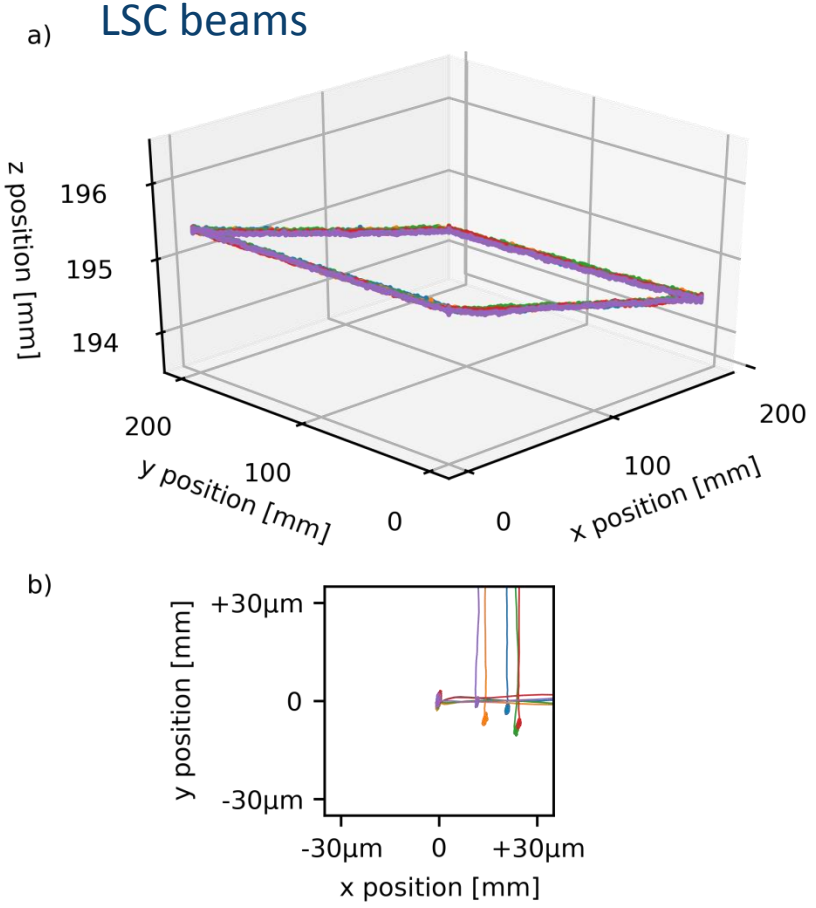
1mm Δz step change

- <15µm *xy* accuracy
- 0.75m travel

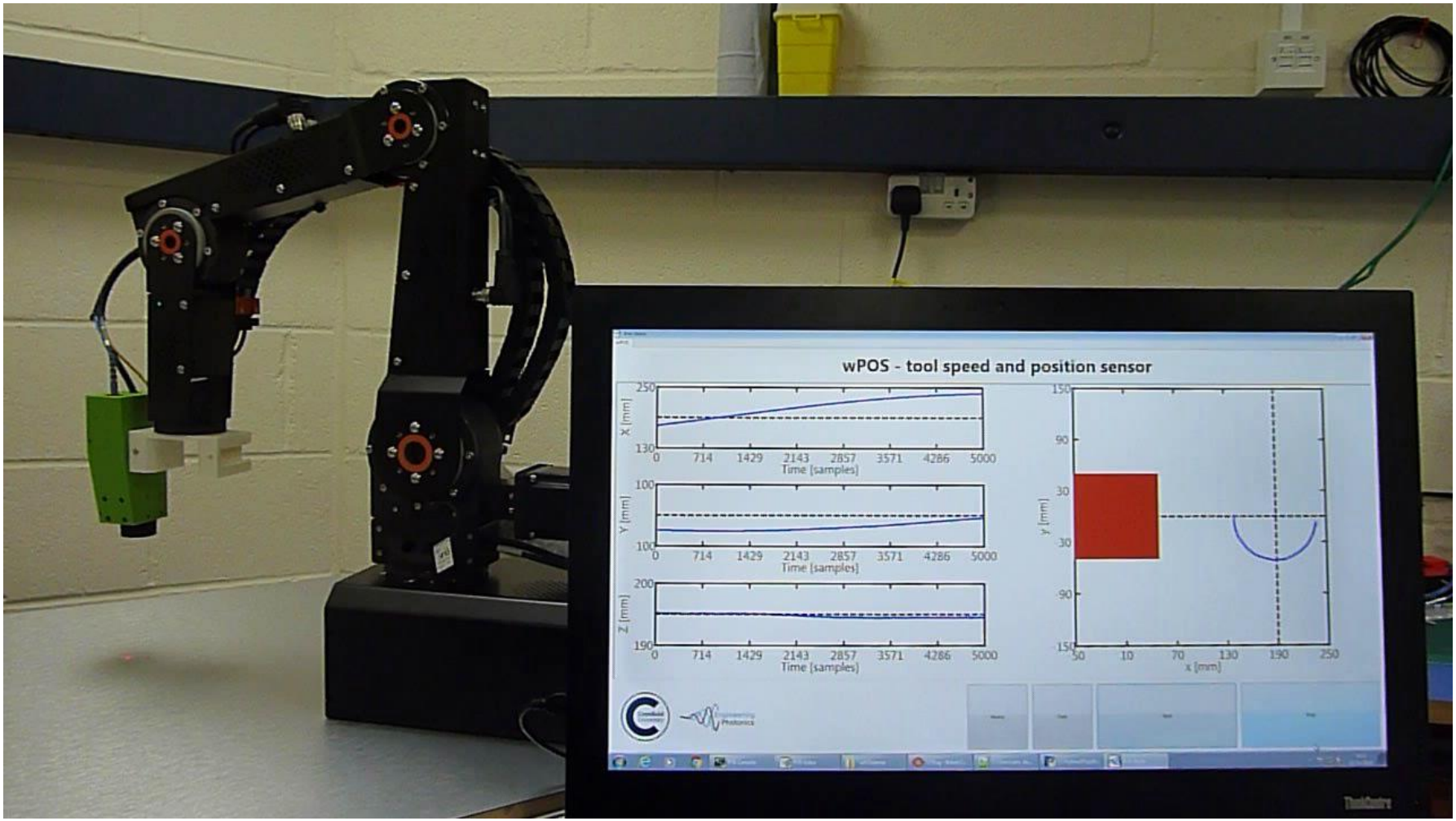


1mm Δz gradient

- <30µm *xy* accuracy after 0.75m travel
- Worse due to offset between RRI & LSC beams



wPOS: Example results (Igus 5 DoF Arm)



Conclusions

- Two optical techniques for position/displacement measurements
- Combined three-degree of freedom sensor
- Application examples and potential areas of application

Future directions

- Further instrumentation development and improvements
  - Fully characterize positioning performance of wPOS system
  - Addition of further degrees-of-freedom
- Application based trials …

Acknowledgements

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Engineering and Physical Sciences Research Council

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