Benchmarking a new machine tool verification system

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Contents

About INSPHERE

Provide a unique blend of expertise in **high-value manufacturing & metrology…**

… with the principal aim of providing **value-added metrology** solutions.

- Integration & Automation Projects
- Measurement Services
- Metrology Training
- Internal Research & Development

Motivation

- Machining in the Aerospace Sector
  - Large, complex machine tools with wide-ranging configurations
  - Parts have tight tolerances
  - Economic imperatives promote rapid metal removal, generating high forces and heating
  - Machines often run 24/7; uptime is relentlessly increased
  - Machine structures are therefore highly vulnerable to wear, deformation and drift

- Current State of Machine Tool Verification
  - Verification processes may demand days of downtime
  - Checks are scheduled infrequently
  - Sometimes they are not done at all!
  - Typically single axes measured independently
  - If used, dynamic tests cover restricted volumes

Develop a rapid machine tool verification system, delivering robust, accurate machine tool monitoring

- Top-level requirements
  - Laser Tracker based
  - Large volume machine tool focus
  - Easy to use – single button execution
  - No Metrology Knowledge
  - Wireless & Standalone (no controller integration required)
  - Rapid Measurement
  - Sensitive to straightness, scaling, squareness, indexing, pivot points, rotary axis.

- Potential gains with BASELINE:
  - Reduces downtime for verification to <60mins
  - Checks become far more frequent
  - Deeper insights into machine performance
  - Clear, actionable data generated for maintenance
  - Manufacturing process confidence increases
  - Machine learning and digital manufacturing are enabled (key i4.0 philosophies)

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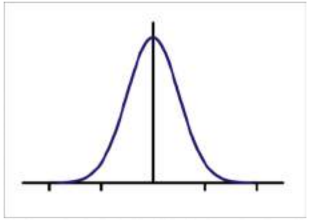
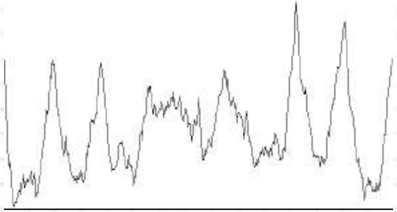
System Repeatability → Signal to Noise → Relative System Bias

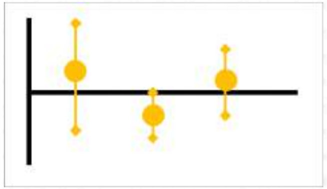
Is the data consistent run-to-run?



Can you detect machine tool variation?



How does the system compare with other systems?



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Is our data consistent?

- Early stage feasibility
- Static measurement are combined via our Network Adjustment
- Lowers the associated laser tracker uncertainty
- An uncertainty estimate is generated.
- Our repeatability is a function of laser tracker performance (inc. environmental, tooling , etc.) & machine tool repeatability.

How repeatable does it need to be?

Signal to noise

Is our system able to detect the errors?

How does machine-to-machine variation compare to our measurement system variation?

- Measurement systems analysis approach
- Minimum two repeat three machines
- Requires at three of the same machine tool & availability
- Identify the measurement process variation in relation to the machine-to-machine variation
- Promising results, static positioning measurement (that have been combined) have good signal strength.
- Dynamic measurements are noisier, with good signal strength when constructing geometry poorer signals on circularity.
- Limited data and only relevant for those machines.

Relative Bias

Objective & Test Procedure

- Part of a NATEP Funded Project

- Testing
  - New software: data collection, point extraction, network adjustment, and analysis.
  - New retro-reflective target
  - New measurement strategy
  - Aligned to ISO standards

- GOAL: to understand how the system performs when compared to commercially available systems.
  - 6DOF laser interferometer
  - Multilateration System
  - Ballbar

Relative Bias

Objective & Test Procedure

- Tests carried out at NAMRC
- Soraluce Machine
- 6 axis (7 with 2 parallel)
- Tests carried out over 10 days
- 6DOF Laser Interferometer – Direct measurement along each axis
- Multilateration System - Indirect measurement of errors, resolved to a mathematical model.

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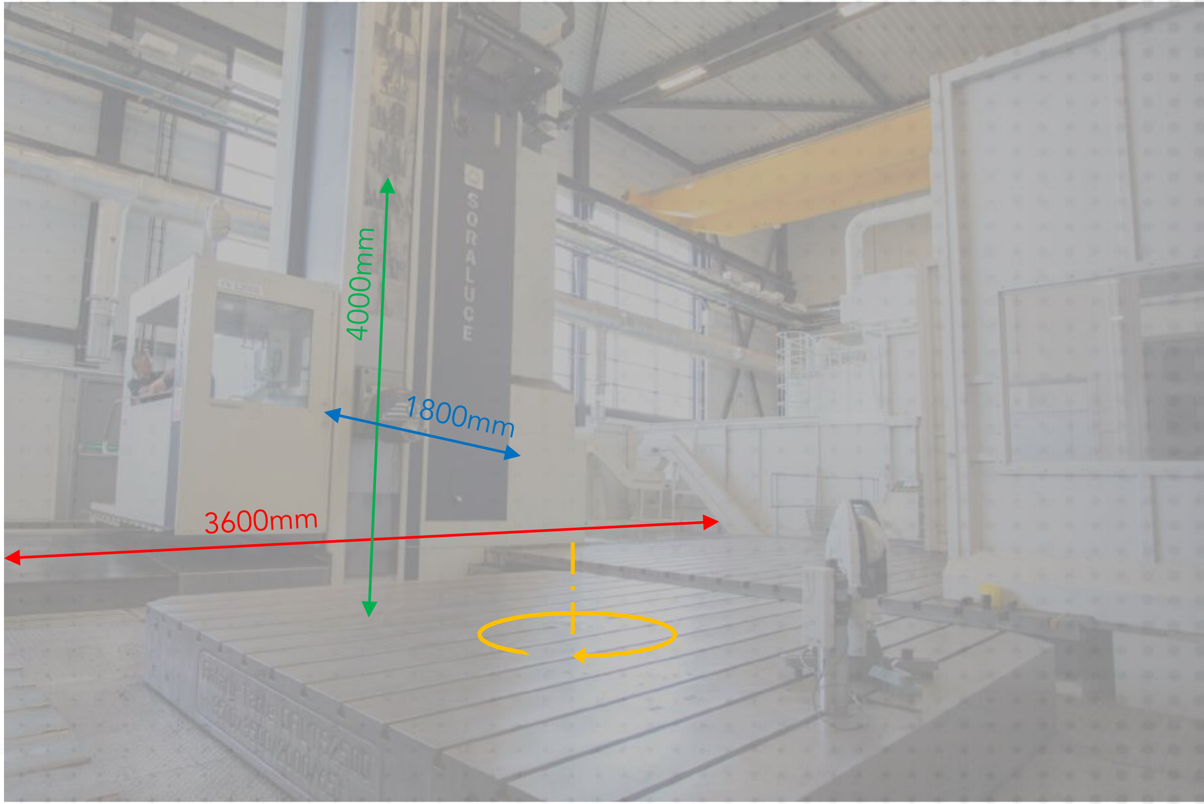
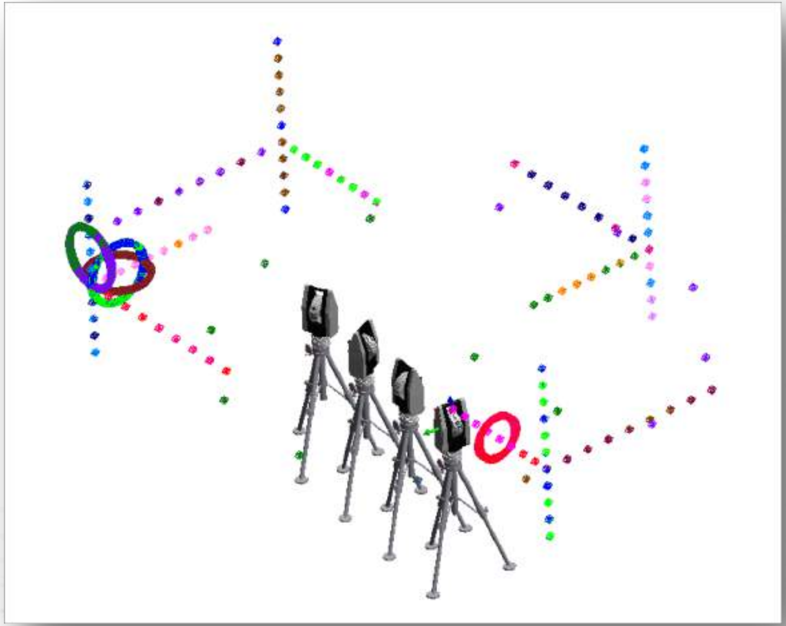
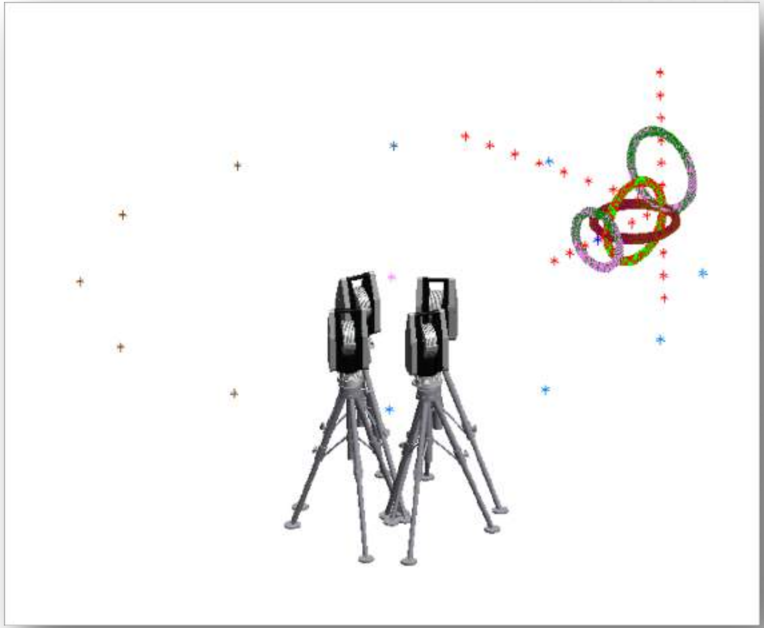


Relative Bias

Pre & Post Network Adjustment

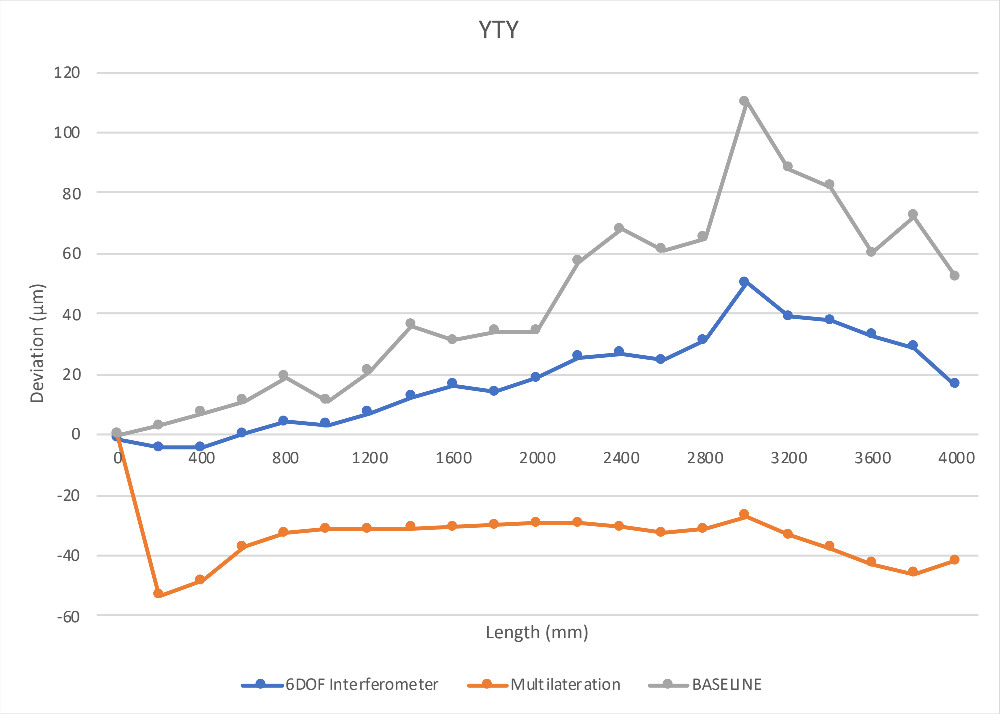
- B-Axis used as an instrument positioner

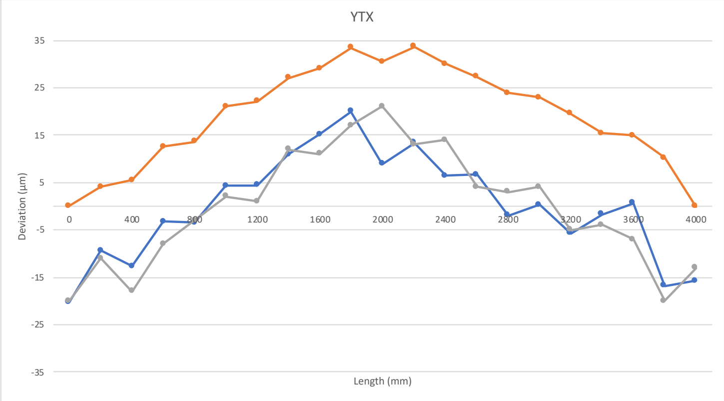


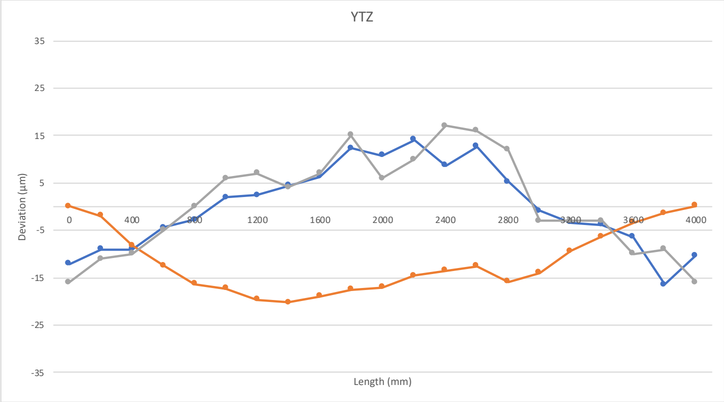


Results

Overview – *Y Axis*

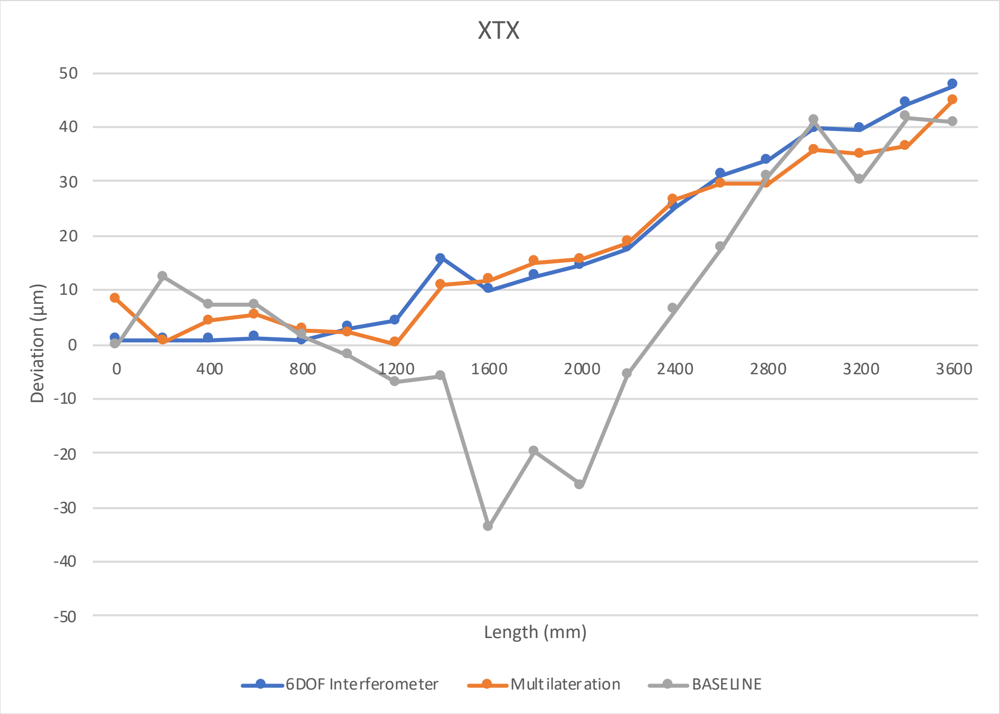


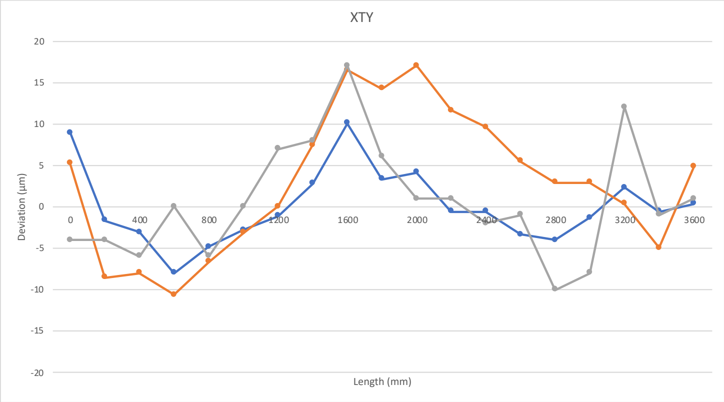


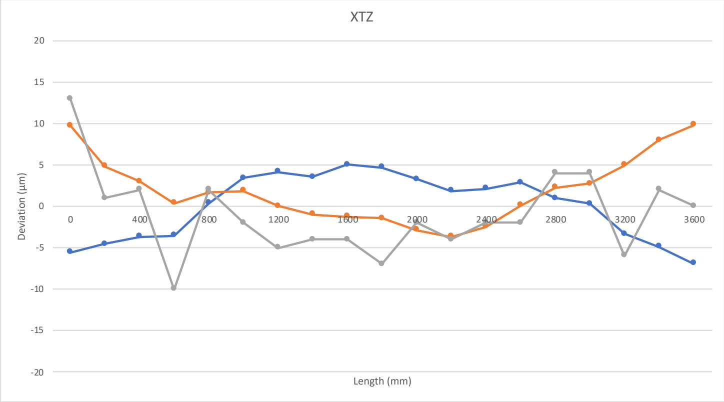


Results

Overview – *X Axis*

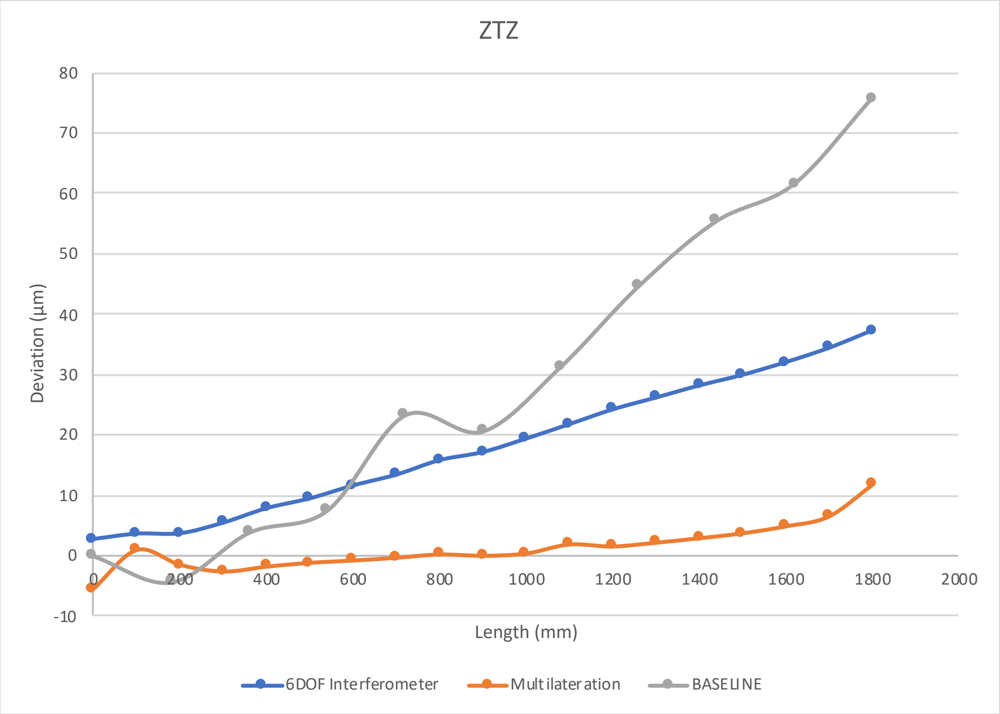


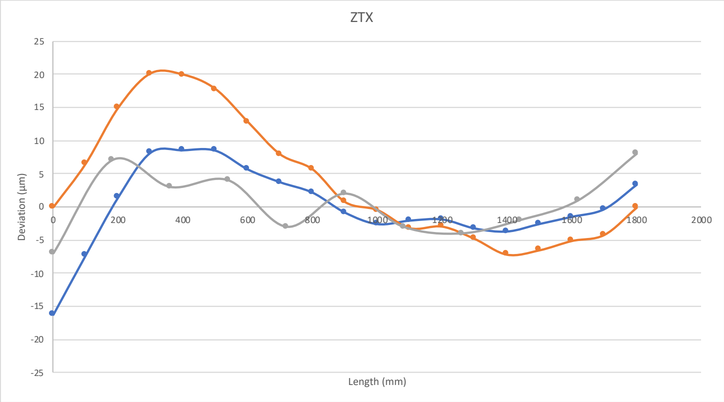


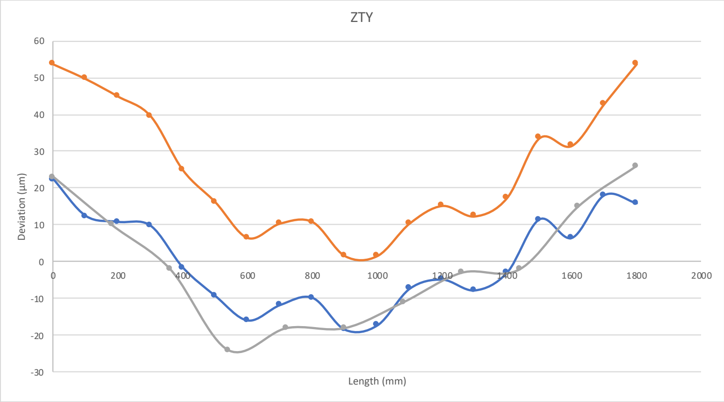


Results

Overview – *Z Axis*

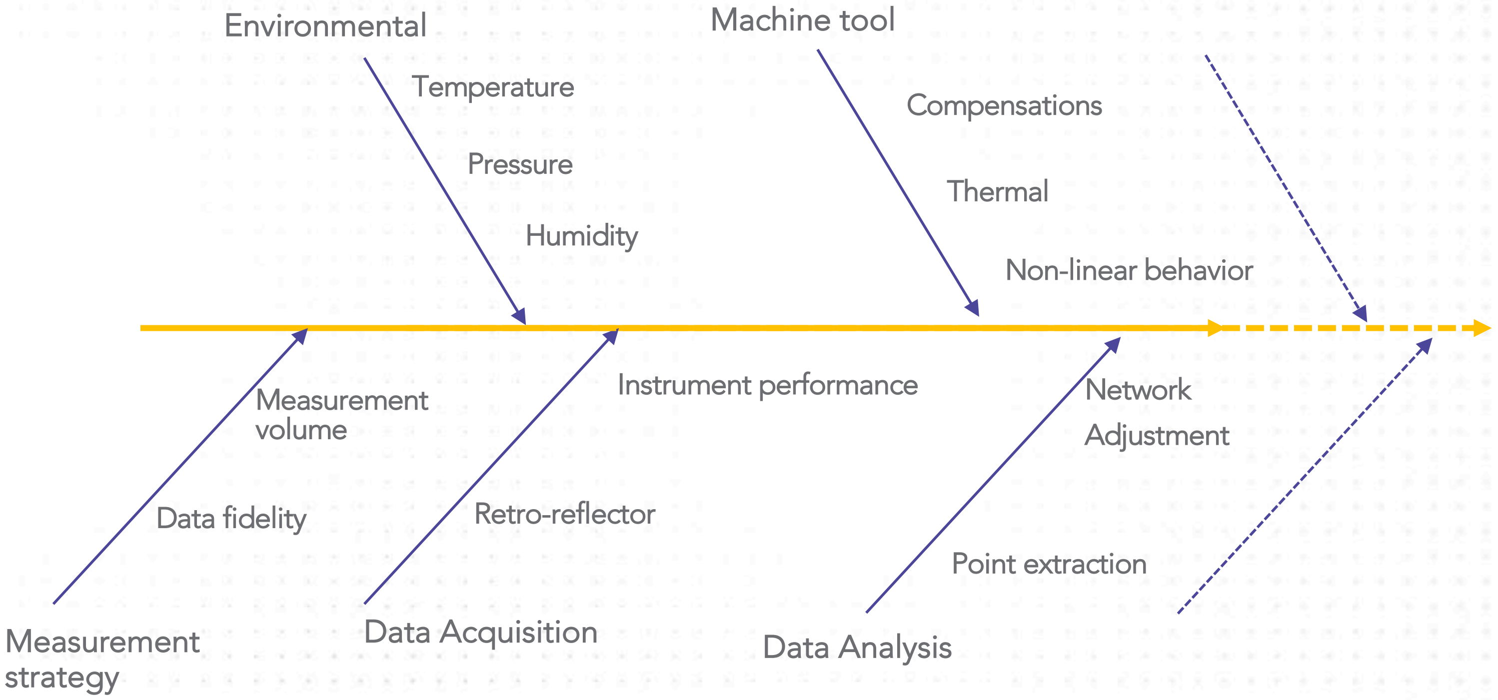






Relative Bias - Results

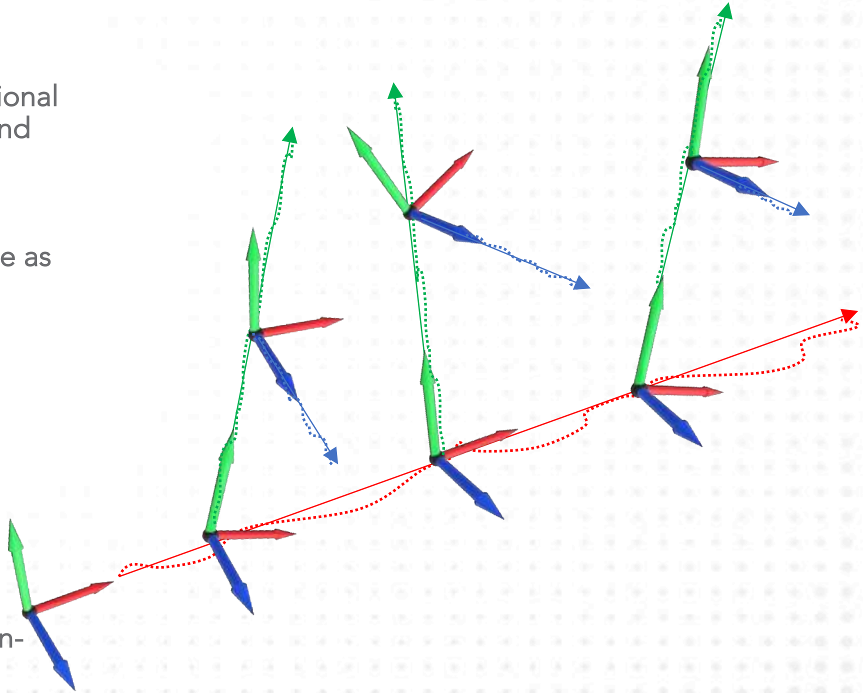
Sources of error, variation & unknowns



Relative Bias - Results

Volumetric discrepancies

- Where you measure matters…
- Machine tool "Pose" matters…
- The benchmarking systems output both translational and rotational information about each axis. That is: the scaling, straightness and yaw, pitch, roll along each axis.
- The 6DOF errors allow the projection errors to the same volume as the BASELINE system.
- We see the that the error profiles are very similar when the compared in the equivalent volume to our BASELINE measurements.
- The "pose" magnifies the errors apparent in the axis
- Correction for rigid body effects only, does not account for non-linear effects.

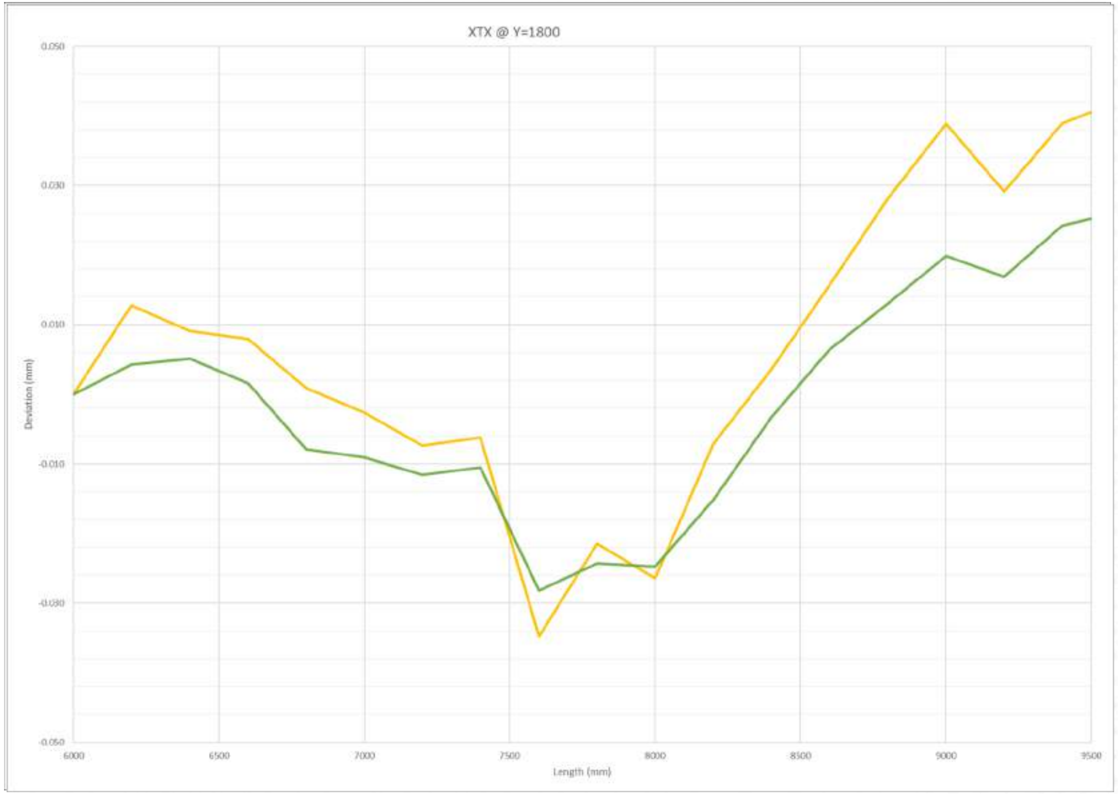


Relative Bias - Results

Volumetric discrepancies

- As we move Y through the volume the observed X-Axis scaling changes…

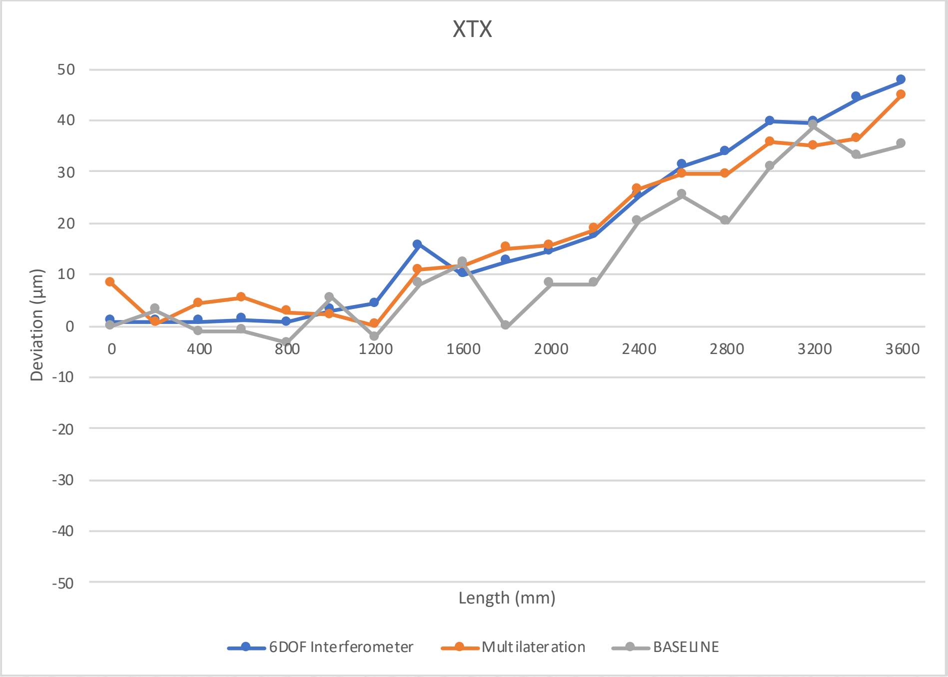
- Overlay the measurement data with the rigid body correction data, and the correlation and ‘shape’ are much closer.

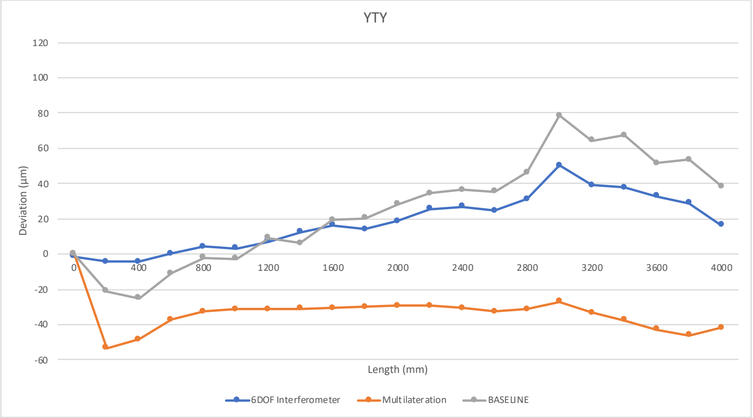


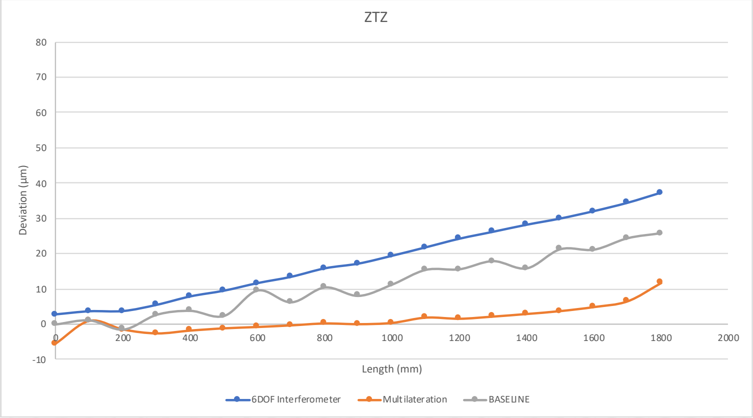
Relative Bias - Results

Volumetric discrepancies

- Using measurement data from a comparable volume
- Data agrees significantly better…







Acknowledgements

NATEP Funding & Partners

- INSPHERE Ltd – Lead Partner
  - Original BASELINE concept proposal
  - Overall process development: machine configurator, analysis algorithms and user interface
  - Previously delivered NATEP project (on time, on budget), which is now being successfully commercialised
- Nuclear AMRC – Partner
  - Experience in machine tool verification
  - Access to large machine tools
  - Access to alternative verification solutions
- Hexagon Manufacturing Intelligence – Partner
  - Metrology instrument hardware provider
- Rolls-Royce – End User
  - Industrial Needs, Application Parameters

Summary

And next steps

Summary

- Where we measure matters significantly
- Analysis methods/extraction of errors matters
- Philosophical questions on WHAT the end-user requires?

Next Steps…

- Still ploughing through data
- Diagonals & Volumetric data
- Analysis of squareness errors, dynamic errors, sensitivity analysis on sampling strategies.
- Demonstration day… 21st March 2019 NAMRC

Questions?

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