Development and testing of OPTIMUM

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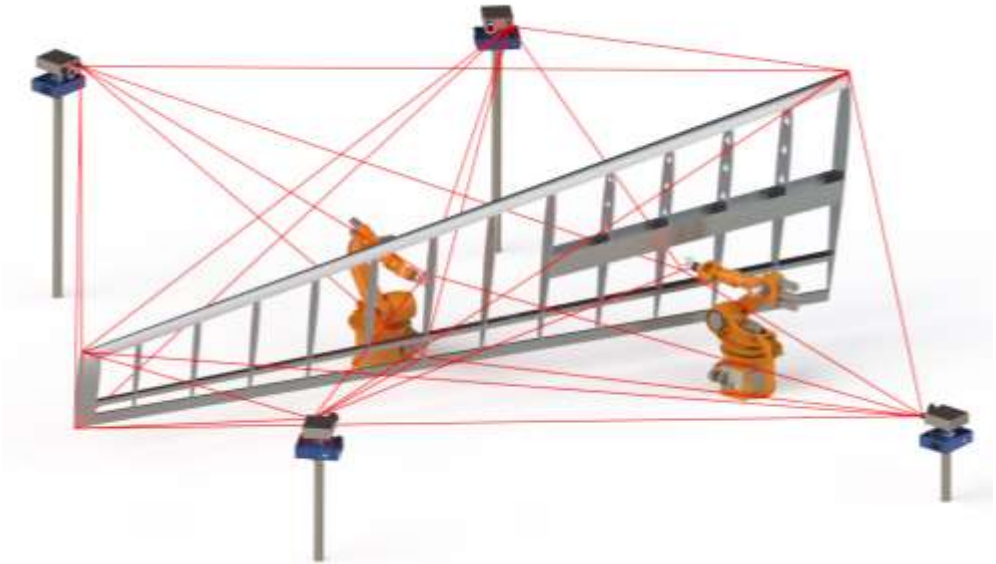
National Physical Laboratory

Questions from end-users

- How good is my instrument?
- How can I be sure my calibration is still valid?
- What's my measurement uncertainty?

Objective is to make a CMS that is:

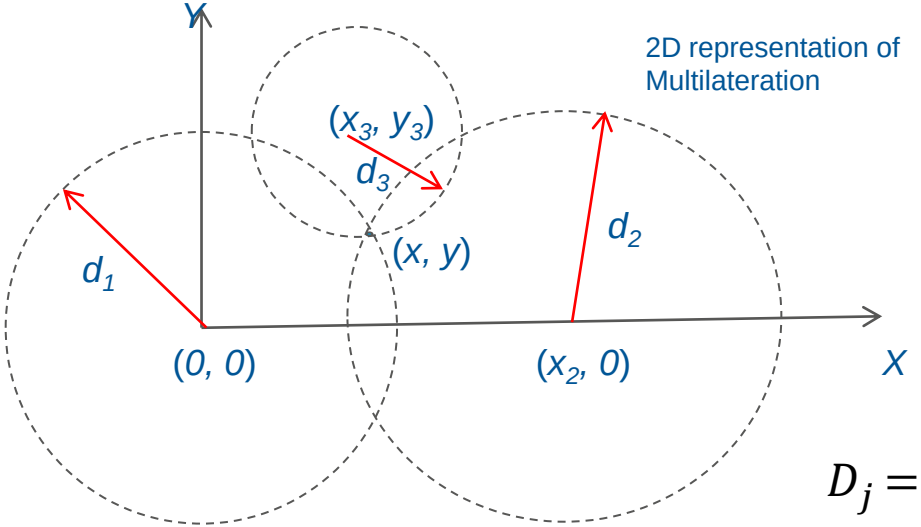
- As **accurate** as the state-of-the-art
- Measures **multiple points** simultaneously
- Inherent **Self-calibrating** – able to compensation for systematic errors
- Has built-in **traceability** to SI metre
- Gives on-line **uncertainty estimation**
- Operating volume 10 m x 10 m x 5 m



OPTIMUM

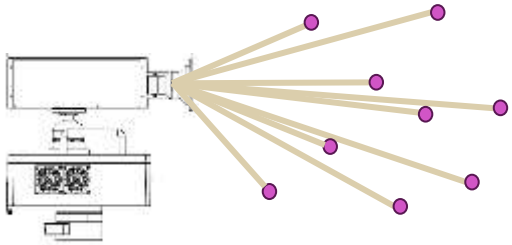
OPtical **T**racking Instrument for **M**easurement **U**sing **M**ultilateration

MULTILATERATION is the process of determining locations of points by measurement of **distances** using the geometry of circles or spheres.

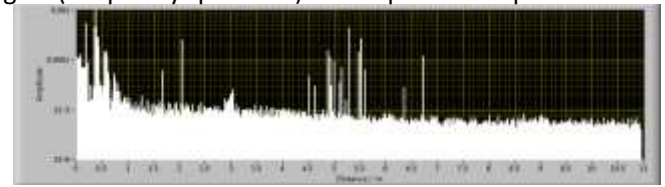


Coordinates are computed by fitting a mathematical **geometric model** to the observed distance measurements. Simultaneously, uncertainty contributions are propagated along with noise and other disturbances through a **stochastic model** to estimate **coordinate uncertainties**.

FREQUENCY SCANNING INETERFEROMETRY (FSI) can measure **distances** to multiple targets simultaneously with **inherent traceability via a gas absorption cell** and the defined speed of light, ***c***.

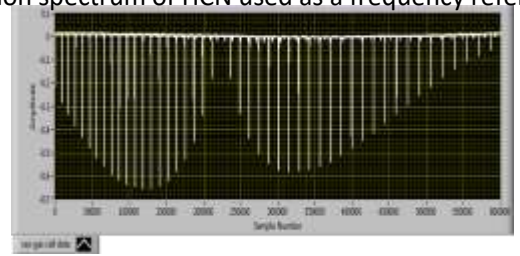


FSI signal (frequency spectrum). Each spike corresponds to a target.

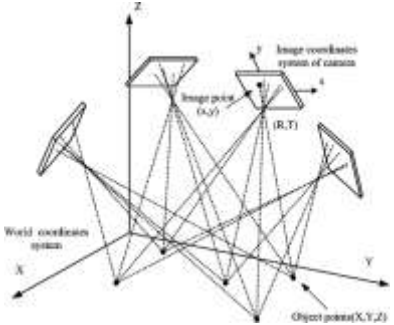


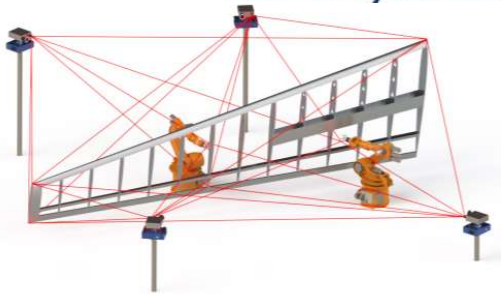
$$D_j = c \frac{f_j}{2\, dv/dt}$$

Absorption spectrum of HCN used as a frequency reference.



Comparison with state-of-the-art



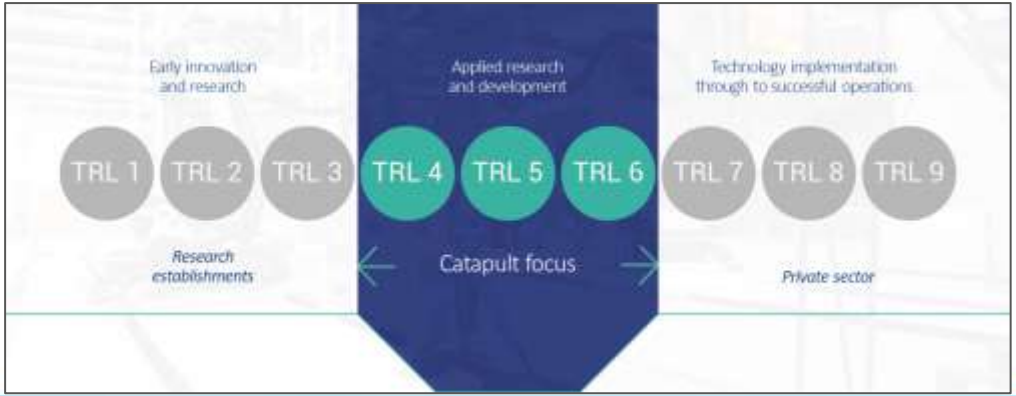


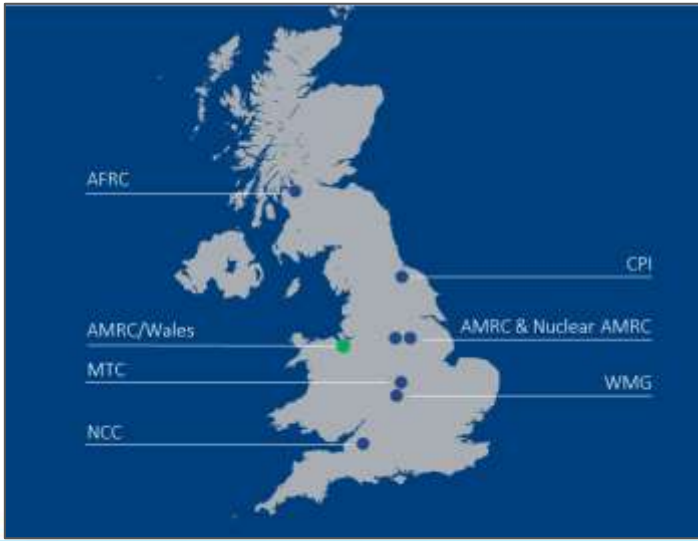
	Photogrammetry	GPS	OPTIMUM
Basic principle	Triangulation - angles	Multilateration, absolute distance, time-of-flight	Multilateration, absolute distance, frequency scanning interferometry
Volume	<1 m^3 to > 10^6 m^3	10^{12} m^3	or > 500 m^3
Precision	$1:10^5$ to $1:10^4$ (determined 'real time')	$0.3:10^6$ (~4 m) (determined 'real time')	$<1:10^6$ (< 1 µm per m)
Uncertainty	$>1:10^5$	~$1:10^6$	~$2\text{-}5:10^6$ (**determined 'real time'**)
Traceability	Scale bar	On-board atomic clock	Gas absorption cell built-in
Calibration	Self-calibrating e.g. camera pose, optical distortion etc but needs scale information	Receiver clock, real-time	**Self-calibrating** - sensor pose, optical distortion, scale factor, real-time, all with uncertainties

AMRC Cymru

- Introduced to support the region's manufacturing community access advanced technologies to drive improvements in productivity, performance and quality.

Key themes:
- Automation
- Design for X
- Digitalisation and simulation
- Product and process verification





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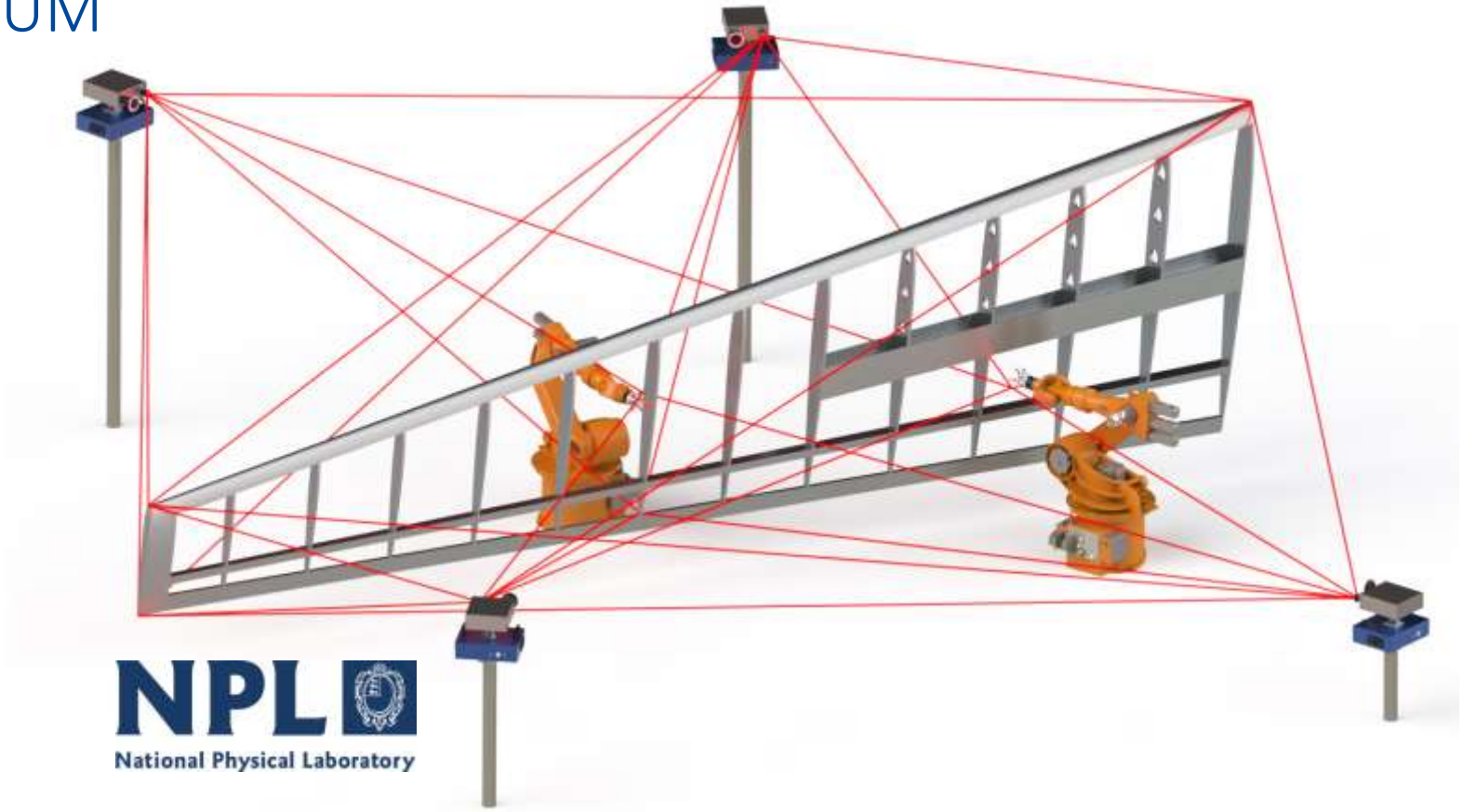
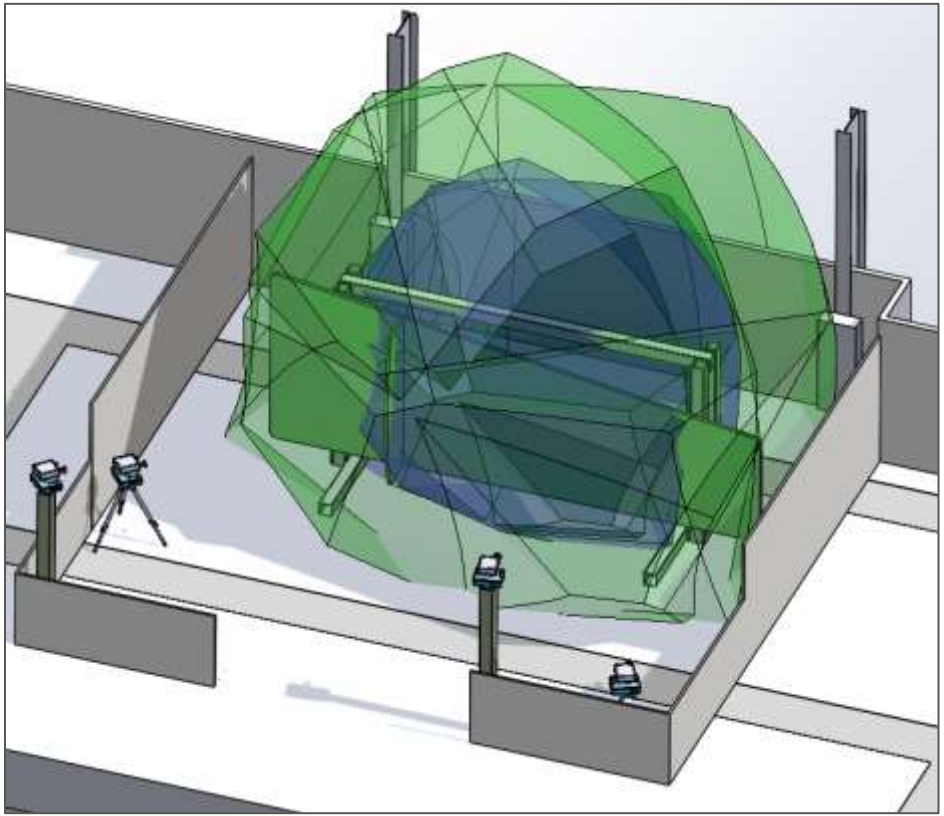
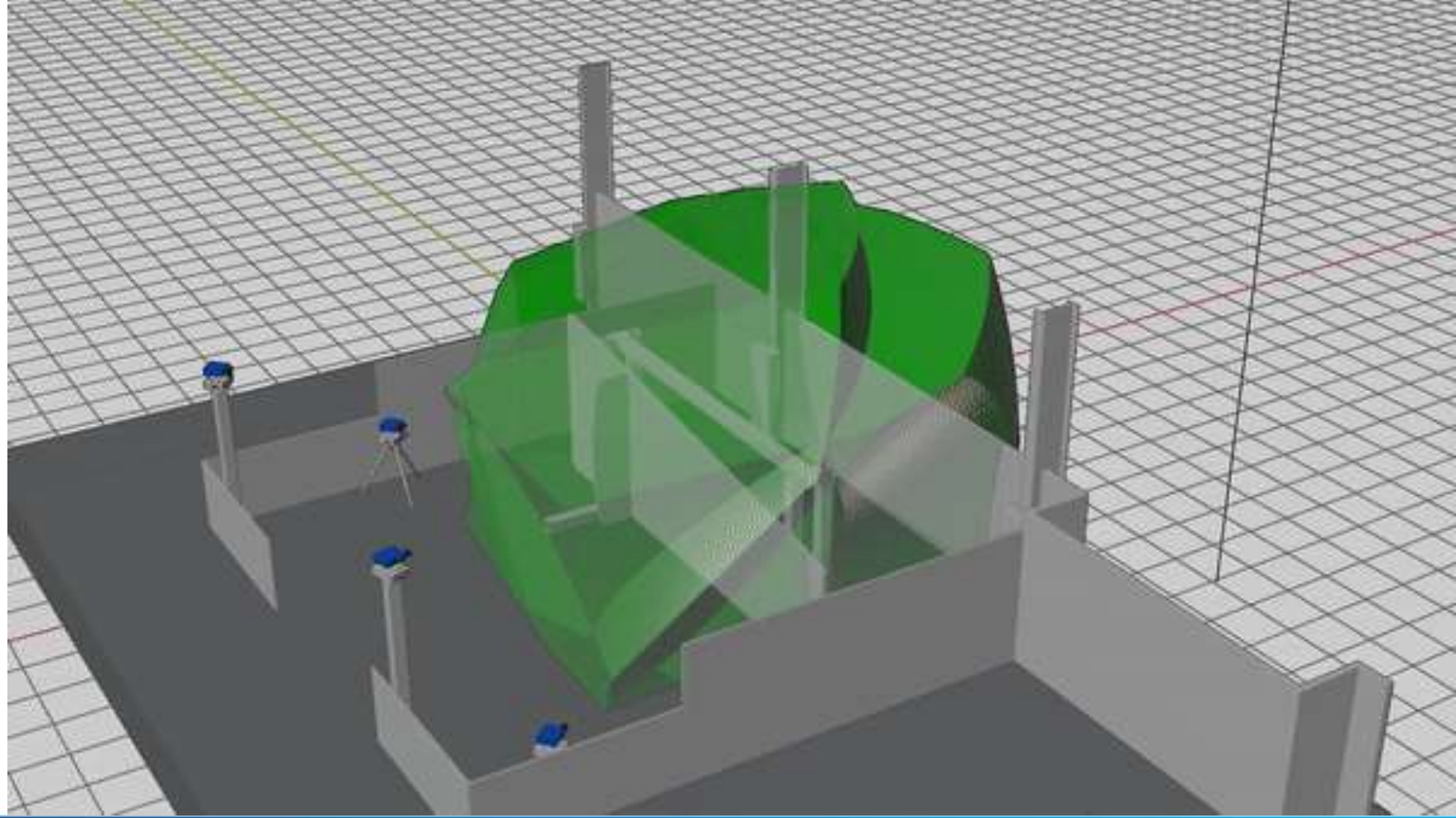


Measurement Volume:

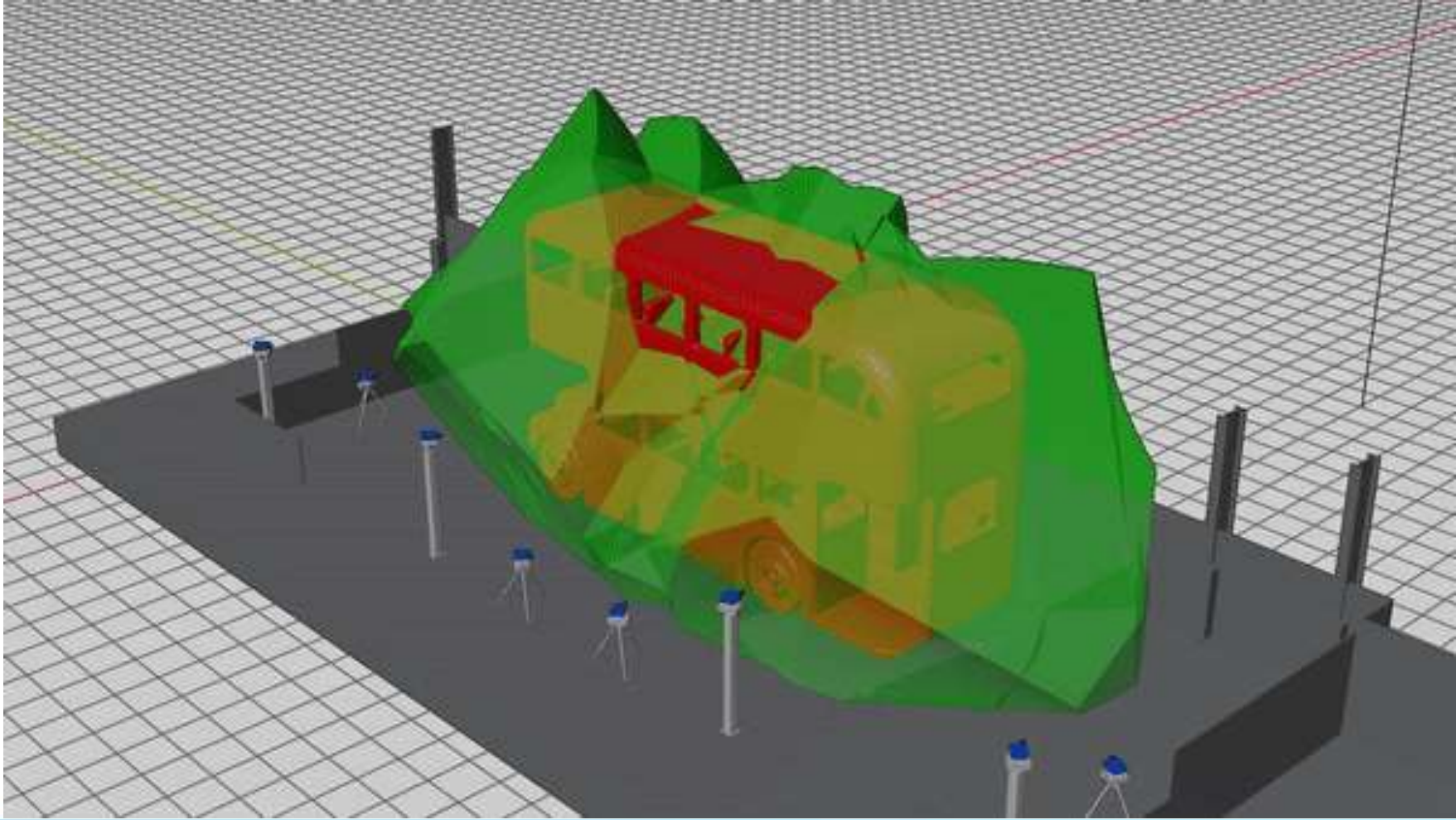
- Sensors have 10 metre range (potential to optimise range)
- Volume depends on geometry of setup
- Need to maintain line of sight to at least 3 sensors (4 to calculate uncertainties)
- We currently have constellation of 4 sensors, but our system can be expanded to 8 sensors.
- Simulation of volume configurations
- Able to simulate point/target uncertainty (based on geometry)



4 Sensor setup – Config 1



8 Sensor setup

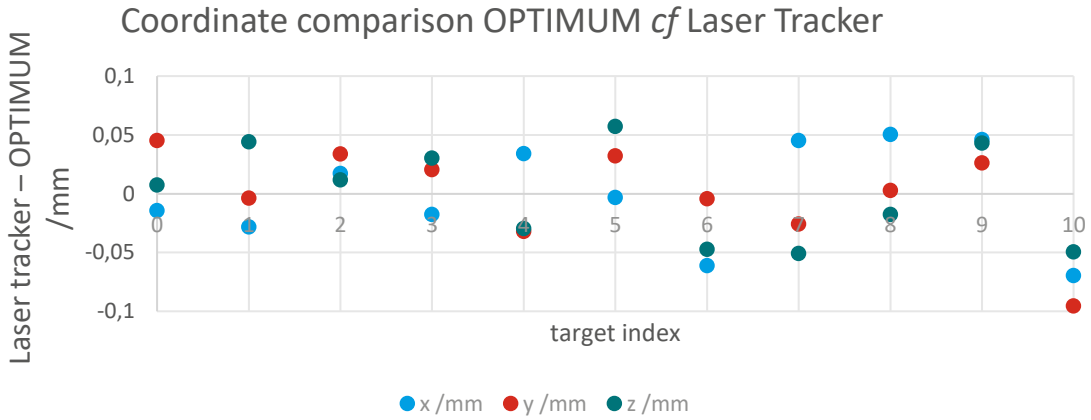


Targets:

- Diameter 17mm glass sphere
- Compatible with standard 1.5 inch nest
- High acceptance angle
- Relatively low cost

Accuracy:

- Dependent on setup geometry (sensor positions)
- Plan to use a laser tracker unified spatial metrology network (USMN) to baseline.
- Target tripods to allow measurement throughout volume
- Trials to determine accuracy are ongoing
- ISO 10360-13:2021 - Part 13: Optical 3D CMS



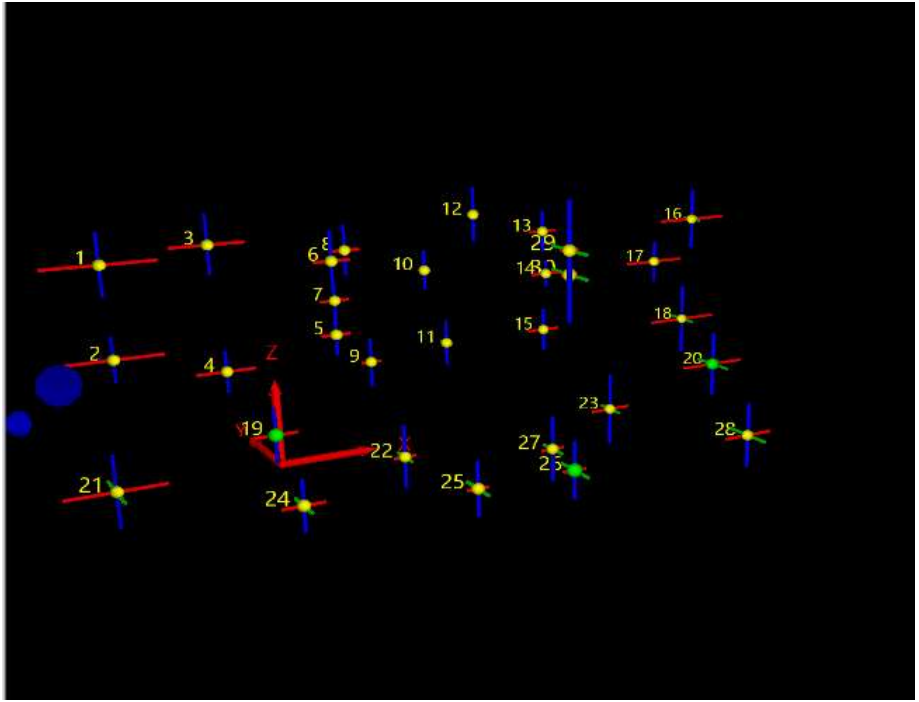
Point uncertainty

Simulation of point uncertainty:

- Based on geometry of sensor network and points
- Able to optimise network prior to measurement

Real time uncertainty:

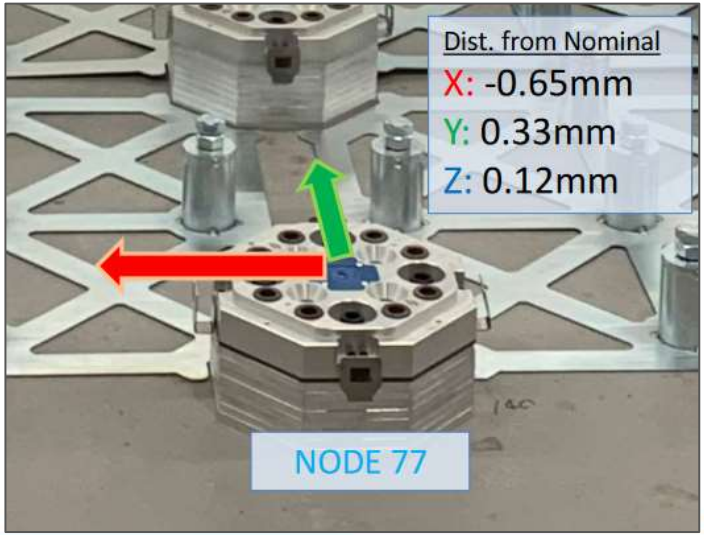
- Other solutions only provide MPE (maximum permissible error)
- Includes a number of factors:
    - Refractive index, gas cell reference
    - Environment
    - Geometry and systematic errors
    - Vibration
- Allows operators to make informed decisions / set a tolerance on allowable uncertainty.



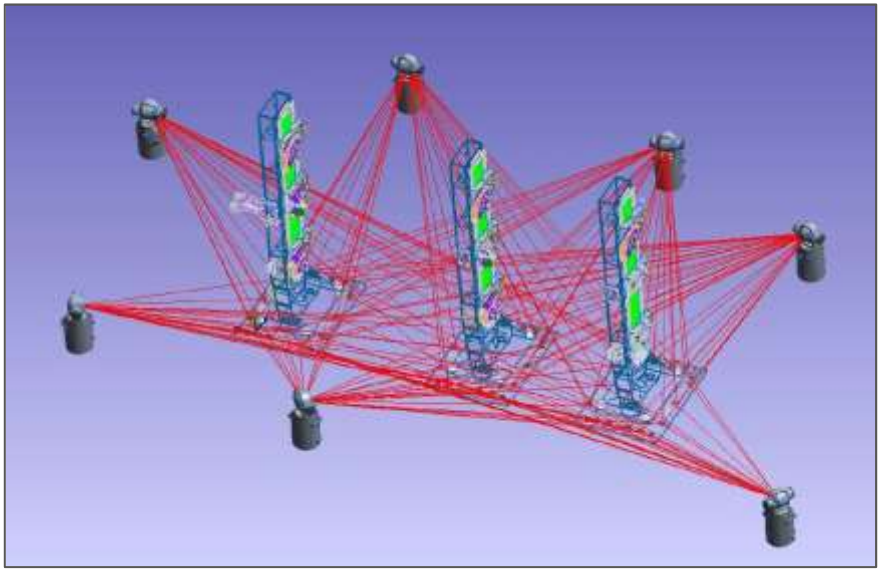
Ref: NPL

Application

- Aerospace jigs / fixtures
  - Certification
  - Fixture monitoring / digital twin
  - Re-configuring
  - Augmented reality - build inspect



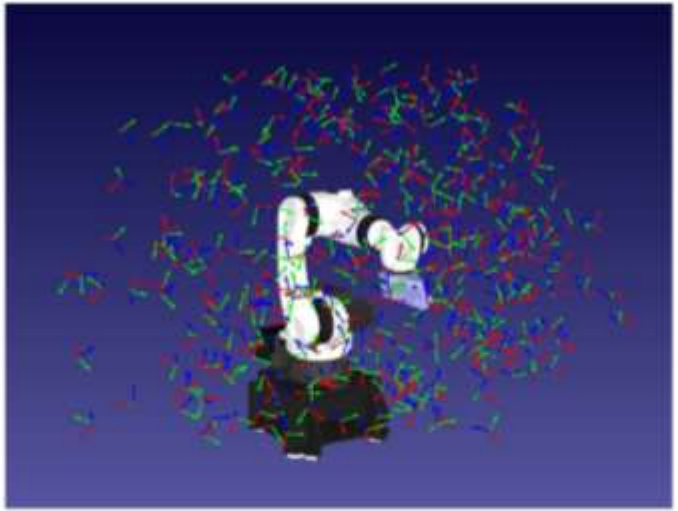
Ref: Electroimpact



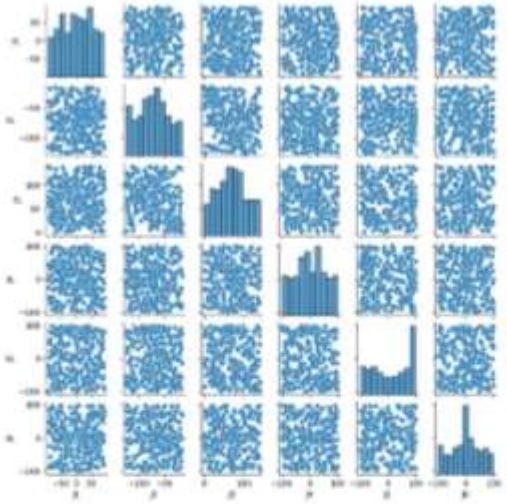
Ref: Electroimpact

Application

- Large machine tool calibration / serial arm robot



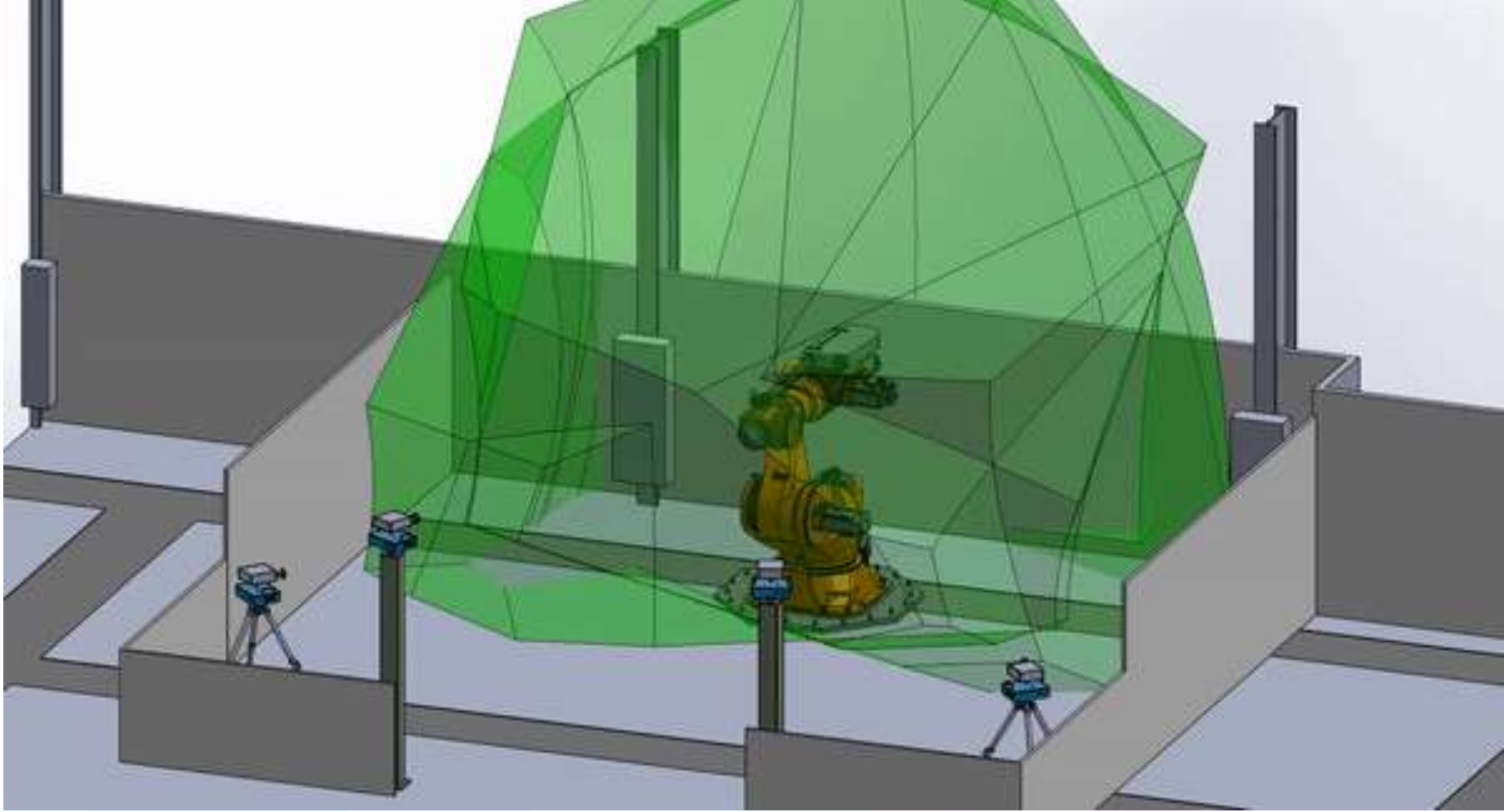
Typical array of KR120 TCP targets for measurement



Joints 'Pair Plot' to confirm randomized joint spread

Electroimpact Proprietary

Ref: Electroimpact



Thank you. For further information please contact or visit:

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