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Aerospace Assembly Automation

Improving robot accuracy for a large working volume using edge-deployed A.I.

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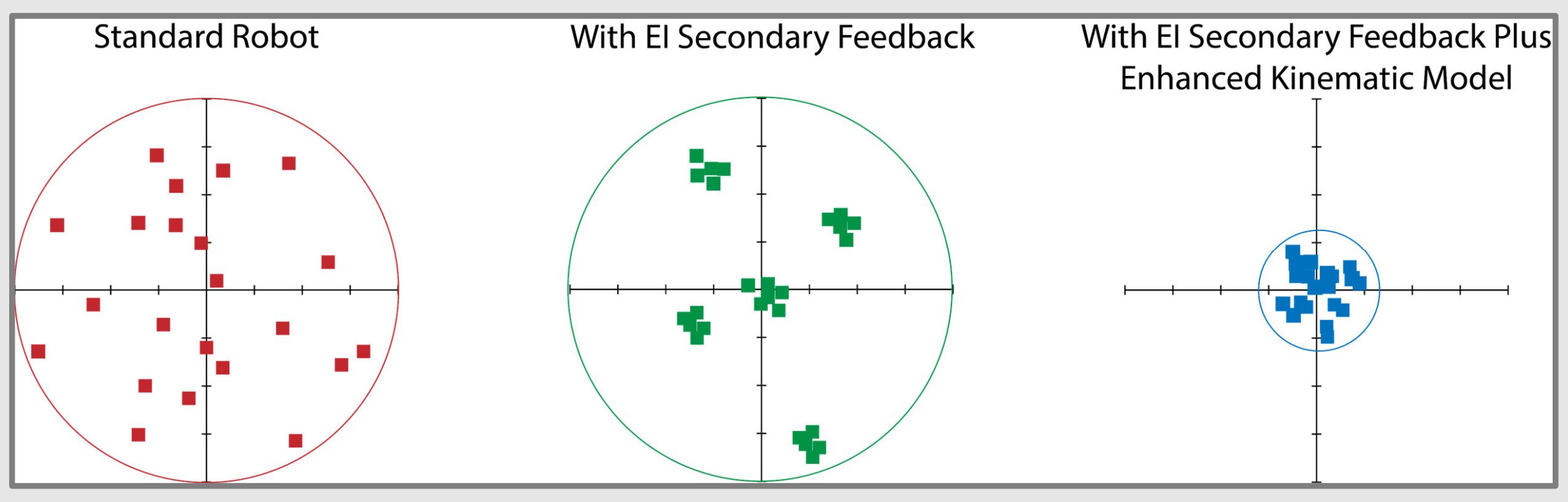
Introduction

Improving positional and path accuracy of industrial robots has long been a pursuit of robot manufacturers and system integrators.
Whilst repeatability figures are often <0.1mm (ISO9283), robot accuracy can vary wildly due to manufacturing tolerances, end effector design and even environmental factors.



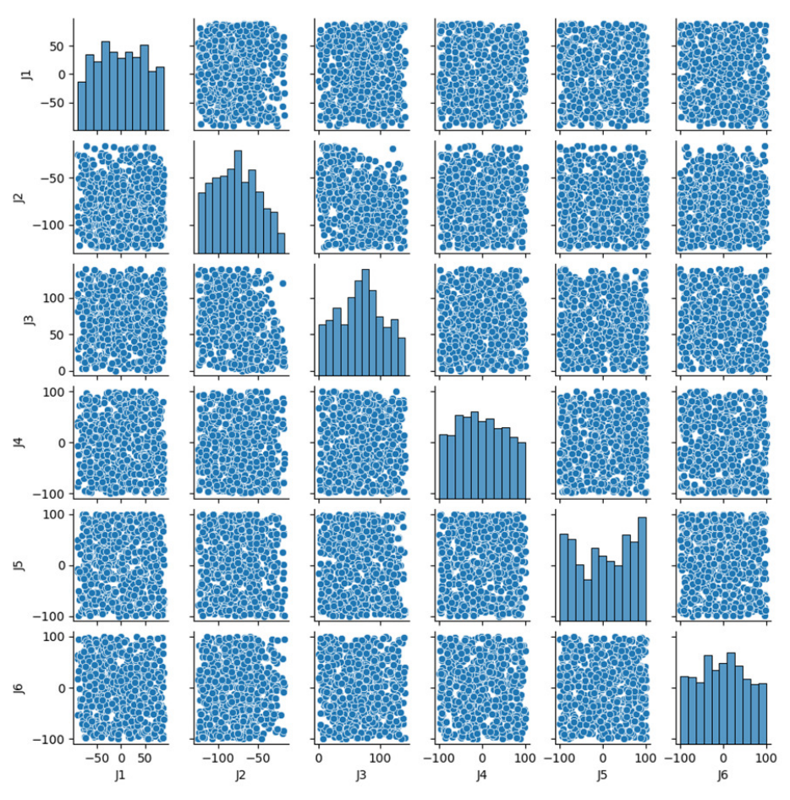
Electroimpact Accurate Robot Technology

www.electroimpact.com/Products/Robots/AchievingAccuracy

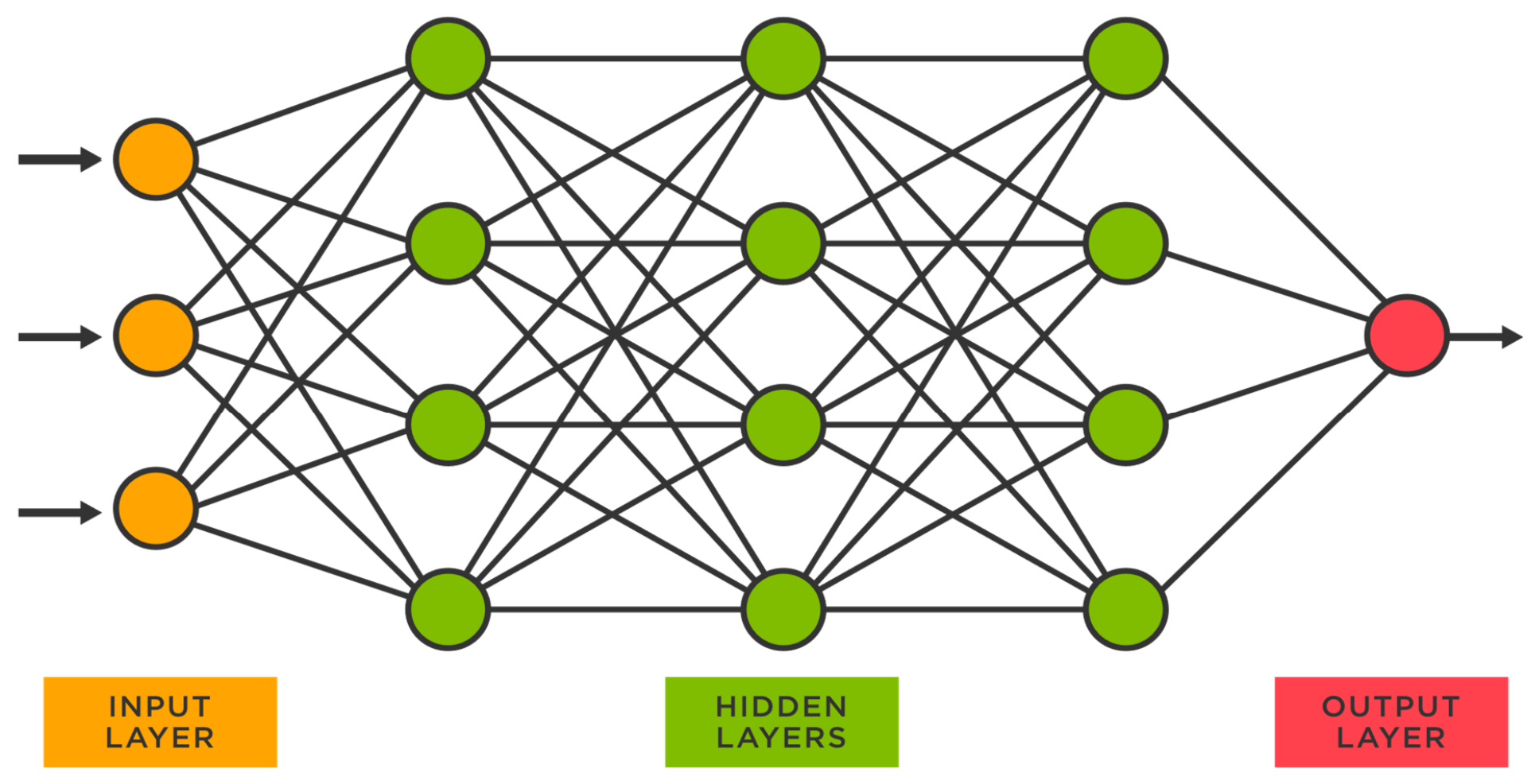
The standard calibration method for small working volumes uses external metrology measurements to optimize the kinematic parameters in the controller.
For more demanding applications (aerospace assembly), a replacement control system combined with secondary feedback can achieve <**0.25mm** (3σ).
This research investigates improving large volume accuracy using minimal additional hardware and advanced modelling techniques.

Developing edge deployable kinematic model

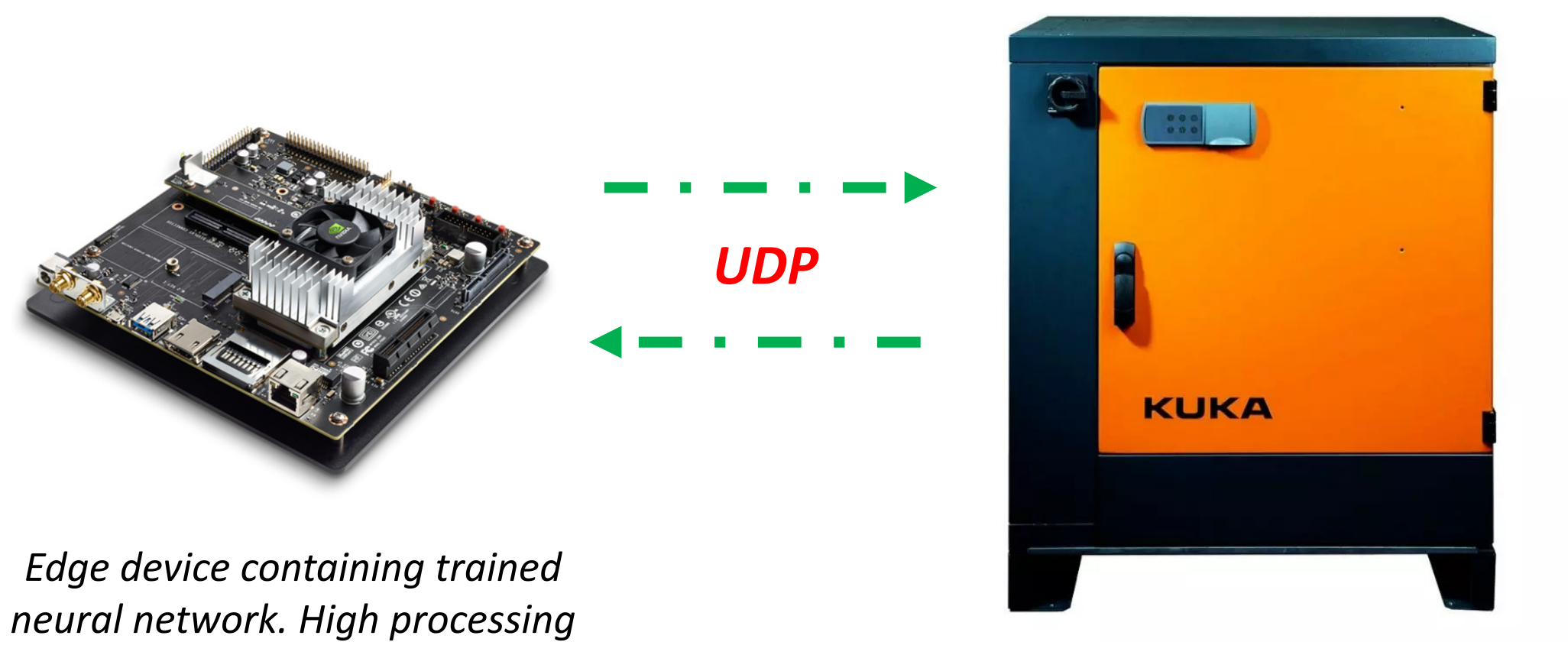
Target positions created over maximum visible volume for laser tracker measurements.
Initial trials performed on a Kuka KR120 R1800.



Pair plot to confirm stochastic nature of measured positions prior to pre-processing for the neural network.



Physics-informed neural network.
***Inputs:** Kinematic and environmental parameters, measured positional errors*
***Output:** corrected cartesian position*



Edge device containing trained neural network. High processing speed required to run both inference and kinematic tasks within controller cycle time

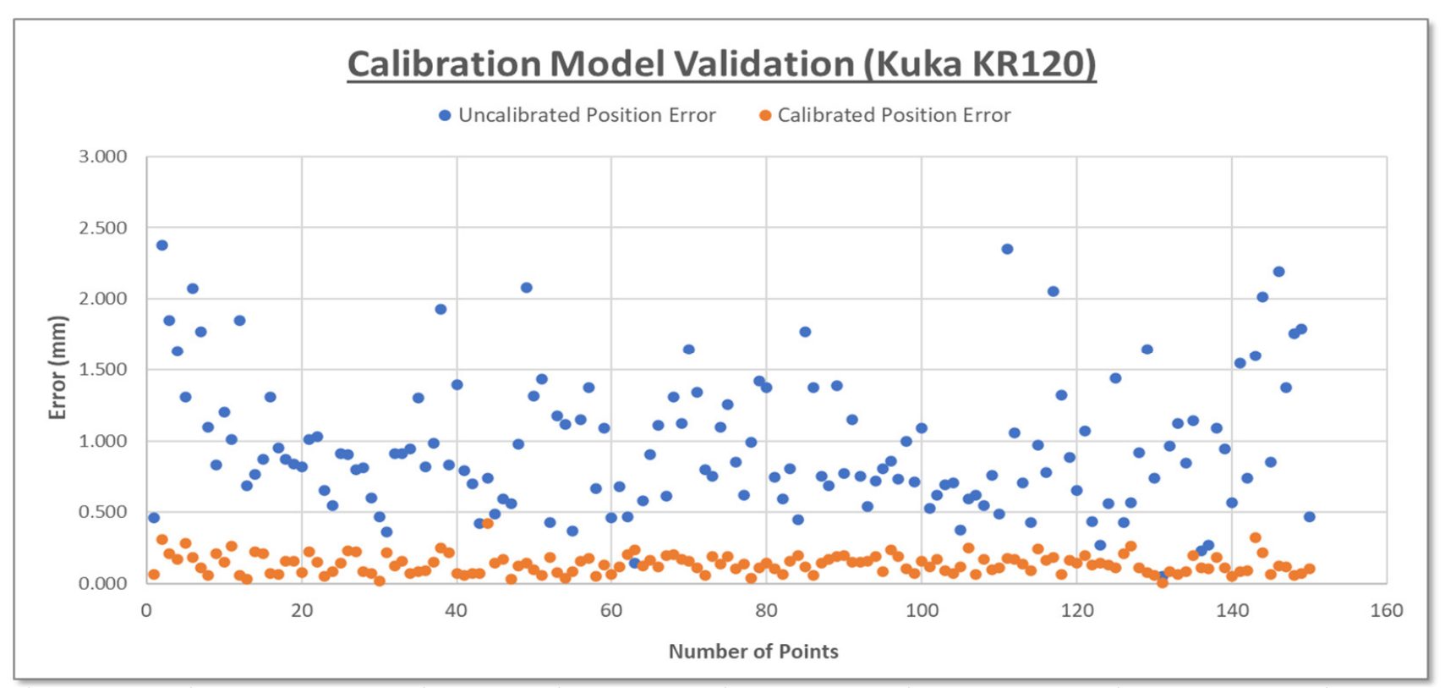
Standard robot controller with additional high-speed sensor control package

Measurement: Approximately 700 cartesian positions are measured using a laser tracker to create an error map. Due to line-of-sight limitations, Axis 1 (J1) is restricted to +/- 100° however the resultant volume is still far larger than the majority of robotic assembly and processing tasks.

Model creation and training: A custom neural network has been developed and optimised specifically to train using very small datasets whilst minimising overfitting. The trained model can be used natively for offline tasks (such as part program creation) or compiled and deployed to an edge device for 'real-time' inference tasks.

Deployment: A high-speed edge device allows positional corrections to be sent directly to the motion controller using optional software packages (i.e. KUKA Robot Sensor Interface (RSI), or FANUC Dynamic Path Modification (DPM).

Validating results for discreet positions and dynamic paths

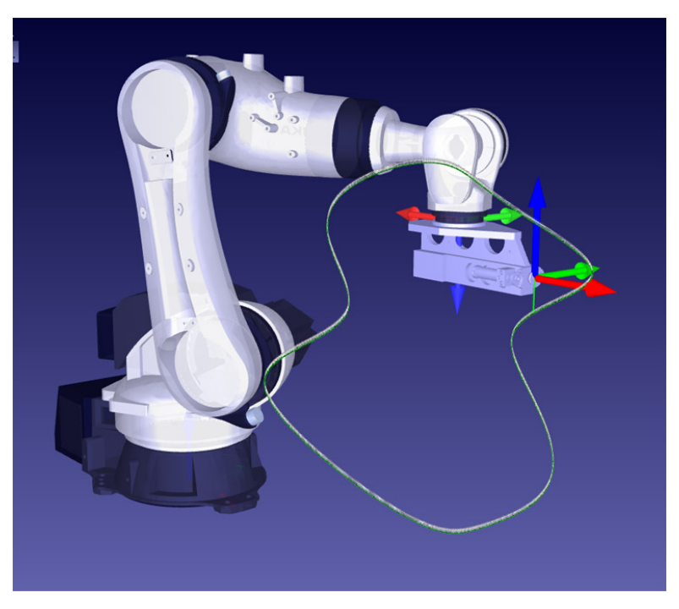


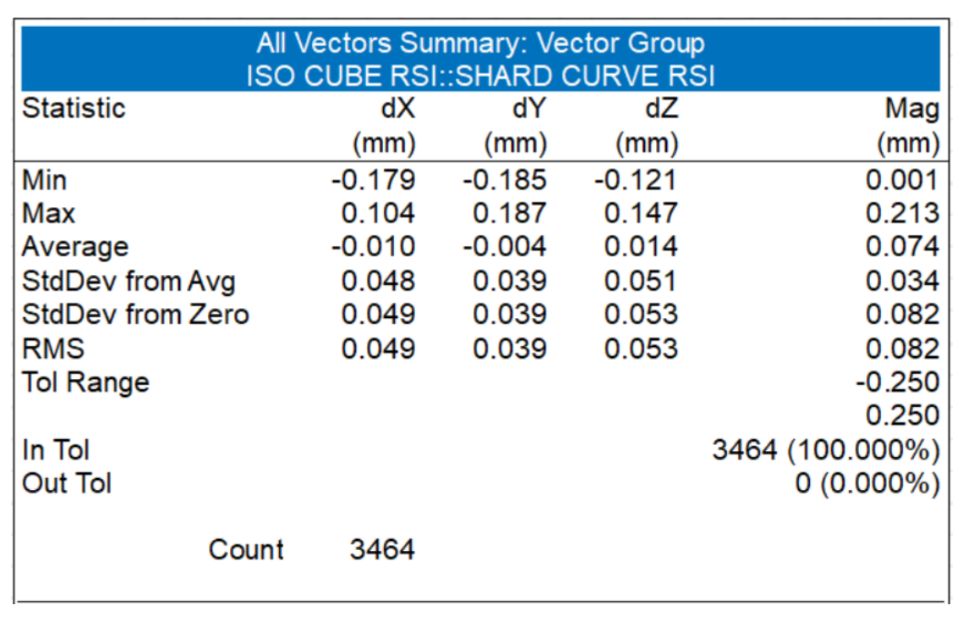
MEASURED POSITIONAL ERRORS

MAX (mm)	MIN (mm)	AVERAGE (mm)	RMS	% <0.5mm	% <0.25mm	STD_DEV (mm	3_SIG (mm)	6_SIG (mm)
2.354	0.008	0.926	1.033	16.2%	2.7%	0.457888	**2.300**	**3.674**

CALIBRATED POSITIONAL ERRORS

MAX (mm)	MIN (mm)	AVERAGE (mm)	RMS	% <0.5mm	% <0.25mm	STD_DEV (mm	3_SIG (mm)	6_SIG (mm)
0.423	0.008	0.137	0.153	100.0%	94.7%	0.067126	**0.338**	**0.540**

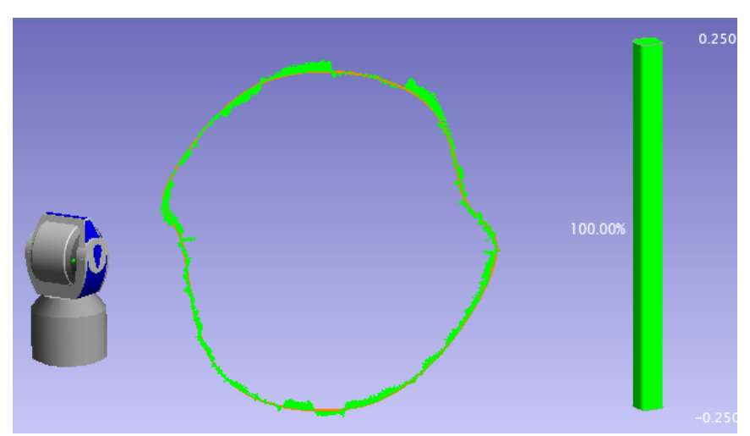


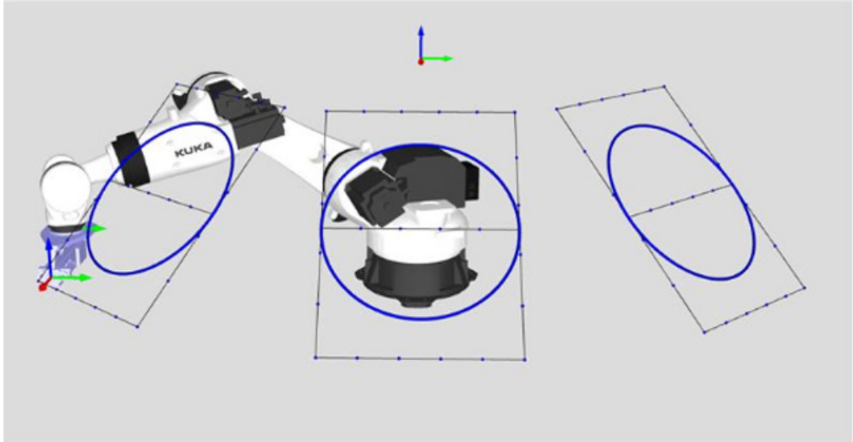


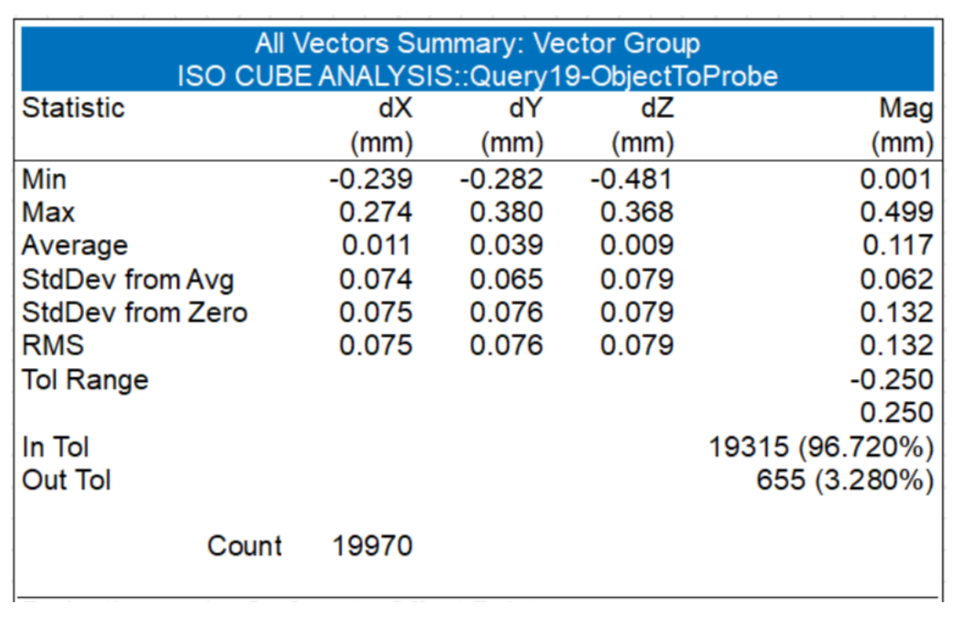
All Vectors Summary: Vector Group
ISO CUBE RSI::SHARD CURVE RSI

Statistic	dX (mm)	dY (mm)	dZ (mm)	Mag (mm)
Min	-0.179	-0.185	-0.121	0.001
Max	0.104	0.187	0.147	0.213
Average	-0.010	-0.004	0.014	0.074
StdDev from Avg	0.048	0.039	0.051	0.034
StdDev from Zero	0.049	0.039	0.053	0.082
RMS	0.049	0.039	0.053	0.082
Tol Range				-0.250 0.250
In Tol				3464 (100.000%)
Out Tol				0 (0.000%)
Count	3464			

Above: Offline creation of nominal curve follow program
***Right:** Measurements captured and evaluated in Spatial Analyzer*



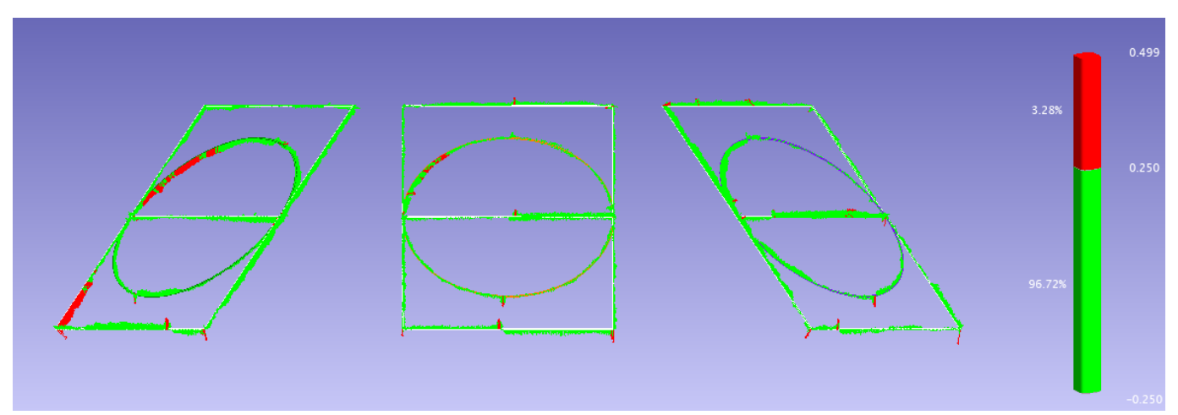




All Vectors Summary: Vector Group
ISO CUBE ANALYSIS::Query19-ObjectToProbe

Statistic	dX (mm)	dY (mm)	dZ (mm)	Mag (mm)
Min	-0.239	-0.282	-0.481	0.001
Max	0.274	0.380	0.368	0.499
Average	0.011	0.039	0.009	0.117
StdDev from Avg	0.074	0.065	0.079	0.062
StdDev from Zero	0.075	0.076	0.079	0.132
RMS	0.075	0.076	0.079	0.132
Tol Range				-0.250 0.250
In Tol				19315 (96.720%)
Out Tol				655 (3.280%)
Count	19970			

***Above:** Offline creation of nominal ISO test path program*
***Right:** Measurements captured and evaluated in Spatial Analyzer*



Validation: In additional to the measured points for training the model, a smaller validation dataset is captured to evaluate the model's performance at discrete (static) locations. Initial results show calibrated positional errors in the range **0.29mm** to **0.44mm** (3σ) across the full measured volume for three different robots:
(KUKA KR120, KUKA KR6, FANUC 200iD/7L)

Dynamic Path Following: Using a cutting profile for a typical composite structure, the edge device was used to provide 'real-time' corrections to the motion controller whilst following the nominal programmed path.
100% of the **3464** measured points fell within **0.25mm** of the nominal curve. (KUKA KR120)

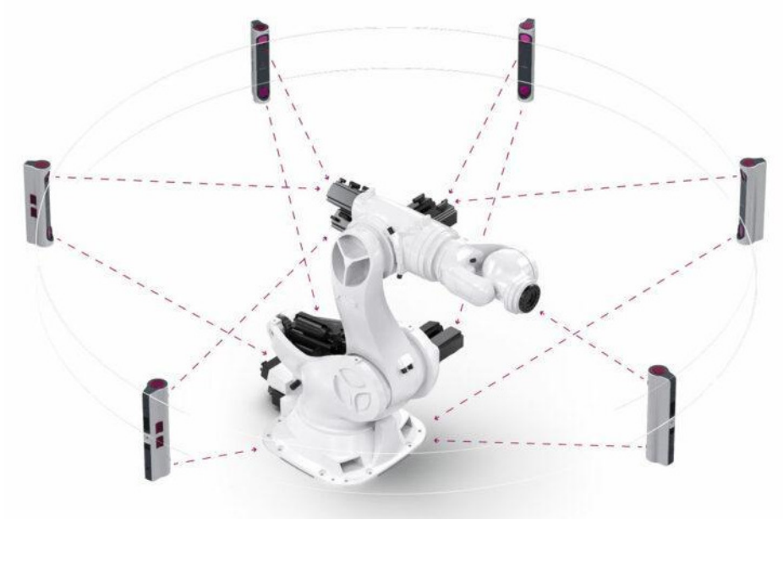
Dynamic Path ISO Cube: To validate path accuracy over a larger volume, the ISO9823 test procedure was generated using offline simulation software at three different rotations: **-45° , 0 °, 45 °.**
96.72% of the **19970** measured points fell within **0.25mm** of the nominal curves. (KUKA KR120)

Future Work: Enhanced data capture and multi-model solutions

Using a laser tracker to capture the position error datasets has two key limitations:

- ***All measurement poses must be within the tracker field of view which limits the dataset volume***
- ***The SMR often requires a manual rotation to achieve line of sight, limiting the size of the robot that can be measured practically***

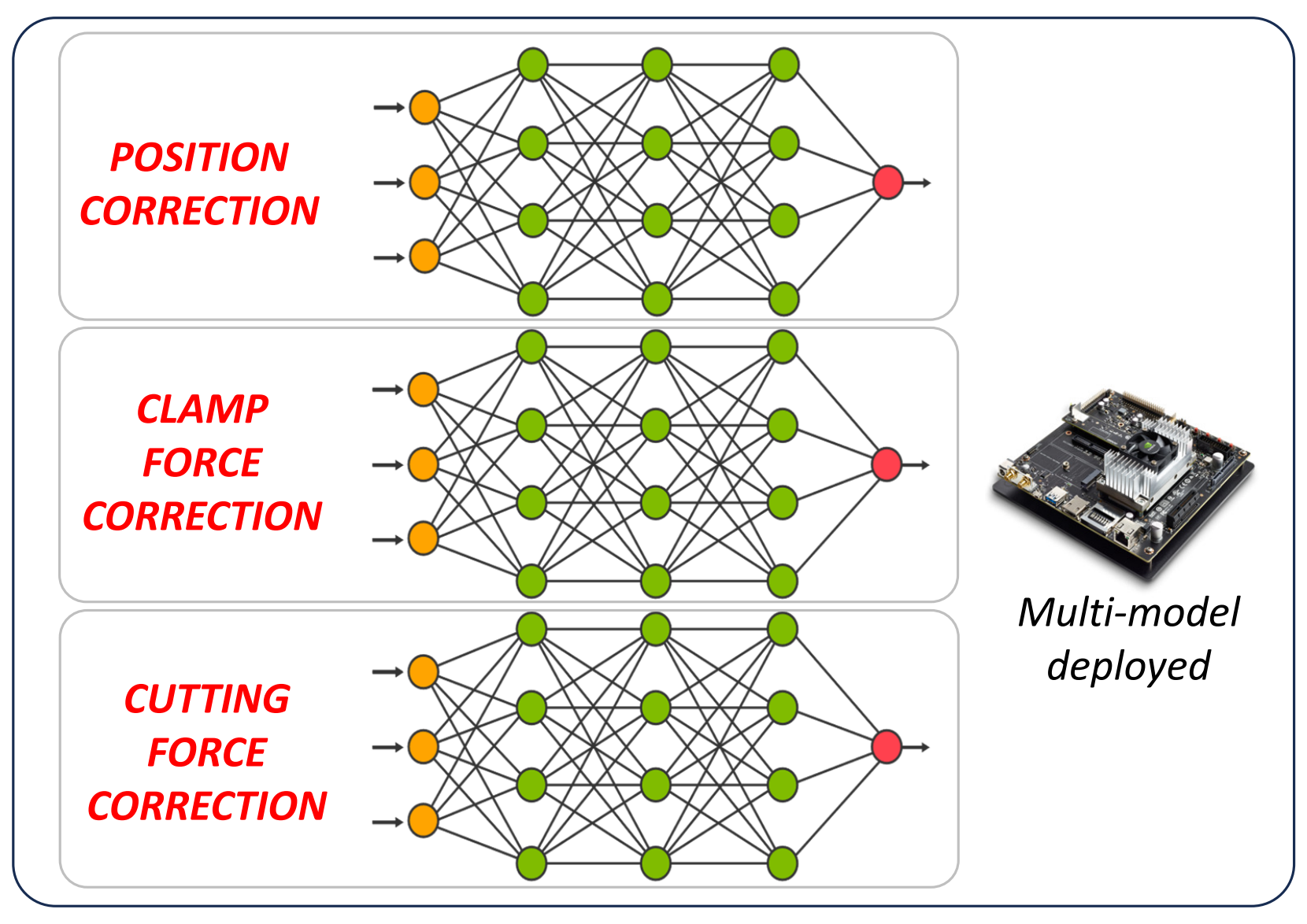
Alternative metrology systems are currently being trialed to mitigate these limitations whilst maintaining the measurement accuracy required for the neural network to successfully converge.



Insphere IONA is a multi-sensor system which can offer an increased measurement volume

Nikon APDIS Laser Radar for non-contact measurement of spherical targets

The path following measurements captured to date have been under a zero-force condition. By utilising a similar neural network methodology, additional correction models can be 'stacked' and deployed to a single edge device.
High speed radial and axial load sensor data can be fed directly to the robot controller allowing 'real-time' corrections – opening up new robotic applications for accurate milling and trimming.



Multi-model deployed

Typical robotic milling application

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