3DMC 2016 1ST 3D METROLOGY CONFERENCE

University of Strathclyde Engineering

Mosaicing for Automated Pipe Scanning (MAPS)

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Background

- 3 year, £1.24M Innovate UK funded Collaborative Research and Development Project (Nuclear Call)
    - Commenced April 2015
    - Follows on from a successful 6 month Innovate UK funded feasibility study 2013-2014

- Objective is to develop innovative new optical hardware and advanced image processing techniques for interactive 3D remote visual inspection (RVI) of pipe work

- 5 member consortium
    - University of Strathclyde
    - Wideblue
    - National Nuclear Laboratory
    - Sellafield Ltd
    - Inspectahire

Motivation

- Remote visual inspection (RVI) is critical for the inspection of the interior condition of pipe work particularly in the nuclear, oil and gas industries

- Conventional RVI equipment produces a video which is analysed online.

- MAPS will convert video feed into 3D textured map of the interior surface of pipe

- Target 2 - 6 inch diameter pipes (80% of pipework is in this range)

- ***Advantages***
    - Minimise inspection/interpretation time of video
    - Replace video with CAD model
    - Improve inspection quality and traceability
    - Provide accurate defect localisation and sizing
    - Act as a positioning system for additional sensors

Example of current technolog

MAPS Probe

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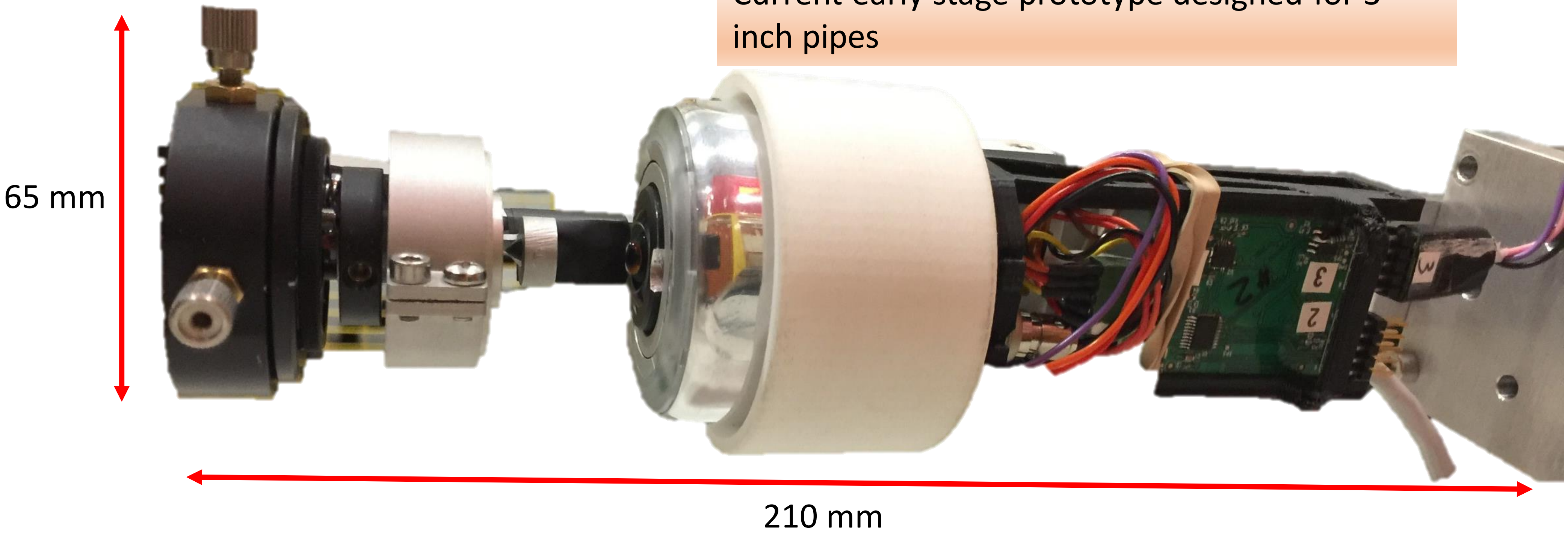
- Maximum pipeline length of 50 m
- Measure inner diameter with an error < 1mm
- Defect resolution of 0.1 mm
- Negotiate 4 x outer diameter bends

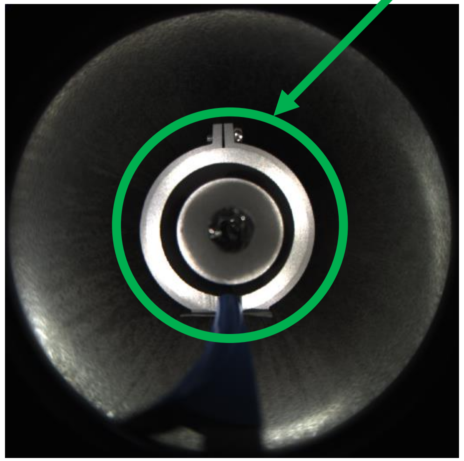
Current early stage prototype designed for 3 inch pipes

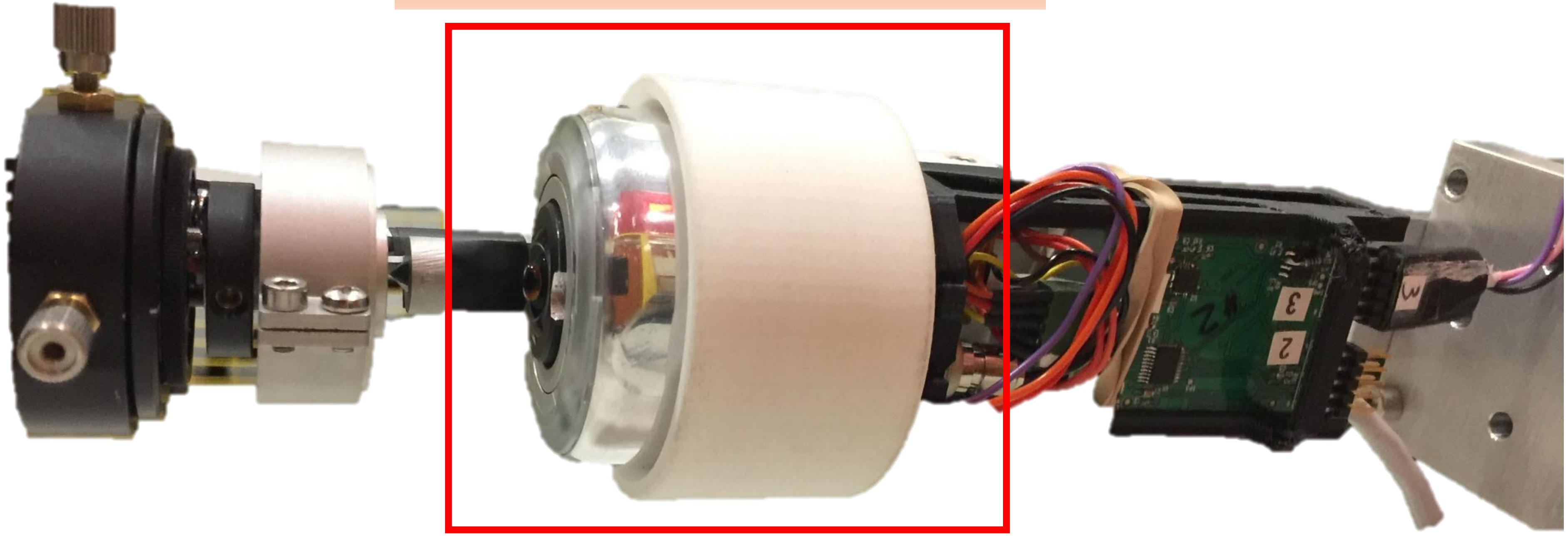


MAPS Probe

- High resolution image sensor and fisheye lens
- LED illumination active
- Use feature extraction to reconstruct surface model
- Central region discarded

Hi Res Camera + LED Illumination Ring and Diffuser





MAPS Probe

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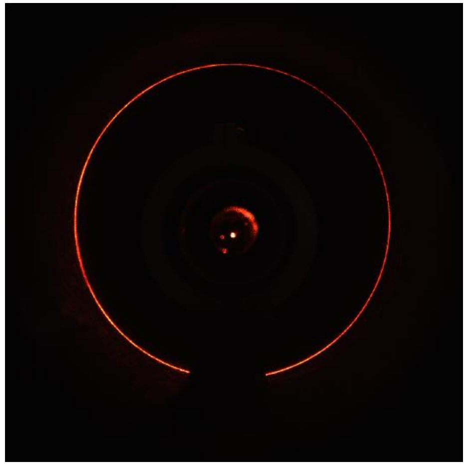
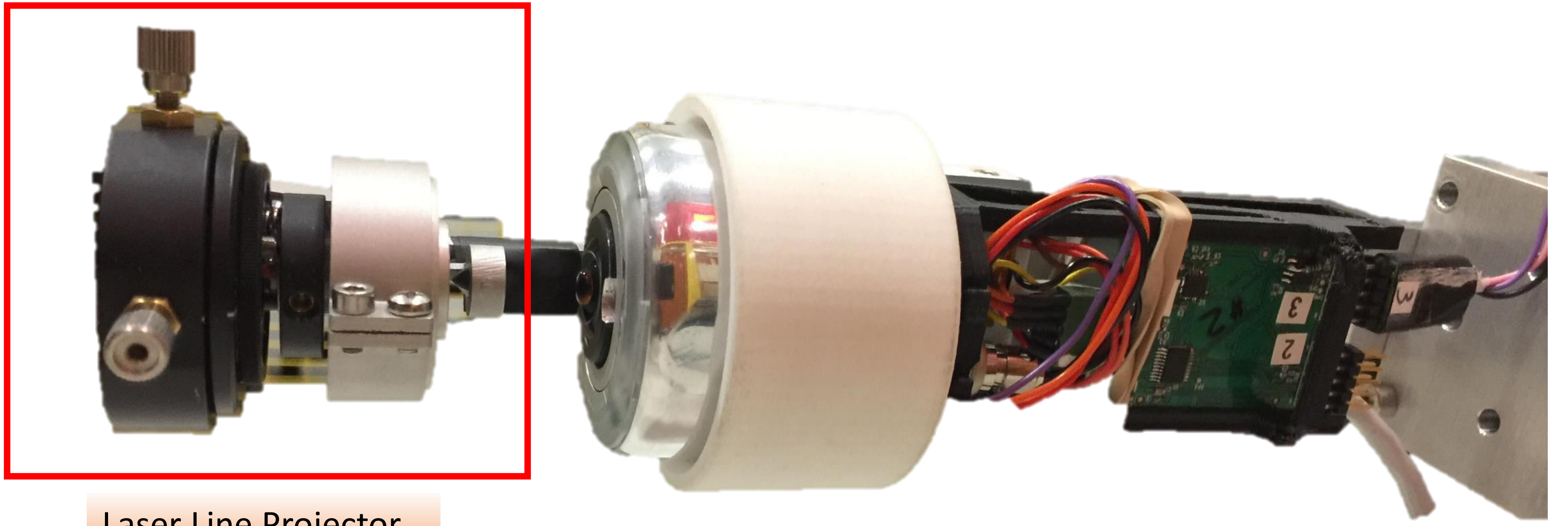
- Laser metrology subsystem
- LED illumination deactivated to aid red laser line extraction
- Translation and orientation adjustment stages for alignment of optical axes

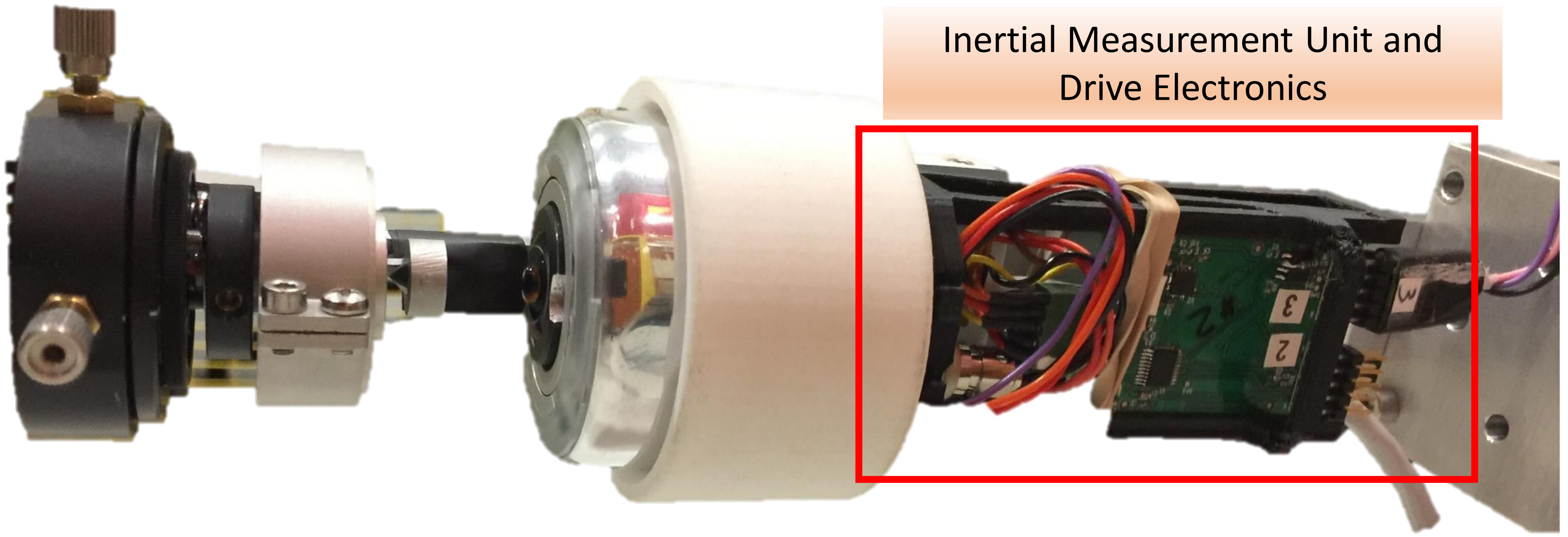




Laser Line Projector

MAPS Probe

- Inertial Measurement Unit used to assist when low/zero feature regions are encountered
- Synchronised measurements with camera
- Potential to provide a source of scaling information for the reconstruction



Processing Approach

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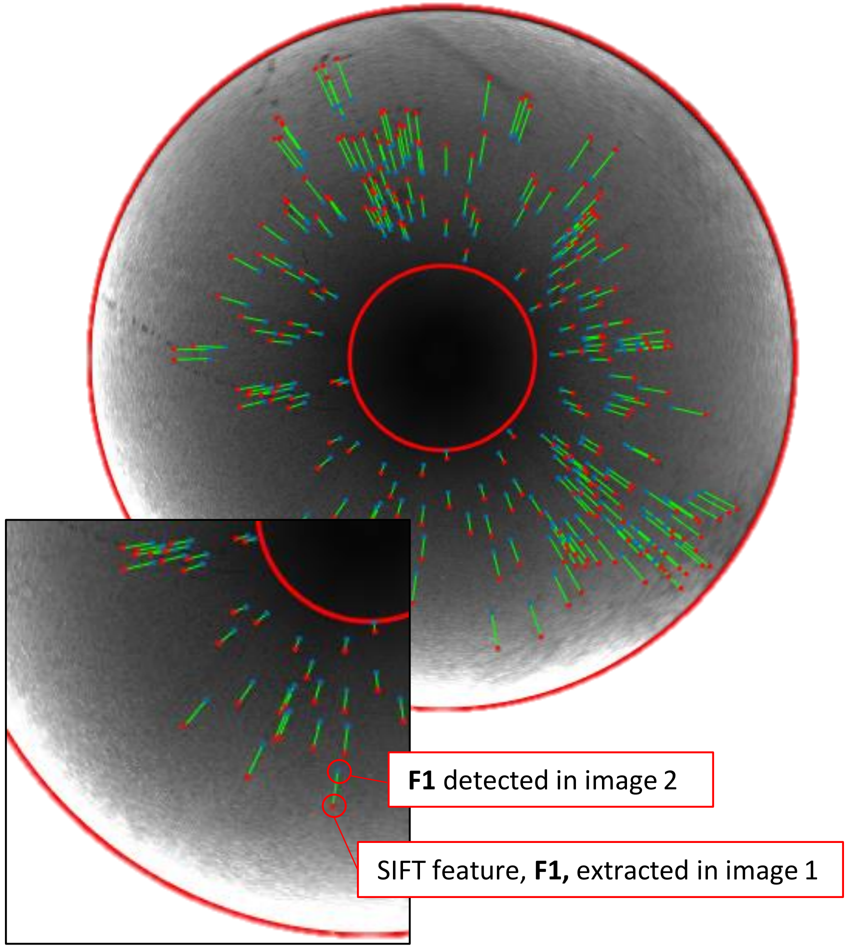
- Push probe to the end of the pipeline and retract at an approximately constant speed
- Measurements on the way in AND out would enable loop closures and therefore bundle adjustment to be effective
- Use the photogrammetric input as a positioning system for projection of high accuracy laser measurements
- Use nominal CAD data to constrain reconstruction by adding control points into reconstruction process
- Project image data on mesh formed from laser point cloud to form photorealistic model

Feature Extraction

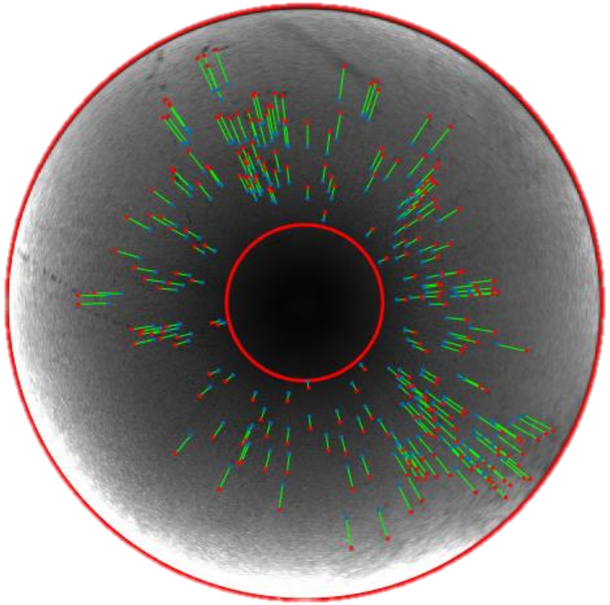
- Image summarised by a set of point features corresponding to textured patches of the image

- For 3D reconstruction at **least 5 features** must be matched across the images to compute the Essential Matrix.
  - If more features are available a least squares estimate can used.
  - Should be well distributed around the image



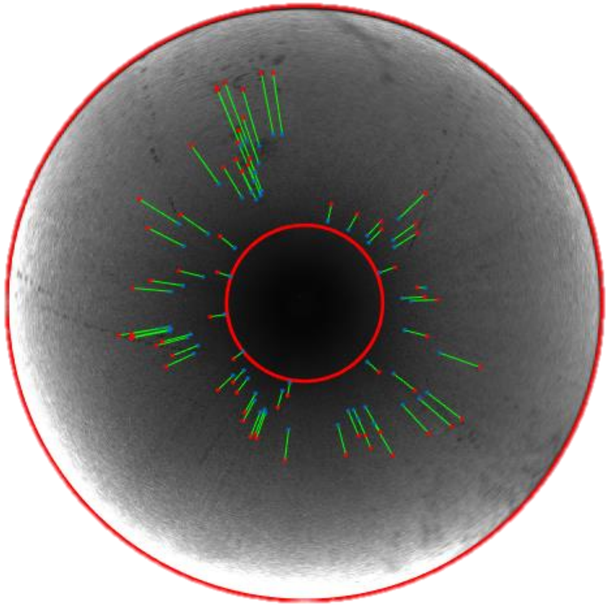
Feature Extraction

Overlap 80% = 5mm



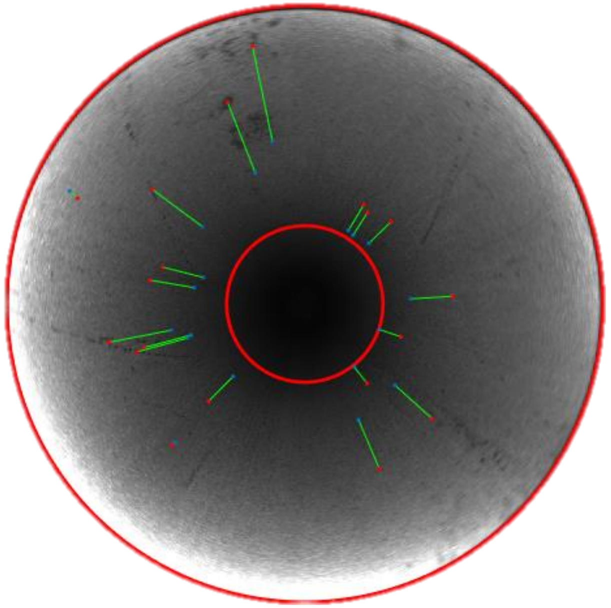
M = 327.8

Overlap 40% = 10mm



M = 81.7

Overlap 26% = 15mm



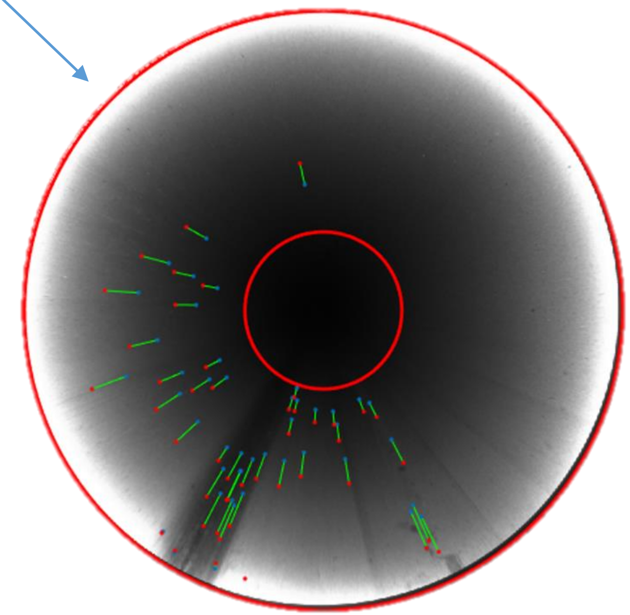
M = 23.3

- M: Average Match Count

Feature Extraction

- Pipework composed of engineering materials which tend to have a uniform texture
  - *Big problem for features which are essentially gradient information!*
- Evaluate plethora of feature extraction algorithms in literature to determine most suitable in use case
- Performance metrics used

1. $\textbf{Putative Match Ratio} = {\#putative\ matches}/{\#features}$
2. $\textbf{Matching Score} = {\#correct\ matches}/{\#features}$
3. $\textbf{Precision} = {\#correct\ matches}/{\#putative\ matches}$



Stainless Steel Pipe

Feature Extraction

- Gold standard algorithm SIFT performed best out of the set of algorithms
- Of note is that BRISK and MSER performed very poorly
- Information loss in going from floating point numbers to binary is very evident for this type of image

Algorithm	Mean Putative Match Ratio	Mean Precision	Mean Matching Ratio	Mean Feature Count	Distribution
SIFT	0.1657	0.99	0.1656	1278	Good
MSER	N/A	N/A	N/A	3.1	N/A
BRISK	N/A	N/A	N/A	2.3	N/A
AKAZE	0.1901	0.8377	0.1620	188.6	OK
CENSURE	0.7223	0.8872	0.6393	10.9	Poor

Camera Model

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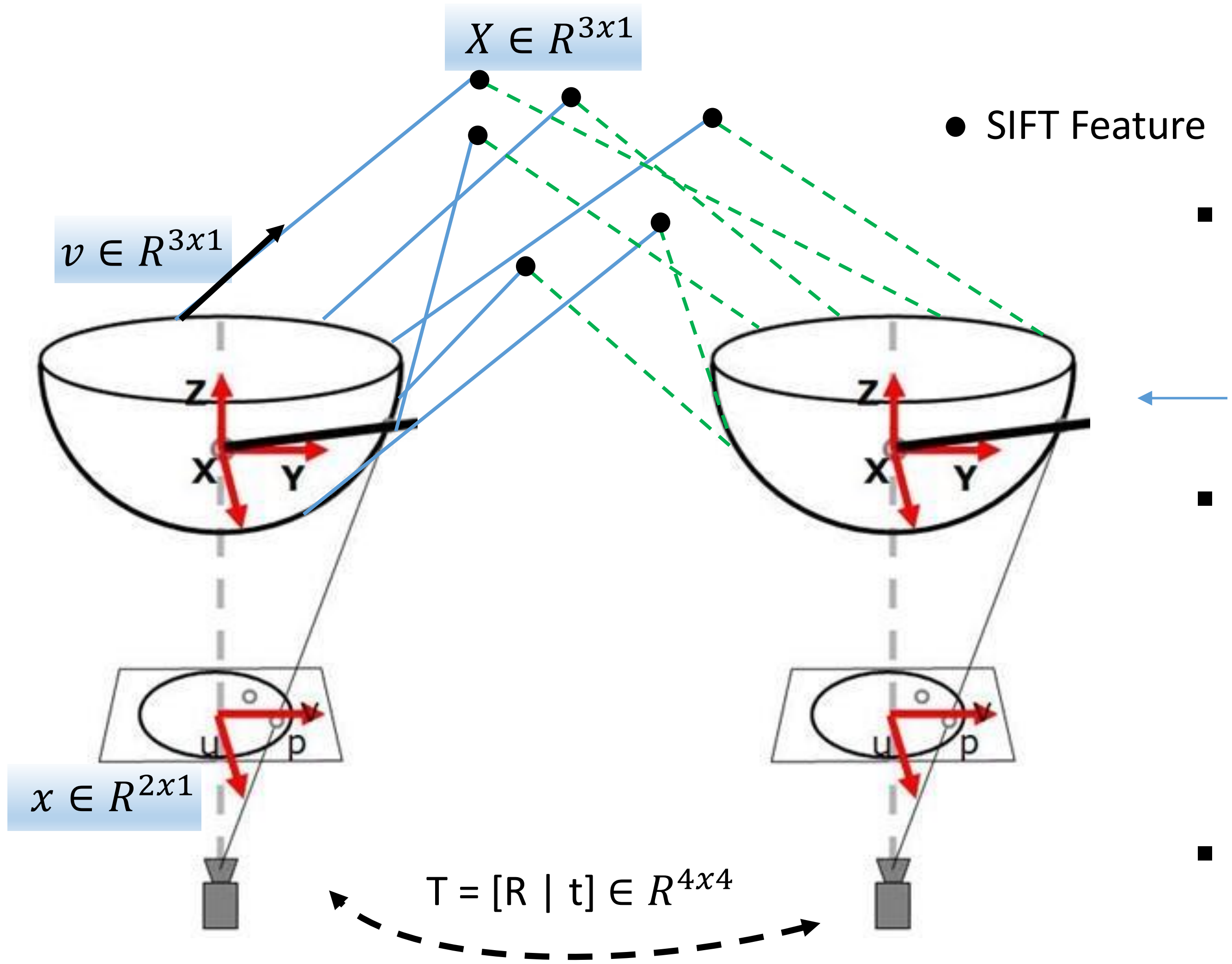


- Image formation modelled by a sphere of equivalence model
  - OCamModel (Scaramuzza)
  - 4th order polynomial representation
- Forward and Inverse projection models

$$x = g(X) \qquad v = f(x)$$

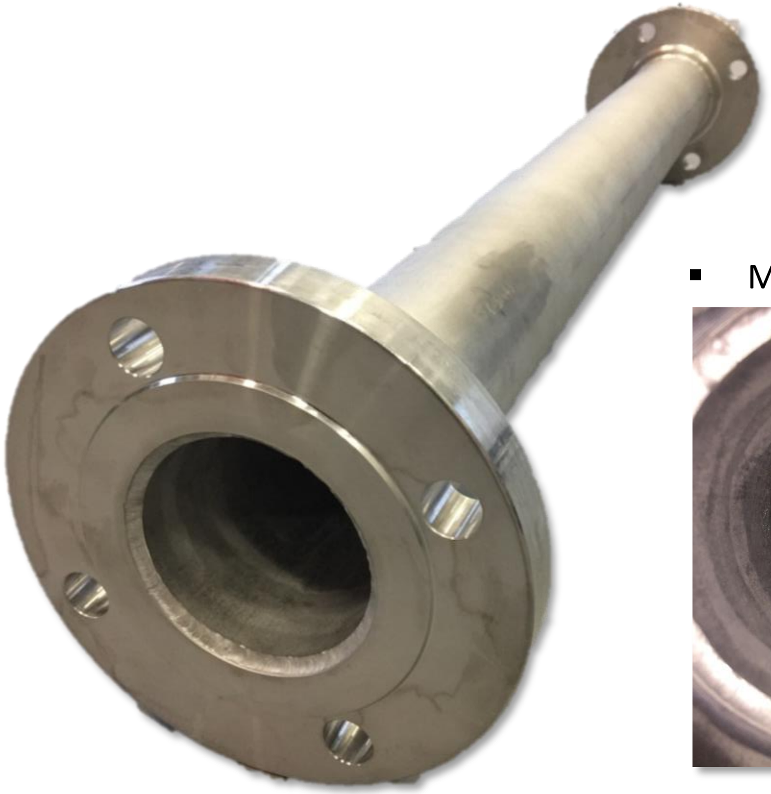
Vector on unit sphere

- Calibrated through calibration grid approach
  - High 3D calibration will be used in the future

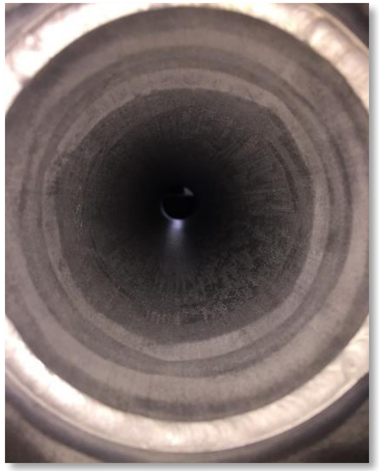
*https://sites.google.com/site/scarabotix/ocamcalib-toolbox

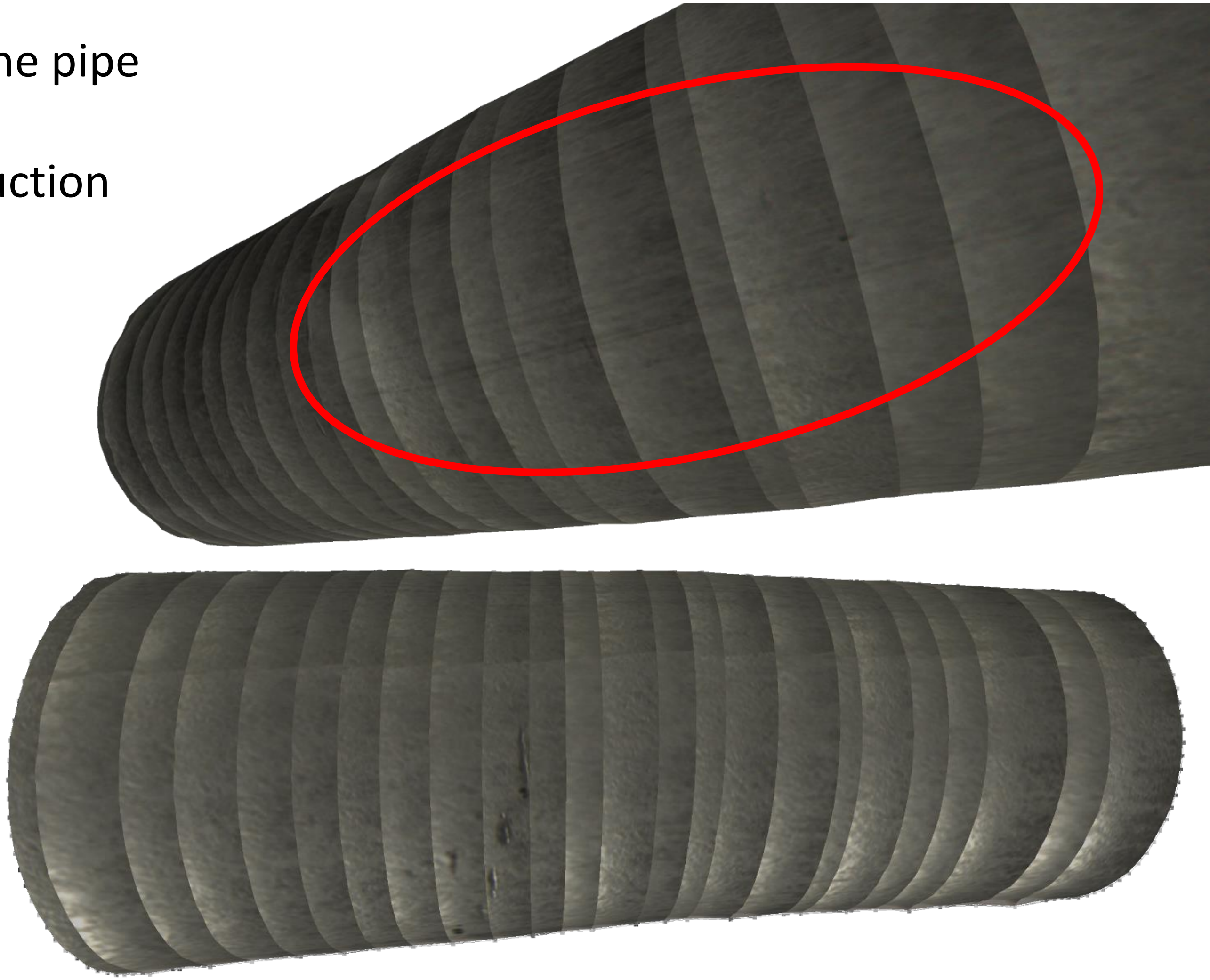
3D Reconstruction

- Model of 3 inch stainless steel nuclear grade pipe section
- Banding affect due to non-uniform lighting inside the pipe
- Detail spanning multiple images visible in reconstruction

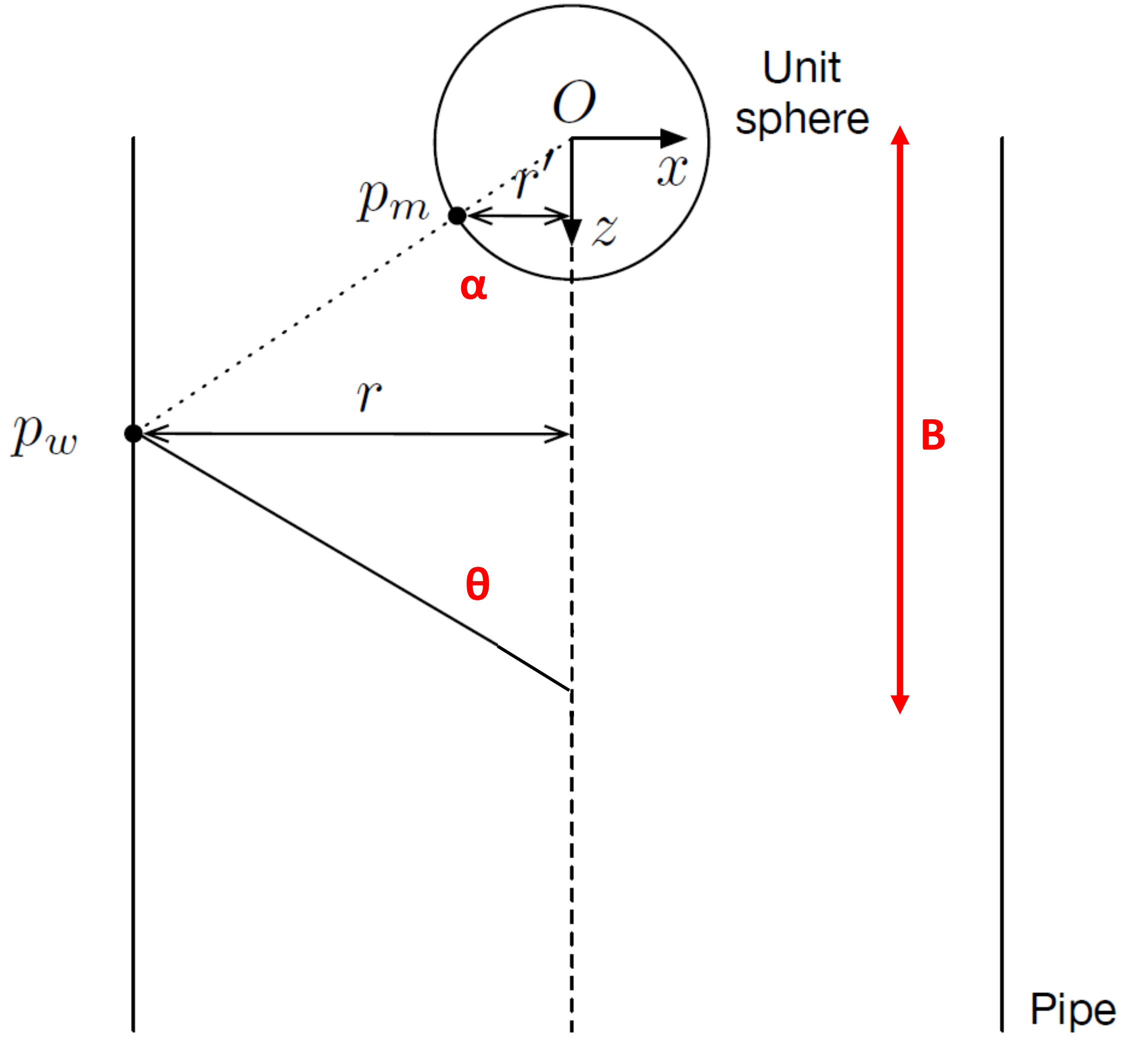


- Matte surface finish

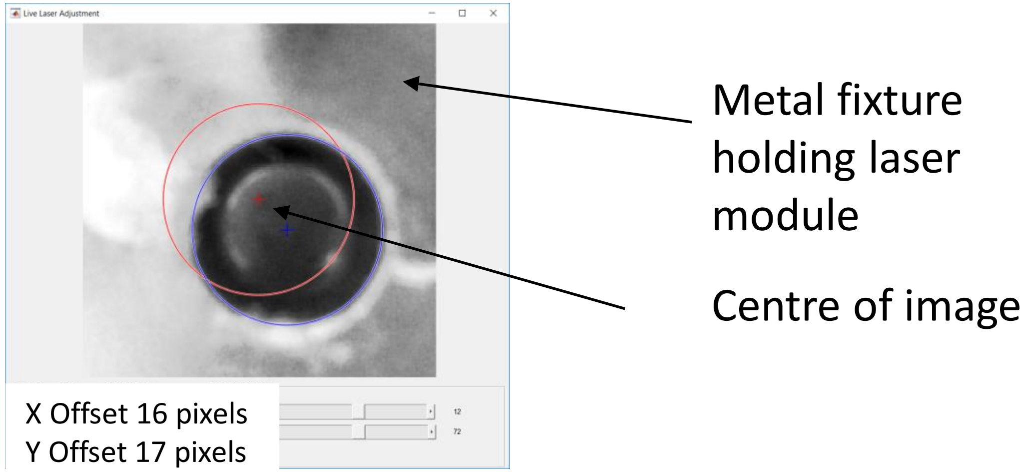




Laser Calibration



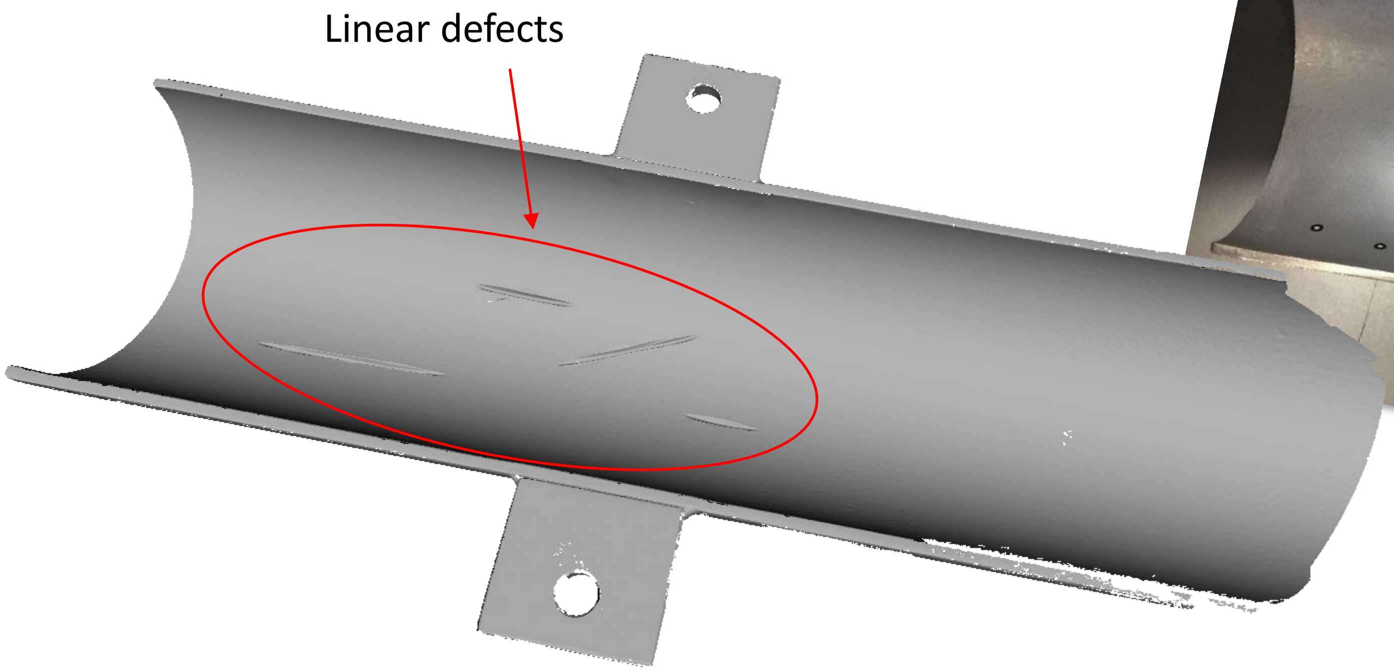
- Model assumes co-linearity of optical elements
  - Difficult to achieve in practice
- Baseline **B** and opening angle **α** need to be estimated
- Real-time feedback of distance between image centre and machined hole centre which holds the mirror
- Image plane and “laser plane” required to be parallel

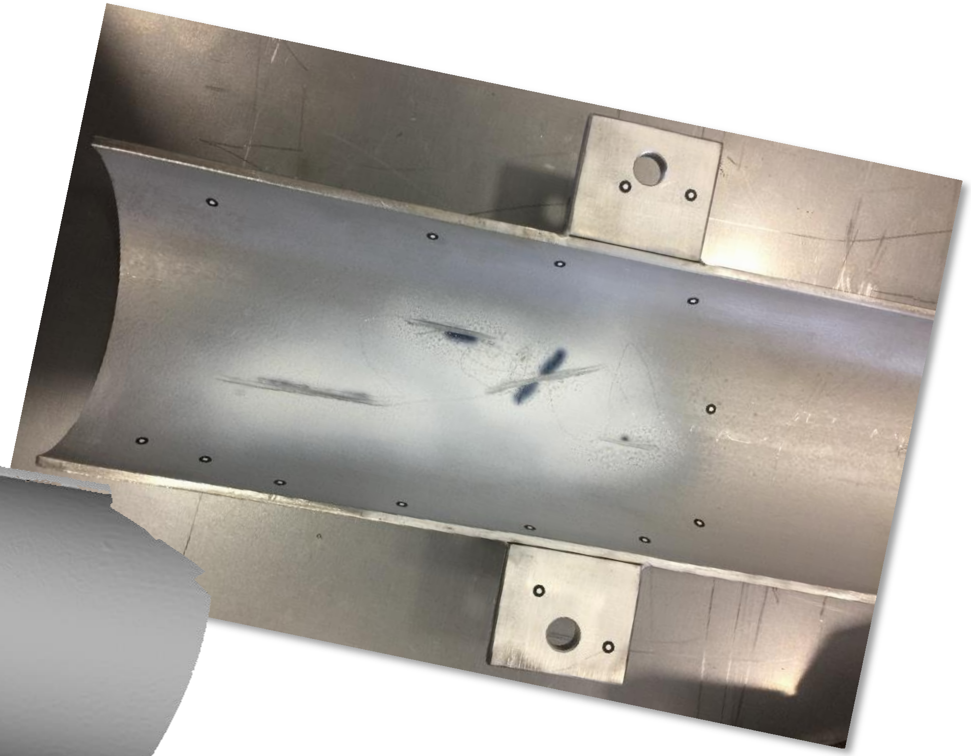


Laser Results

- Defects created within ≈250 mm long region of a split pipe sample

- Ground truth geometry captured by an ATOS GOM Triple Scan
- Dense data ≈ 1 million 3D points

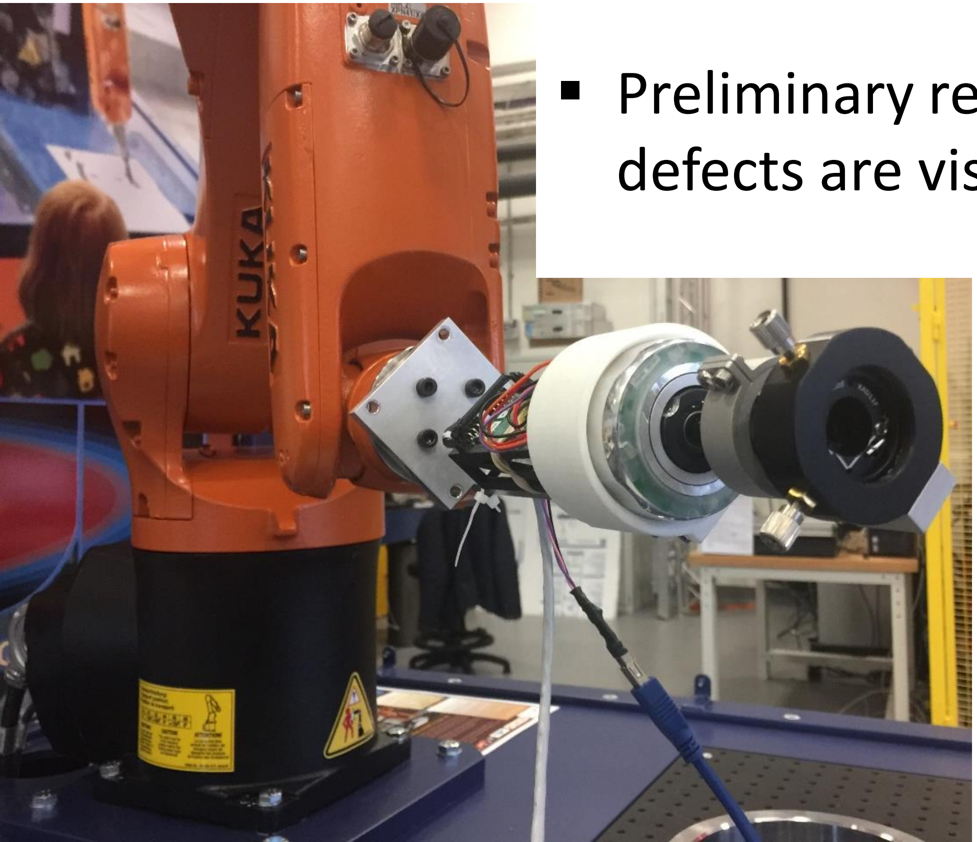


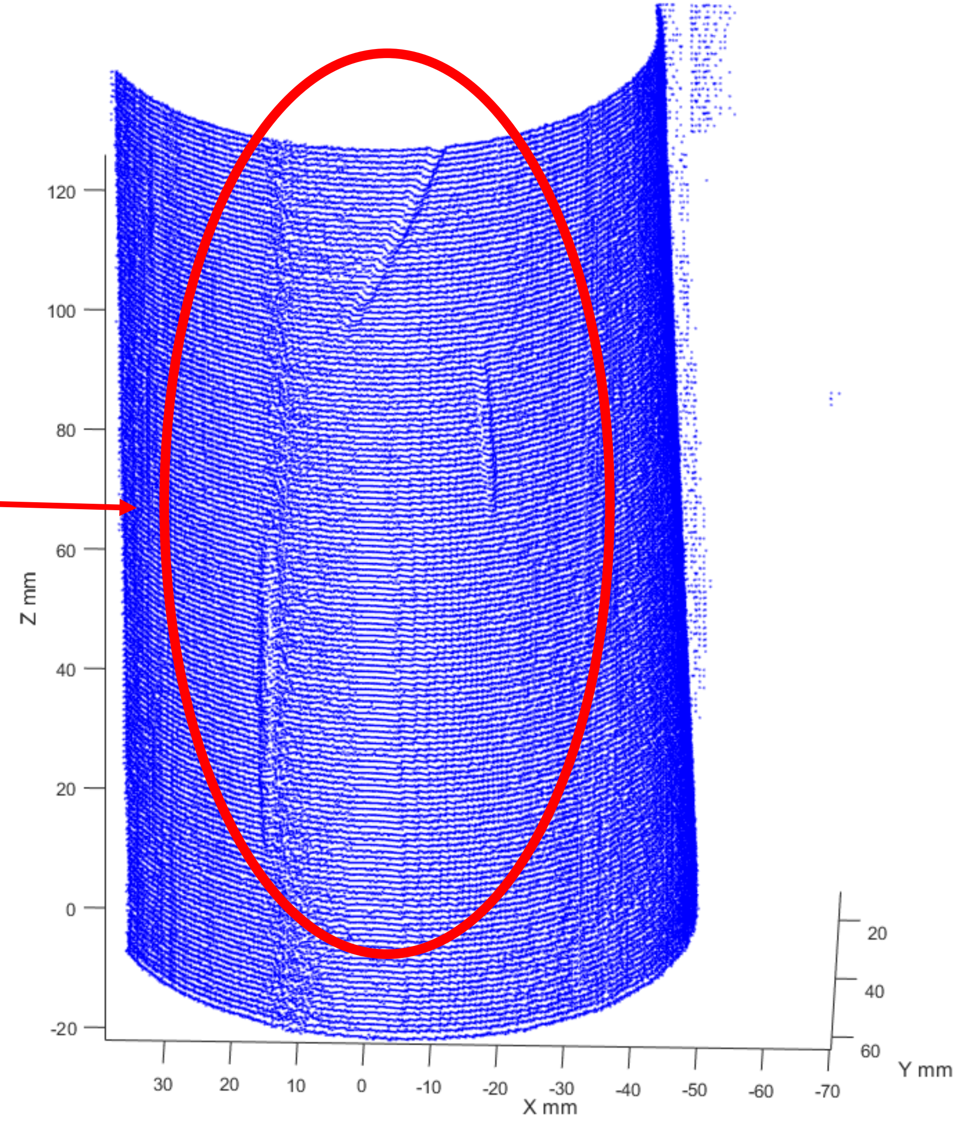


- Surface whitened for optimal scan

Laser Results

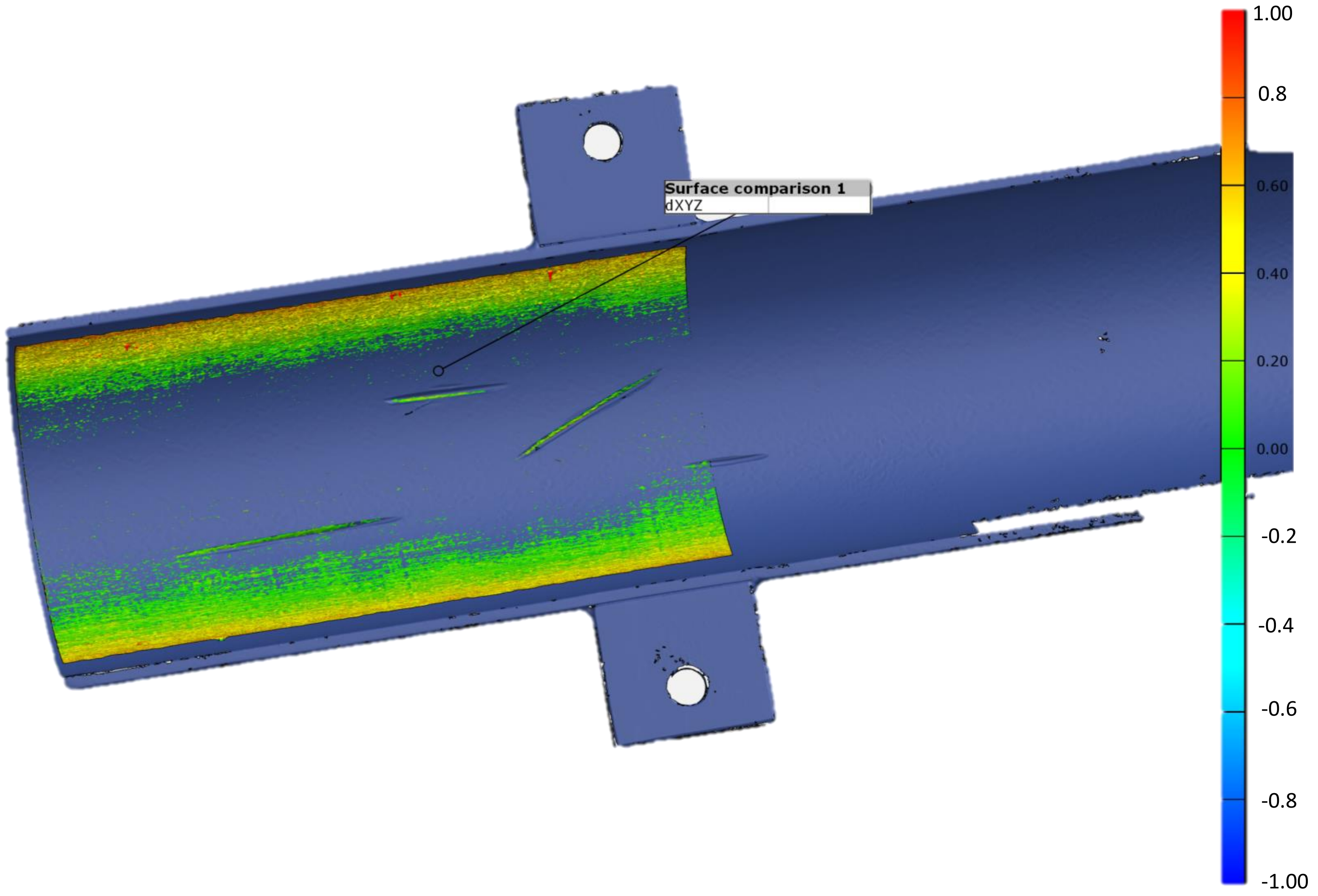
- Probe driven on a linear path by a KUKA robot in 0.5 mm steps
- Preliminary results with probe – defects are visible





Laser Results

- Initial results look promising
- RMSE approx. 0.8mm
- Refinement of camera calibration possible



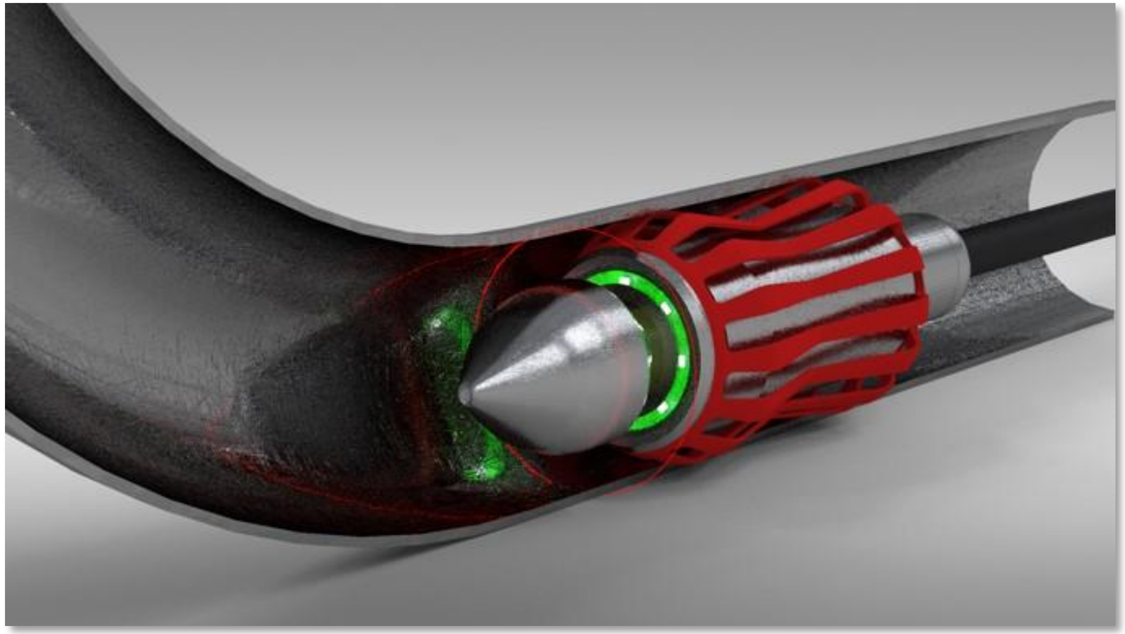
Conclusion/Future Work

- Bespoke probe for 3D pipe mapping in development to provide step change in visual inspection of nuclear pipelines

- Current offline reconstruction capability

- Laser metrology subsystem shown to produce sub millimetres results on split pipe sample

- **Next steps:** Realtime mapping in SLAM type approach



Proposed Probe V2 model

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