EVALUATION OF STRETCHED WIRE MEASUREMENT BASED ON PHOTogrammetry IN THE CONTEXT OF CERN

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Ecartometry for accelerator alignment

- Radial offsets with respect to stretched wire
- Precision 0.05 mm within sliding window of 150 m
- Team of 2 persons: 500 m accelerator per day

- Time consuming, cost intensive
- Personnel in radioactive area

How can radial alignment be automated?

- Wire of 120 m

MB
MQ
Could photogrammetry be a solution?

Magnet fiducials can be signalized and measured, but a stretched wire?

Recent developments

• Hardware: High resolution cameras
  ➔ also thin wires become visible
  0.3 mm diameter at 1-2 m distance

• Software: AICON DPA / 3D Studio
  Module feature measurement – Curved line measurement
  No homologous points but multiple epipolar geometry
Test bench

- Test bench used to define different parameters
- Afterwards precision and accuracy for wire measurement has been evaluated

- Steel grooves at each side
- 26 precise ceramic balls in contact
- Up to 25 wires stretched between balls
- Photogrammetric sticker targets
- Metrology with precision of 2 µm
- Knowledge of wire position in horizontal, NOT in vertical direction
Tested parameters ...

Wire
- Non-reflective
- Dark for good contrast
- Monofilament
- Non-metallic
- Of adapted size, wire should correspond to 1-2 pixel in image

black, monofilament fishing wire of 0.3 mm diameter

Software
- Edge method
- Spacing 0.25 mm – 2.0 mm
- Contrast values 20-40
... tested parameters

Camera
• Nikon D3x with 24 Megapixel
• AICON «metric» 28 mm lens
• ISO 100-600
• Exposure time 1/125 – 1/250 sec.
• Aperture 11 or 16
• Top mounted flash

Configuration
• 16 images at distance of ~1.4 m
• Intersection angles above 90 degree
How to analyze the measurement?

• 10 wires measured 10 times
• Horizontal 2D distances between 5 sticker targets and 10 wires
→ 500 measurements for analysis
• Least squares fitted mean line of measured points
• Problems:
  • Shadow
  • Lines do not end
→ Iterative error detection
Real scale test

- LHC dipole mock-up in wooden tunnel
- 165 magnet fiducials and additional targets
- 3 wires
- Plumb line as 4th wire for definition of vertical
- 10 photogrammetric measurements
Real scale test - Results

- 3D coordinates of 165 targets

<table>
<thead>
<tr>
<th>Sigma of points</th>
<th>X (µm)</th>
<th>Y (µm)</th>
<th>Z (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision AICON</td>
<td>4.2</td>
<td>7.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Repeatability</td>
<td>4.0</td>
<td>7.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Depth

- 2D horizontal distances between 10 targets and 3 wires

<table>
<thead>
<tr>
<th></th>
<th>σ (µm)</th>
<th>min (µm)</th>
<th>max (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire 1 nylon</td>
<td>8.0</td>
<td>-29.4</td>
<td>28.9</td>
</tr>
<tr>
<td>Wire 2 vectran</td>
<td>6.3</td>
<td>-20.8</td>
<td>22.0</td>
</tr>
<tr>
<td>Wire 3 nylon</td>
<td>7.9</td>
<td>-24.4</td>
<td>26.3</td>
</tr>
</tbody>
</table>

04.10.2016
Comparison to Wild T3000

- Comparison to theodolite measurement
- 3D coordinates by intersection
- Precision 10-20µm
- Differences for 3D coordinates

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<th>min (µm)</th>
<th>max (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadratic mean</td>
<td>8.1</td>
<td>15.2</td>
<td>13.3</td>
</tr>
</tbody>
</table>

- Wire by multiple plane intersection
- Differences for 2D distances

<table>
<thead>
<tr>
<th></th>
<th>Wire 1</th>
<th>Wire 2</th>
<th>Wire 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nylon</td>
<td>vectran</td>
<td>nylon</td>
</tr>
<tr>
<td>Quadratic mean</td>
<td>19.9</td>
<td>34.2</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Alternative Approach

- Existing AICON Move Inspect for collimator train
**Alternative Approach**

- **Measurement, calibration, bundle adjustment**
- **Approximate detection of line in all 2D image**

  **RANSAC (random sample consensus)**

  **Additional Knowledge**
  - Line is horizontal
  - Two edges close to each other
  - Wire passes through entire image
  - Colour can be chosen
Alternative Approach

- Measurement, calibration, bundle adjustment
- Approximate detection of line in all 2D image
- Measurement of edge points for each line

• Sub pixel edge detector Trujillo-Pino
• Iterative correction of distortion
• Edge points separated for both edges
Alternative Approach

Measurement, calibration, bundle adjustment

Approximate detection of line in all 2D image

Measurement of edge points for each line

- Mean line by linear regression for each edge
- Angle bisector corresponds to wire measurement in image
Alternative Approach

- Measurement, calibration, bundle adjustment
- Approximate detection of line in all 2D image
- Measurement of edge points for each line
- Transformation of lines from image space to planes in object space
- Calculation of mean line in each image

- Intersection points of line with image borders projected in object space by collinearity equations
Alternative Approach

Measurement, calibration, bundle adjustment → Approximate detection of line in all 2D image → Measurement of edge points for each line

Intersection of multiple planes in a line ← Transformation of lines from image space to planes in object space ← Calculation of mean line in each image

- Line calculated by individual adjustment or within bundle adjustment
Alternative approach - Results

- Set of images from standard project
- Plane calculation with alternative approach
- Multiple plane intersections
- Offset of planes to wire
- Comparison to AICON measurement
  - Sigma of differences < 8 μm
Conclusion and outlook

• Photogrammetry is possible tool for ecartometry
• Precision of distances between points and wire less than 10 µm

What comes next?
• Real scale comparison with Micro-triangulation as developed in the PACMAN project (see talk from V. Vlachakis Friday morning)
• Definition of scale
• Introduction of the vertical
• Measurement of complete wire / complete sector in manual mode

• Interesting approach during detector fiducialisation, for example wire chambers
• To be studied...
Thank you!

Merci!