ACCURACY ASSESSMENT OF THE FARO FOCUS³D AND LEICA HDS6100 PANORAMIC TYPE TERRESTRIAL LASER SCANNER THROUGH POINT-BASED AND PLANE-BASED USER SELF-CALIBRATION

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<table>
<thead>
<tr>
<th>Manufacturer’s Spec. (1/2)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FARO FOCUS³D</strong></td>
<td><strong>LEICA HDS6100</strong></td>
</tr>
<tr>
<td>Architecture</td>
<td>Panoramic Panoramic</td>
</tr>
<tr>
<td>HFOV</td>
<td>360°/305°</td>
</tr>
<tr>
<td>Range principle</td>
<td>Phase-based Phase-based</td>
</tr>
<tr>
<td>Scan</td>
<td>976,000Hz 508,000Hz</td>
</tr>
<tr>
<td>Unambiguity interval</td>
<td>153.49m 79m</td>
</tr>
<tr>
<td>Spot size</td>
<td>3.8mm + 0.16mrad 3mm + 0.22mrad</td>
</tr>
<tr>
<td>Range precision @ 25m</td>
<td>≤ 0.95mm (0.50mm) 1mm</td>
</tr>
<tr>
<td>Range accuracy @ 25m</td>
<td>≤ 2 mm</td>
</tr>
</tbody>
</table>

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Can the low-cost Faro Focus3D deliver the same level of precision and accuracy as the Leica HDS6100?
Methodology (1/7)

Methodology (2/7)

\[ \rho_y = \sqrt{x_y^2 + y_y^2 + z_y^2} + \Delta \rho \]
\[ \theta_y = \tan^{-1}\left(\frac{y_y}{x_y}\right) + \Delta \theta \]
\[ \alpha_y = \tan^{-1}\left(\frac{z_y}{\sqrt{x_y^2 + y_y^2}}\right) + \Delta \alpha \]
Methodology (3/7)

Range Systematic Errors

Horizontal Circle Systematic Errors

Vertical angle Systematic Errors
Methodology (5/7)

Point-based Calibration

```
\[ \begin{bmatrix}
X_{ij} \\
Y_{ij} \\
Z_{ij}
\end{bmatrix}
\]
```

\[ \begin{bmatrix}
x_i \\
y_i \\
z_i
\end{bmatrix} \]

\[ \begin{bmatrix}
x_j \\
y_j \\
z_j
\end{bmatrix} \]

Object Space

Scanner Space \( j \)

\( \theta_{ij} \)

\( \alpha_{ij} \)

Methodology (6/7)

Plane-based Calibration

```
\[ \begin{bmatrix}
X_{ij} \\
Y_{ij} \\
Z_{ij}
\end{bmatrix}
\]
```

\[ \begin{bmatrix}
x_i \\
y_i \\
z_i
\end{bmatrix} \]

\[ \begin{bmatrix}
x_j \\
y_j \\
z_j
\end{bmatrix} \]

Object Space

Scanner Space \( j \)

\( \theta_{ij} \)

\( \alpha_{ij} \)

Plane \( k \)
Methodology (7/7)

Additional observations

\[ \alpha = \alpha_{\text{obs}} \pm \sigma_{\alpha} \]
\[ \psi = \psi_{\text{obs}} \pm \sigma_{\psi} \]
\[ \kappa = \kappa_{\text{obs}} \pm \sigma_{\kappa} \]

Experiment (1/1)

Small Room
5 m by 5m by 3m

Large Room
14 m by 11 m by 3 m
Results (1/5)

**Dual-axis Compensator**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Manufacturer</th>
<th>Determined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus3D</td>
<td>54&quot;</td>
<td>346&quot;</td>
</tr>
<tr>
<td>HDS6100</td>
<td>7.2&quot;</td>
<td>133&quot;</td>
</tr>
</tbody>
</table>

**Digital Compass**

<table>
<thead>
<tr>
<th>Scanner</th>
<th>Determined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus3D</td>
<td>40&quot;</td>
</tr>
</tbody>
</table>

Results (2/5)

**Horizontal circle residuals as a function of elevation angle**

![Graphs showing horizontal circle residuals as a function of elevation angle]
Results (2/5)

Side View

Top View

Results (3/5)

<table>
<thead>
<tr>
<th></th>
<th>HDS6100</th>
<th>Focus3D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>$\sigma_r$ [mm]</td>
<td>0.55</td>
<td>0.53</td>
</tr>
<tr>
<td>$\sigma_{\theta}$ ['']</td>
<td>38.4</td>
<td>34.2</td>
</tr>
<tr>
<td>$\sigma_{\phi}$ ['']</td>
<td>36.0</td>
<td>32.1</td>
</tr>
</tbody>
</table>
### Recovered systematic errors for the Focus3D through point-based and plane-based self-calibration

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Range offset</th>
<th>Horizontal circle eccentricity</th>
<th>Non-orthogonality of encoder &amp; vertical axis</th>
<th>Collimation axis error</th>
<th>Trunnion axis error</th>
<th>Vertical circle index error</th>
<th>Non-orthogonality of encoder &amp; trunnion axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.54 ± 0.23</td>
<td>-27.5 ± 9.2</td>
<td>-13.6 ± 3.1</td>
<td>50.3 ± 4.5</td>
<td>-203.6 ± 8.8</td>
<td>24.2</td>
<td>12.3 ± 2.0</td>
</tr>
<tr>
<td>2</td>
<td>1.12 ± 0.23</td>
<td>-51.8 ± 3.8</td>
<td>-8.6 ± 0.2</td>
<td>2.9 ± 6.8</td>
<td>-8.6 ± 4.4</td>
<td>20.2</td>
<td>12.3 ± 2.0</td>
</tr>
<tr>
<td>3</td>
<td>2.12 ± 0.31</td>
<td>-54.5 ± 5.2</td>
<td>49.6 ± 4.8</td>
<td>44.2 ± 9.6</td>
<td>12.3 ± 2.0</td>
<td>20.2</td>
<td>12.3 ± 2.0</td>
</tr>
<tr>
<td>4</td>
<td>0.48 ± 0.18</td>
<td>-58.1 ± 3.6</td>
<td>58.1 ± 2.2</td>
<td>-49.6 ± 3.6</td>
<td>-9.8 ± 2.0</td>
<td>20.2</td>
<td>12.3 ± 2.0</td>
</tr>
<tr>
<td>5</td>
<td>0.96 ± 0.23</td>
<td>-32.6 ± 9.8</td>
<td>50.2 ± 2.7</td>
<td>-59.1 ± 4.1</td>
<td>-38.9 ± 2.0</td>
<td>20.2</td>
<td>12.3 ± 2.0</td>
</tr>
<tr>
<td>6</td>
<td>2.02 ± 0.42</td>
<td>49.6 ± 6.5</td>
<td>102.0 ± 17.7</td>
<td>-113.3 ± 17.7</td>
<td>128.7 ± 17.7</td>
<td>20.2</td>
<td>12.3 ± 2.0</td>
</tr>
</tbody>
</table>

### Differences between the signalised target positions determined by the HDS6100 and Focus3D

<table>
<thead>
<tr>
<th>Room</th>
<th>Before Calibration [mm]</th>
<th>After Calibration [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE_X</td>
<td>RMSE_Y</td>
</tr>
<tr>
<td>Small</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Large</td>
<td>0.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

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Conclusion

• Modelled systematic errors in the FARO Focus\textsuperscript{3D} and Leica HDS6100 using point-based and plane-based self-calibration

• Raw observations of the HDS6100 are more precise than the Focus\textsuperscript{3D}

• At close-range, the 3D object space reconstructed by both scanners are comparable

• Future work will improve the calibration routine for modelling errors in the Focus\textsuperscript{3D}

Acknowledgments

Thank You!