Alignment of Multiple Time-of-Flight 3-D Cameras for Reconstruction of Walking Feet

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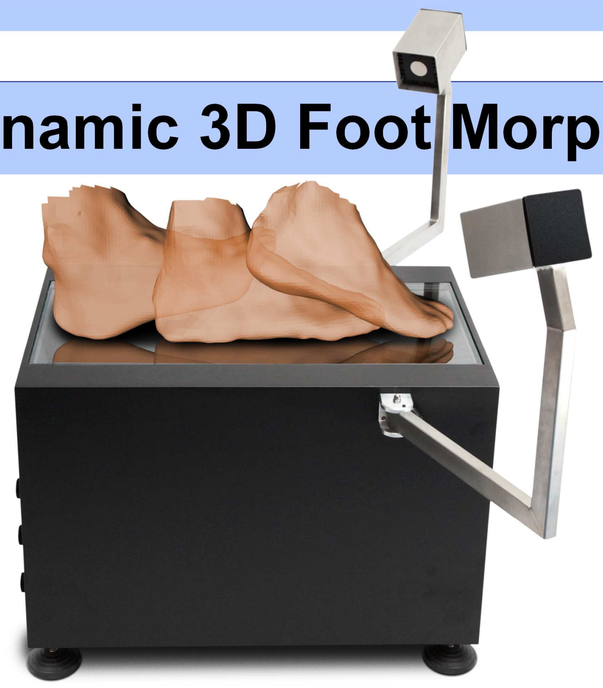
Dynamic 3D Foot Morphology Scanning

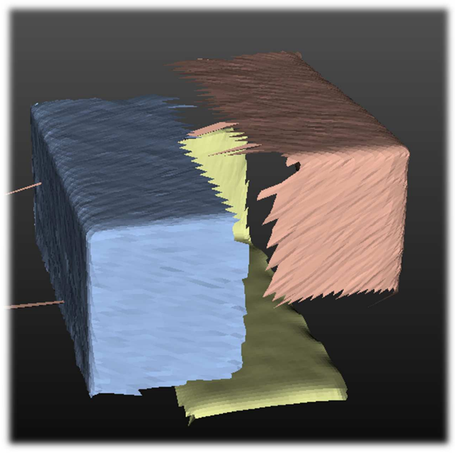
Foot Scanning using Time-of-Flight

- 3 synchronized ToF-cameras
- ca. 40 frames per second
- Measurement of complete surface of foot
- Capable of measuring feet accurately [1]
- System is portable
- Fast & easy calibration needed



Registration Task

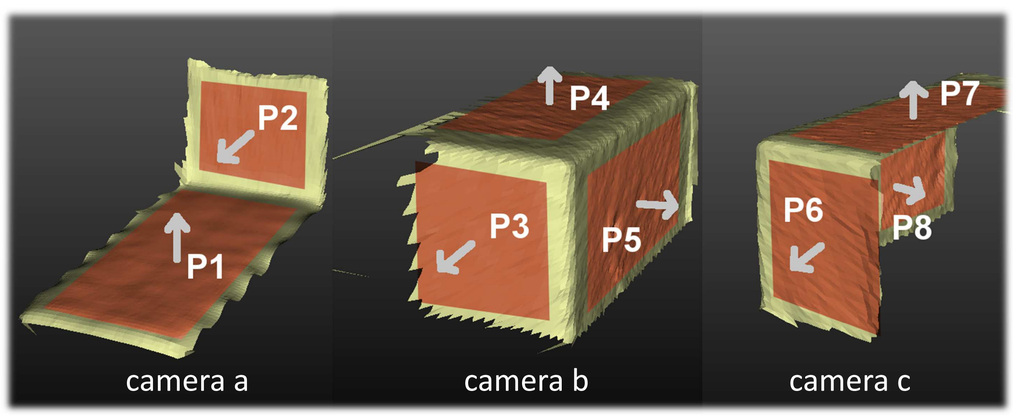
- Raw data is not aligned correctly
- World coordinate system needed
- Each camera is virtually moved
- Rigid transformation parameters:
  - 3x translation (X-, Y-, Z-Axis)
  - 3x rotation (X-, Y-, Z-Axis)



Data before registration

Method

1. Acquisition of calibration phantom with cameras a, b, c
2. Seedpoint-based extraction of planes
   - $P_1 \dots P_8$
3. Known relations for plane pairs P_i , P_j
   - angles r_{ij} and translations t_{ij}
4. Minimization of objective function [2]
   - set of rigid transforms $\Phi = [\phi_a, \phi_b, \phi_c]$
   - ϕ_a as fixed reference: Φ has 12 entries



Calibration phantom acquisitions from all three cameras.

M angular constraints ($\mathbf{n}_i$ is normal of P_i):

$$e_r^{ij}(\Phi) = (\arccos(\phi_k(\mathbf{n}_i)^T \cdot \phi_l(\mathbf{n}_j)) - r_{ij})^2$$

$$k, l \in [a, b, c] | k \neq l \qquad i, j \in [1 \dots 8] | i \neq j$$

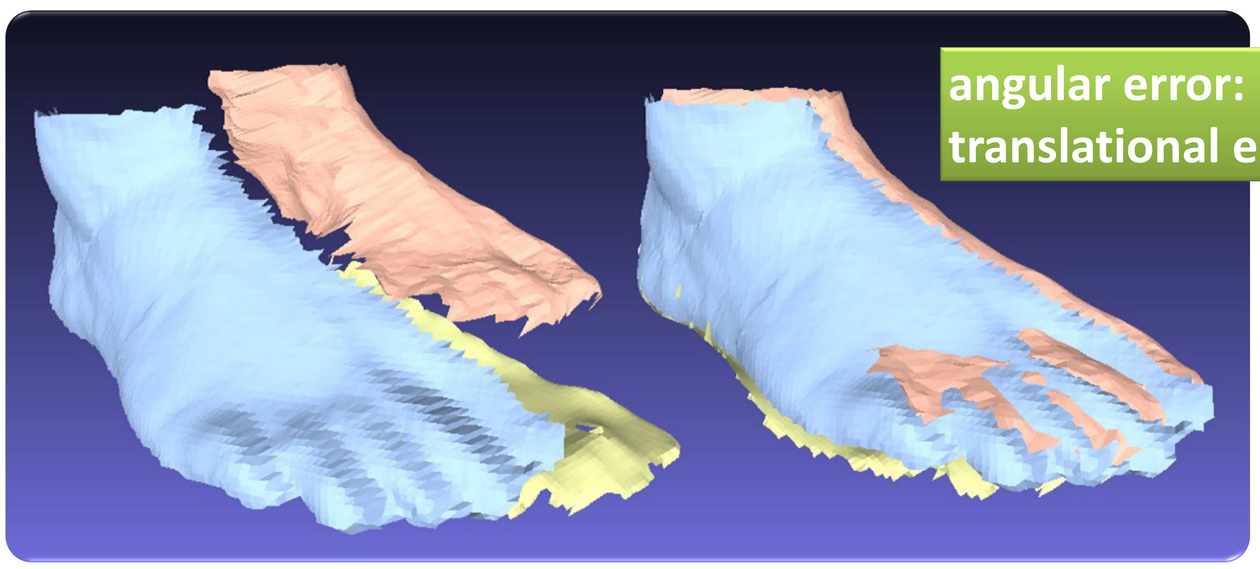
N translational constraints ($\mathbf{p}_i \in P_i$):

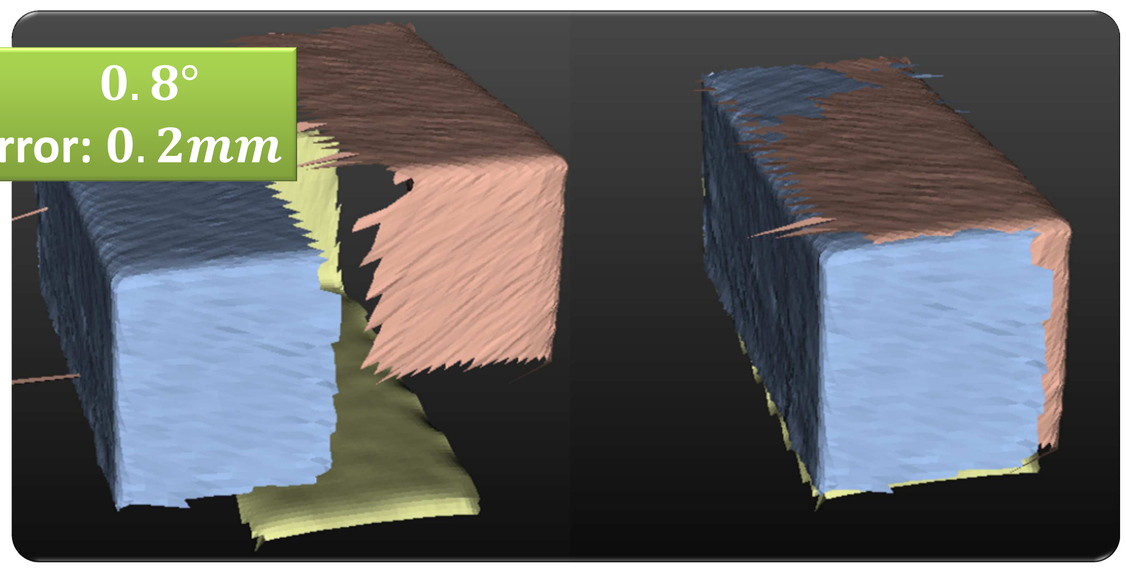
$$e_t^{ij}(\Phi) = (\left|(\phi_k(\mathbf{n}_i)^T \cdot (\phi_l(\mathbf{p}_j) - \phi_k(\mathbf{p}_i)))\right| - t_{ij})^2$$

Objective function:

$$\hat{\Phi} = \underset{\Phi}{\operatorname{argmin}} \sum_{c_r=1}^{M} e_r^{c_r}(\Phi) + \sum_{c_t=1}^{N} e_t^{c_t}(\Phi)$$

Results





Conclusion

- Fast and easy to use registration procedure is proposed
- Time-of-Flight data requires special treatment
- Registration is possible with accuracies of
  - **0.8° mean angular error**
  - **0.2mm mean translational error**

Outlook

- Seedpoint-based plane extraction requires user interaction
- Procedure can be automated by
  - **Reducing the number of planes per image to 1 & autodetection**
  - **Increasing the number of acquisitions to >= 3**
- **Complete procedure will be almost automatic**

References

[1] Liu S, et al.: “Dynamic foot scanning using Time-of-Flight devices”, *Proceedings of ISB XXIII*, Brussels, Belgium, 2011

[2] Kanzow C, et al.: “Levenberg-Marquardt methods for constrained nonlinear equations with strong local convergence properties”, *Journal of Computational and Applied Mathematics.* **172**: pp 375 – 397, 2004

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