Sphere-based Calibration for Multimodal Sensor Systems

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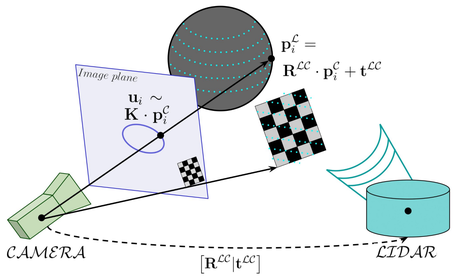
Motivation

Checkerboard pattern

- Most common calibration target for cameras
- In sparse 3D point clouds, hard to detect the board edges accurately

Sphere-based approach

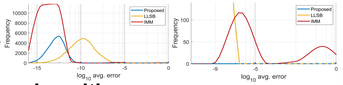
- Guarantees continuous surface in 3D
- Sphere projection → Ellipse detection in the image



Synthetic and real test results

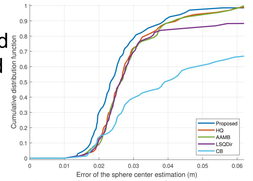
Stability analysis of the three-point methods

- 25,000 synthetic scenarios on log. scale
- Proposed, IMM: more precise on average
- IMM stability error around zero



CFD and boxplot of the sphere and chessboard position errors

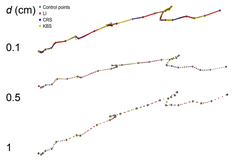
- Real stereo camera pair + LIDAR data
- 3-point and 5-point ellipse detectors, circle-based approach, Matlab Calibration Toolbox are compared
- Challenging depth estimation for spheres
- Proposed method has a minor error with 2-4 mm while reaching the exact value of the CDF

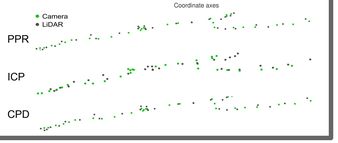


Trajectory estimation and registration

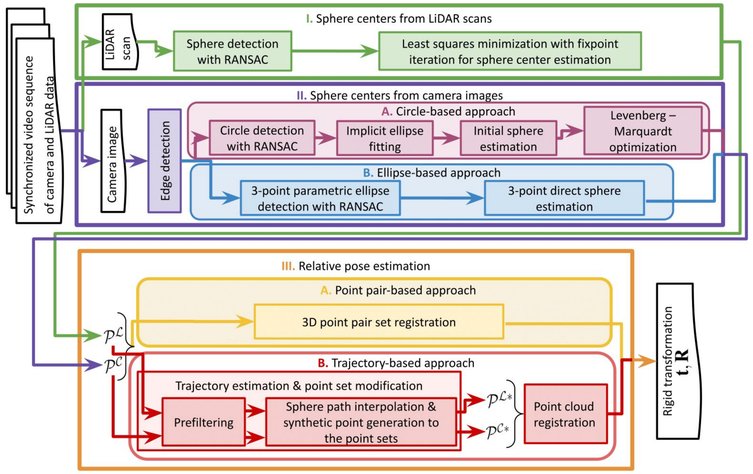
- Real synchronized data sequences
- Estimation with linear interpolation, Catmull–Rom and Kochanek–Bartels spline
- Regirtation with Iterative Closest Point and Coherent Point Drift algorithms
- Varying sampling frequency *d*
- Ideal target distance:

$$d_s^{\mathcal{L}} < \frac{r}{\tan\frac{(n-1)\cdot\delta}{2}}$$



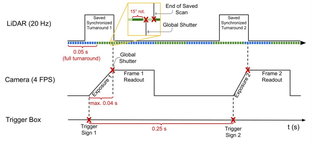


Proposed pipeline and its variants



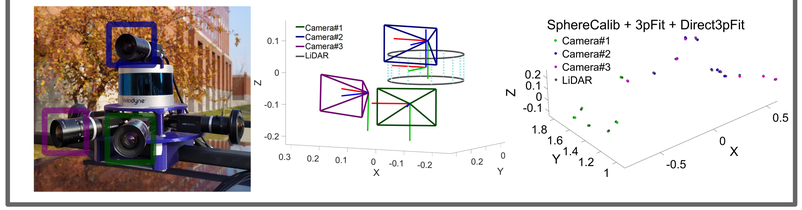
Contributions

1. **Automatic calibration pipeline for 2D-3D sensor calibration [1]**
   - For cameras with narrow lenses
   - Circle-based estimation
   - Adaptive RANSAC threshold
2. **Image-based three-point sphere detection and 3D localization [2]**
   - Special ellipse fitting: axial and projection constraints
   - Min. no. of inliers reduced from five to three for ellipse fitting
   - Solution for minimal and overdetermined cases
   - Direct ellipse and sphere estimation
   - No numerical optimization needed
   - Minimizing geometric error
3. **Trajectory registration [3]**
   - Continuous synchronized 2D-3D input
   - Extended point set → Spline interpolation
   - Point cloud registration for object paths

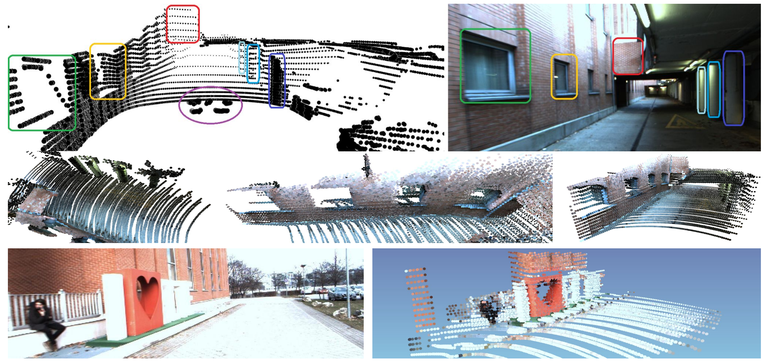


Sensor pose estimation

The schematic figure of the sensor setup using the extrinsic parameters (middle) estimated from the sphere center registration (right) represents a realistic adjustment considering the mounted setup (left).
Test devices: Hikvison digital cameras (74° FoV) + Velodyne VLP-16 LiDAR



Colorized point clouds: corridor and university logo



References

[1] Toth, T., Pusztai, Z., Hajder, L., *Automatic LiDAR-Camera Calibration of Extrinsic Parameters Using a Spherical Target*, 2020 IEEE International Conference on Robotics and Automation (ICRA), 2020
[2] Toth, T., Hajder, L., *A Minimal Solution for Image-Based Sphere Estimation*, International Journal of Computer Vision (IJCV), 2023
[3] Toth, T., Valasek, G., Hajder, L., 3D Trajectory Registration for Sensor Calibration, 26th Computer Vision Winter Workshop (CVWW), 2023