Analyzing LiDAR Scan Skewing and its Impact on Scan Matching

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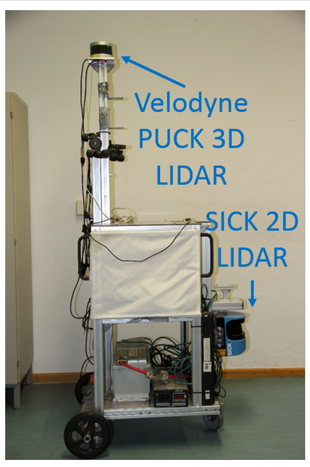
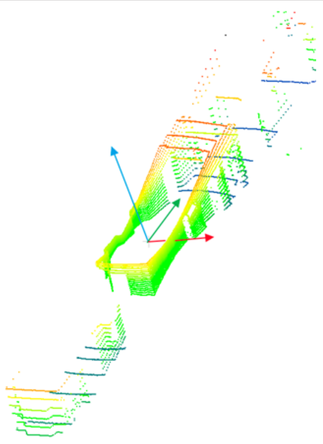
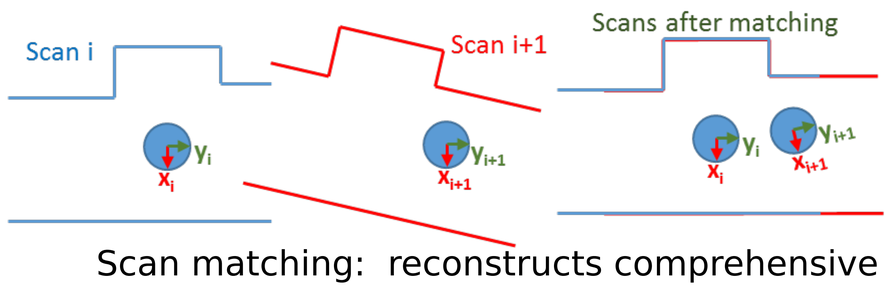


Trolley with LiDAR

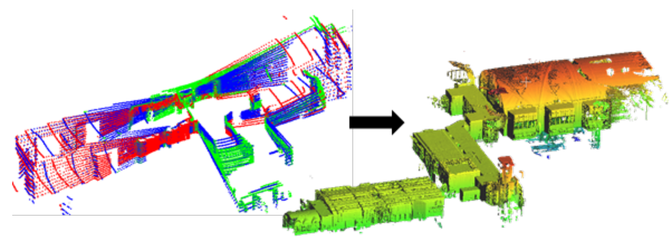


A LiDAR Scan

Objectives:
- Systematically study the scan skewing problem.
- Reduce the impact of skewing on scan matching necessary for 3D mapping.



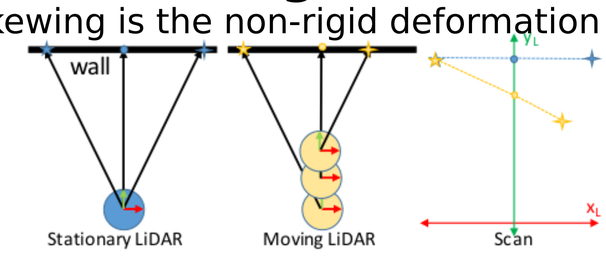
Scan matching: reconstructs comprehensive models and recovers sensor trajectory



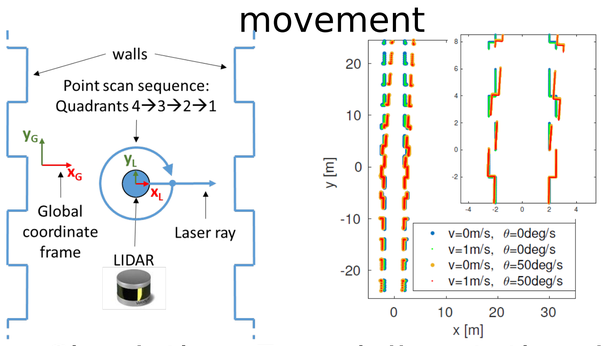
Scan matching is used to build 3D maps

The Skewing Problem

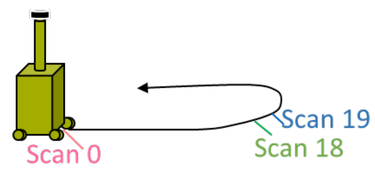
Skewing is the non-rigid deformation of moving Lidar scans

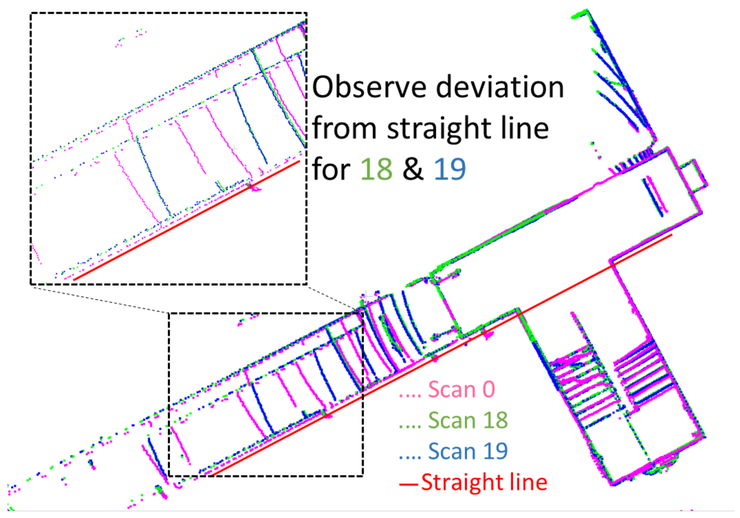


Reason: Sequential scanning during movement



Simulation: Especially rotational movements lead to strong skewing





Real Scans: scans acquired during rotation exhibit visible skewing

We show for constant translation and rotation, the registration is not affected

$$\mathbf{p_i^j} = \mathbf{R_{i(j)}} \cdot (\mathbf{R_0^j} \cdot \mathbf{p_i} + \mathbf{t_0^j}) + \mathbf{t_{i(j)}}$$

Scan Matching Framework

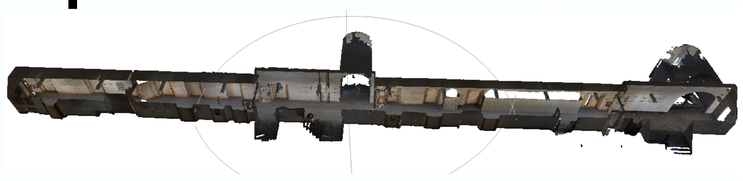
Algorithm 1: The scan matching pseudo-code. Estimate the individual scan-to-scan transformations T[i].

```
oldScan ← loadPointCloud (pointCloudFile[1]);
T[1] ← Identity(4,4);
for i ← 2 to numScanFiles do
    newScan ← loadPointCloud (pointCloudFile[i]);
    T[i] ← matchScan (newScan,oldScan,T[i-1]);
    oldScan ← newScan;
```

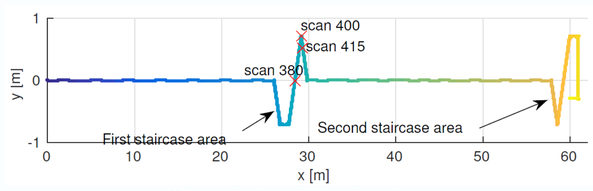
Algorithm 2: `matchScan(scanSrc,scanTar,Tprev)`

```
hasConverged ← false;
T ← Tprev;
while !hasConverged do
    scanSrcPreAligned ← transform(scanSrc,T);
    corrs ← computeCorrespondences(scanSrcPreAligned,scanTar);
    Trefine ← estimateTfromCorrs(corrs,scanSrcPreAligned,scanTar) ;
    T ← Trefine ·T ;
    hasConverged ← checkConvergence(Trefine);
```

Experimental Verification of Skewing Impact

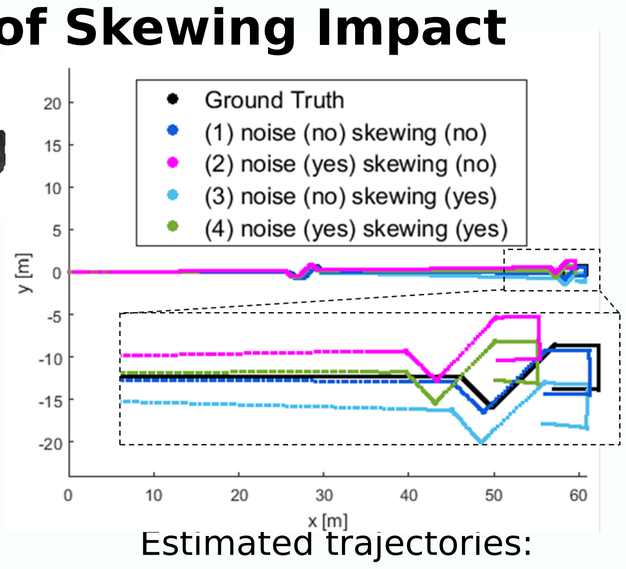


Mesh used to create synthetic LiDAR scans

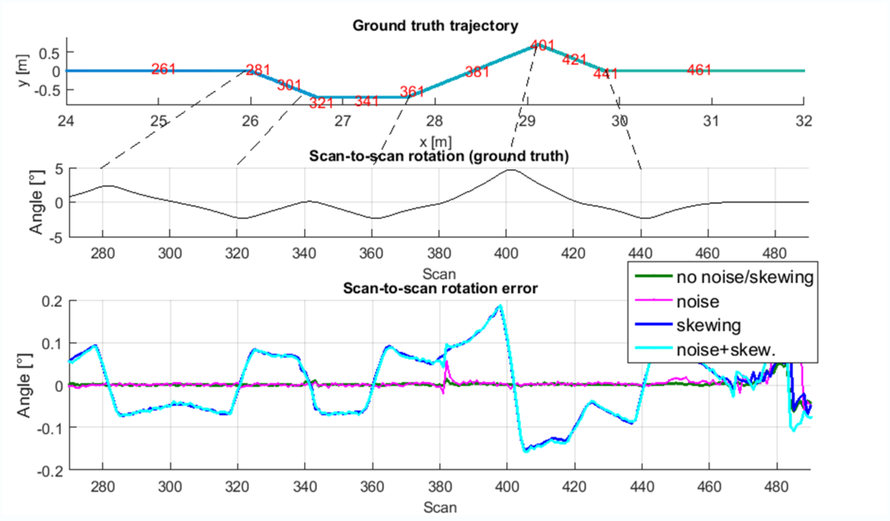


Simulated trajectory

Simulate LiDAR data with controlled distortions



Estimated trajectories: Skewing leads to trajectory drift



Scan-to-Scan Errors: Skewing induces errors in rotation estimation

Skewing-Aware Matching with GA-LMS

Deriving the GA-LMSpt2pls

$$\mathcal{F}(\mathbf{R}) = \frac{1}{K}\sum_{i=1}^{K} \|(\mathbf{y_i} - \mathbf{R}\mathbf{x_i}) \cdot \mathbf{n_i}\|^2$$

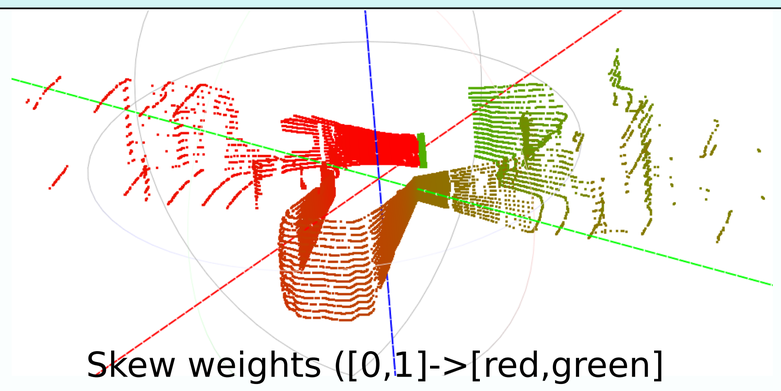
reformulate

$$J(r) = \frac{1}{K}\sum_{i=1}^{K} \left|(y_i - rx_i\tilde{r}) \cdot n_i\right|^2$$

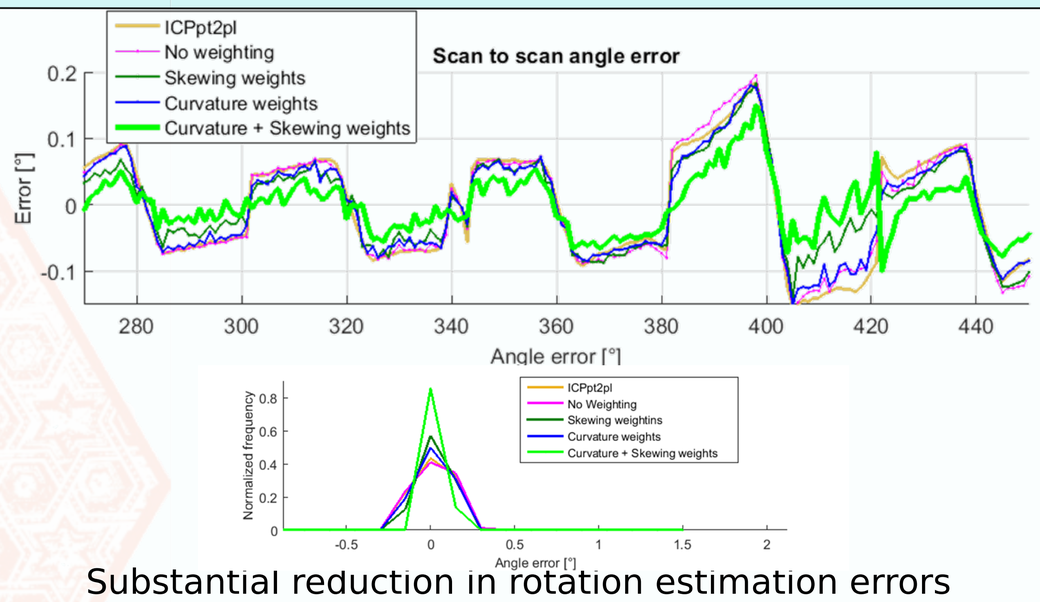
$$r_i = r_{i-1} + \mu(i)(n_i \wedge rx_i\tilde{r})r$$

Skewing-Aware GA-LMSpt2pl

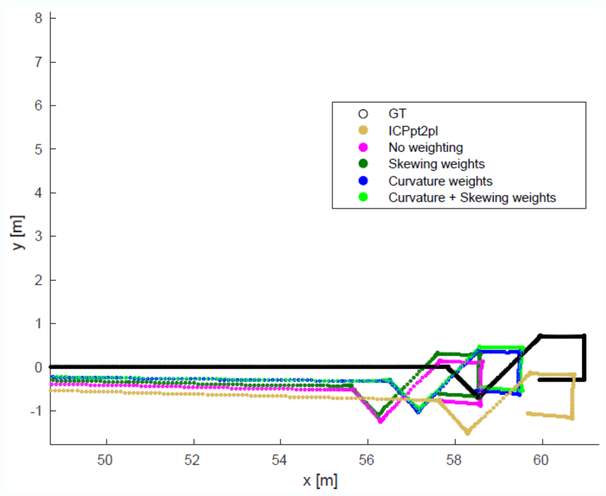
$$r_i = r_{i-1} + w(i)\mu(i)(n_i \wedge rx_i\tilde{r})r$$
$$w(i) = f_w(w_c(i), w_s(i))$$
$$w_s(i) = cos(\theta_z(i)/4)$$
$$w_c(i) = max(0.25, min(c_i/c_r, 1.0))$$



Skew weights ([0,1]->[red,green]



Substantial reduction in rotation estimation errors



Leads to reduced trajectory drift

Summary
- Skewing causes non rigid deformation
- Causes drift in trajectory estimate
-GA-LMS can be used to reduce impact by weighting iterations

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